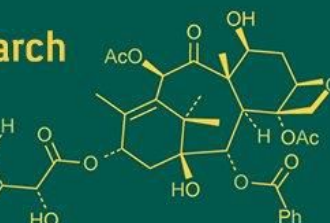
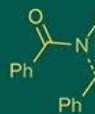


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; 10(4): 60-63
www.biochemjournal.com

Received: 13-02-2026
Accepted: 16-03-2026

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A comprehensive review of silkworm genetic improvement strategies for enhancing silk production

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i4a.8056>

Abstract

Silk production is a globally important agro-based industry that relies primarily on the domesticated silkworm *Bombyx mori*. The productivity and quality of silk are strongly influenced by the genetic characteristics of silkworm strains. Over the years, various genetic improvement strategies have been developed to enhance silk yield, cocoon quality, disease resistance, and environmental adaptability. Traditional breeding approaches such as hybridization and selective breeding have played a major role in developing high-yielding silkworm strains. In recent years, advances in molecular biology and biotechnology have introduced modern tools including marker-assisted selection, genomic analysis, transgenic technology, and genome editing techniques such as CRISPR-Cas9. These approaches enable precise modification of genetic traits associated with silk production and disease resistance. Furthermore, omics technologies such as genomics, transcriptomics, and proteomics have improved our understanding of silkworm genetics and silk gland biology. This review discusses the major genetic improvement strategies used in silkworm breeding and highlights the role of modern biotechnological tools in enhancing silk productivity and quality. The integration of traditional breeding methods with advanced molecular technologies provides promising opportunities for sustainable and efficient sericulture development.

Keywords: Silkworm breeding, *Bombyx mori*, genetic improvement, CRISPR, silk productivity, sericulture biotechnology

1. Introduction

Sericulture is an important agro-based industry that provides employment and income for millions of rural households worldwide [1]. The domesticated silkworm *Bombyx mori* is the primary species used for commercial silk production due to its ability to produce high-quality silk fibers. Silk is valued for its unique properties such as high tensile strength, elasticity, and smooth texture, making it useful in textile, biomedical, and industrial applications. The productivity of sericulture largely depends on the genetic potential of silkworm strains and the quality of mulberry leaves used as feed. Over the past century, significant progress has been made in silkworm breeding to develop strains with improved silk yield, disease resistance, and environmental adaptability [2-4]. Traditional breeding methods such as selection, hybridization, and crossbreeding have played a key role in enhancing silkworm productivity. However, conventional breeding techniques often require long breeding cycles and may not precisely target specific genetic traits. With the advancement of molecular genetics and biotechnology, new approaches such as marker-assisted selection, genomic analysis, and gene editing have emerged as powerful tools for improving silkworm strains. These technologies allow scientists to identify genes associated with desirable traits and manipulate them to enhance silk production and cocoon quality [5]. Recent advances in genome sequencing and gene-editing technologies have significantly improved the understanding of silkworm genetics. Modern techniques such as CRISPR-Cas9 enable precise modification of genes related to silk protein synthesis, disease resistance, and stress tolerance, offering new possibilities for genetic improvement in sericulture. Therefore, integrating traditional breeding methods with modern molecular approaches has become essential for developing improved silkworm strains capable of meeting the increasing global demand for silk.

2. Conventional Breeding Approaches in Silkworm Genetic Improvement

Traditional breeding methods have been widely used in sericulture to improve the genetic performance of silkworm strains. These methods primarily involve selection, hybridization, and crossbreeding to combine desirable traits from different strains.

2.1 Selection Breeding

Selection breeding involves choosing superior individuals based on desirable traits such as cocoon weight, shell ratio, larval survival, and silk yield. Through repeated selection over several generations, breeders can gradually improve the genetic potential of silkworm populations. Selection breeding has successfully produced several improved silkworm varieties with higher silk productivity and better adaptability to different environmental conditions [6]. However, this approach is time-consuming and may require many generations to achieve significant improvements.

2.2 Hybridization

Hybridization is another important breeding technique used to enhance silk production. It involves crossing two genetically different silkworm strains to produce hybrid offspring that exhibit hybrid vigor (heterosis). Hybrid silkworms often show improved growth rate, disease resistance, and cocoon yield compared to their parental lines. Hybrid silkworm varieties are widely used in commercial sericulture because they provide higher productivity and better economic returns for farmers [7-8]. Many countries have developed high-yielding bivoltine hybrids through systematic breeding programs.

2.3 Crossbreeding and Line Breeding

Crossbreeding involves mating individuals from different strains or breeds to combine beneficial traits such as high silk yield and environmental adaptability. Line breeding, on the other hand, focuses on maintaining specific desirable genetic traits within a population by controlled breeding within closely related individuals [9]. These conventional breeding approaches have contributed significantly to the development of improved silkworm strains used in modern sericulture.

3. Molecular Breeding and Marker-Assisted Selection

Recent advancements in molecular genetics have enabled the use of molecular markers for silkworm breeding programs. Marker-assisted selection (MAS) allows breeders to identify specific genes associated with desirable traits such as silk yield, cocoon weight, and disease resistance [10]. Quantitative trait loci (QTL) analysis has been widely used to identify genomic regions controlling economically important traits in silkworms. Researchers have discovered genes associated with silk protein synthesis and larval

development that can be used as markers for genetic improvement. Molecular markers such as simple sequence repeats (SSR), single nucleotide polymorphisms (SNPs), and amplified fragment length polymorphisms (AFLP) have been used to analyze genetic diversity and assist breeding programs. These markers enable faster identification of superior silkworm strains and improve the efficiency of breeding strategies [11]. Marker-assisted breeding helps reduce the time required for developing improved silkworm varieties compared to conventional breeding methods. By selecting individuals with specific genetic markers, breeders can ensure that desirable traits are passed on to future generations.

4. Genetic Engineering and Transgenic Silkworms

Genetic engineering has opened new opportunities for improving silkworm productivity and silk quality. Transgenic technology allows scientists to introduce foreign genes into the silkworm genome to enhance specific traits. For example, researchers have introduced spider silk genes into silkworms to produce silk fibers with improved mechanical strength. Transgenic silkworms have also been developed to produce recombinant proteins for biomedical and industrial applications. [12] Genetic engineering techniques have also been used to enhance disease resistance in silkworms by modifying genes involved in immune responses. This approach helps reduce the impact of viral and bacterial infections that commonly affect silkworm populations. Although transgenic technology offers many advantages, its application in sericulture is still limited due to regulatory concerns and biosafety considerations.

5. Genome Editing Technologies in Silkworm Improvement

Genome editing technologies such as CRISPR-Cas9, TALENs, and zinc-finger nucleases have revolutionized genetic research in silkworms. Among these tools, CRISPR-Cas9 is the most widely used due to its efficiency, precision, and simplicity. CRISPR technology enables scientists to modify specific genes associated with silk production, growth regulation, and disease resistance [13-17]. Researchers have successfully used CRISPR to increase silk yield by manipulating genes involved in silk gland development and protein synthesis. Genome editing also allows the creation of silkworm strains resistant to viral pathogens such as *Bombyx mori* nucleopolyhedrovirus (BmNPV), which is a major cause of crop loss in sericulture [18-21]. Furthermore, CRISPR technology enables the insertion of genes that improve silk fiber properties or allow the production of novel biomaterials [22]. These advances demonstrate the potential of genome editing to transform silkworm breeding and improve the sustainability of sericulture.

Table 1: Conventional Silkworm Breeding Methods for Genetic Improvement

Breeding Method	Description	Major Advantages	Limitations
Selection breeding	Selection of superior individuals based on traits such as cocoon weight, shell ratio, and larval survival	Improves desirable traits over generations	Time-consuming and slow genetic progress
Hybridization	Crossing genetically different silkworm strains to produce hybrids with heterosis	Higher cocoon yield, better survival, improved silk quality	Requires careful parental line maintenance
Crossbreeding	Mating individuals from different strains to combine useful characteristics	Enhances adaptability and productivity	May cause genetic instability in later generations
Line breeding	Controlled mating within related individuals to maintain specific traits	Maintains uniformity in desirable traits	Risk of inbreeding depression

Table 2: Molecular and Biotechnological Approaches for Silkworm Genetic Improvement

Technique	Principle	Application in Sericulture	Benefits
Marker-Assisted Selection (MAS)	Uses molecular markers linked to desirable genes	Identification of traits such as cocoon weight and disease resistance	Faster breeding and improved selection accuracy
Quantitative Trait Loci (QTL) Mapping	Identification of genomic regions controlling economic traits	Mapping genes related to silk production and larval growth	Enhances understanding of complex traits
Transgenic Technology	Introduction of foreign genes into the silkworm genome	Production of stronger silk fibers and recombinant proteins	Improves silk quality and adds industrial value
Genome Editing (CRISPR-Cas9)	Precise modification of specific genes	Improving silk protein production and disease resistance	Highly precise and efficient genetic modification

Table 3: Major Traits Targeted in Silkworm Genetic Improvement Programs

Trait	Importance in Sericulture	Genetic Improvement Strategy
Cocoon weight	Determines silk yield and economic value	Selection breeding and hybridization
Shell ratio	Indicates the amount of silk obtained from cocoons	Marker-assisted breeding
Silk filament length	Important for silk quality and textile processing	Genetic selection and genome analysis
Disease resistance	Reduces crop loss due to pathogens	Transgenic and genome editing technologies
Environmental adaptability	Enables silkworm survival under climate variability	Development of tolerant hybrid strains
Larval survival rate	Influences cocoon productivity and farm profitability	Molecular breeding and improved management

6. Role of Omics Technologies in Silkworm Genetic Improvement

Omics technologies such as genomics, transcriptomics, proteomics, and metabolomics have greatly enhanced the understanding of silkworm biology. These technologies help identify genes involved in silk production, metabolism, and immune responses. Transcriptomic studies have revealed the expression patterns of genes in the silk gland responsible for fibroin and sericin synthesis [23-25]. Proteomic analyses have also provided insights into the structure and function of silk proteins. Integration of multi-omics data allows researchers to identify candidate genes for genetic improvement and develop targeted breeding strategies. Advanced bioinformatics tools are also being used to analyze large genomic datasets and identify genetic markers associated with desirable traits [26-28]. These technologies are expected to play an increasingly important role in the future of silkworm breeding and sericulture biotechnology.

7. Future Perspectives

The future of silkworm genetic improvement lies in the integration of traditional breeding with modern molecular and genomic technologies. Advances in genome sequencing, gene editing, and synthetic biology will enable the development of silkworm strains with higher productivity, improved silk quality, and enhanced resistance to diseases and environmental stress. The use of artificial intelligence and bioinformatics tools in analyzing genomic data may further accelerate silkworm breeding programs [15]. In addition, sustainable breeding strategies should focus on maintaining genetic diversity while improving desirable traits. Continued research and collaboration between scientists, farmers, and policymakers will be essential for translating these technological advancements into practical applications in the sericulture industry.

8. Conclusion

Silkworm genetic improvement has played a crucial role in enhancing silk production and ensuring the sustainability of the sericulture industry. Traditional breeding methods such as selection and hybridization have significantly contributed to the development of high-yielding silkworm strains. However, modern molecular and biotechnological approaches have further expanded the possibilities for

precise genetic improvement. Techniques such as marker-assisted selection, transgenic technology, genome editing, and omics-based research have improved our understanding of silkworm genetics and enabled the development of improved strains with superior productivity and disease resistance. The integration of these advanced technologies with conventional breeding strategies will be essential for meeting the growing global demand for silk and ensuring the long-term sustainability of sericulture.

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