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Non-Spinning Silkworm in Sericulture: A Critical Barrier to Cocoon Production

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Sericulture, the science and art of silk production through the rearing of silkworms, has sustained agrarian economies for thousands of years. In many Asian countries, especially India, China, Japan, and Thailand, it is not merely an agricultural practice but an intricate part of rural livelihood, employment generation, and cultural heritage. At the core of this enterprise lies the domesticated silkworm a species that has co-evolved with human intervention to become a reliable producer of one of nature's finest fibers silk. In the traditional model of sericulture, the silkworm passes through five larval stages, feeding exclusively on mulberry (*Morus spp.*) leaves. Upon completion of the fifth instar, the mature larva ceases feeding and begins spinning a protective silk cocoon, within which it undergoes metamorphosis into a pupa and eventually an adult moth. The entire economic viability of sericulture hinges on this single act of spinning the cocoon**.** It is from these cocoons that silk filament is reeled and it composed of primarily fibroin and sericin. However, in recent years, a perplexing and economically significant phenomenon has been observed: the emergence of non-spinning silkworms**.** These are silkworms that, despite completing all larval stages and appearing morphologically normal, fail to spin a cocoon or spin defective, irregular, or loose fiber masses that are unsuitable for reeling. This phenomenon, once rare and incidental, is now being reported with increasing frequency across various rearing regions posing a serious threat to the sustainability of sericulture.

Introduction

The spinning of a cocoon is not a simple mechanical act; it is a complex physiological and behavioral process regulated by interplay of hormonal, genetic, and environmental signals. The silk glands of the larva particularly the posterior and middle silk glands-undergo rapid hypertrophy during the final instars, synthesizing vast amounts of fibroin and sericin. These proteins are stored in liquid form until the larva begins to spin. The transition from larva to pupa is orchestrated by hormones such as ecdysone and juvenile hormone, which regulate not only moulting and metamorphosis but also the activation of silk gland secretion. Disruption at any point in this tightly controlled developmental cascade can result in impaired silk secretion or behavioral failure in spinning**.**

Several scientific investigations suggest that the causes of non-spinning behavior are multifactorial. Genetic mutations in silk-producing genes, endocrine imbalance, viral infections (especially *Bombyx mori* nucleopolyhedrovirus), high temperature stress, low humidity, and poor mulberry leaf quality are all potential contributors. Furthermore, environmental contamination such as the use of chemically polluted water for irrigation or pesticide residues on mulberry leaves has also been implicated in altering silk gland function. Inbreeding depression and poor seed quality further exacerbate the problem, especially in regions lacking strict quality control in seed production. The rise of non-spinning silkworms is not merely a biological curiosity—it carries significant economic implications. Cocoon yield per 100 dfls (disease-free layings) may drop sharply, the uniformity of cocoon size and shape is affected, and reeling efficiency declines. For small-scale farmers who rely on sericulture for income, this translates into measurable financial loss. At a national level, it affects cocoon availability, raw silk production, and ultimately the competitiveness of the sericulture sector in global markets.

Yet, within this challenge lies a unique opportunity. From a scientific perspective, non-spinning silkworms serve as model organisms to study gene regulation, silk protein synthesis, and the physiological basis of insect behavior. Advances in molecular biology, such as RNA interference and CRISPR-Cas9 genome editing, allow researchers to selectively knock out or replace silk-producing genes, creating transgenic silkworms capable of producing medically valuable proteins instead of silk. In this context, non-spinning strains are not a drawback but a biotechnological resource with enormous potential for the pharmaceutical and nutraceutical industries. Thus, the issue of non-spinning silkworms represents a dual narrative in modern sericulture: one of immediate concern due to its negative impact on silk productivity, and the other of long-term promise in terms of genetic research and industrial application. Addressing this challenge requires a multidisciplinary approach integrating field-level diagnostics, improved rearing practices, disease management, genetic screening, and climate adaptation strategies.

Biology of cocoon spinning

In the normal developmental process of the silkworm, cocoon spinning is an essential physiological behavior that protects the pupa and ensures successful metamorphosis. However, in certain strains or mutant lines, silkworms fail to spin cocoons, and these are referred to as non-spinning silkworms**.** These silkworms differ significantly from their spinning counterparts in terms of genetic makeup, silk gland function, behavior and silk protein expression**.**

1. Genetic and molecular basis

The non-spinning trait in silkworms is often the result of genetic mutations affecting the expression or function of silk-related genes. Normal silk production involves two primary genes:

- FibH and FibL – coding for the heavy and light chains of fibroin, the main structural protein of silk.
- Ser1 – coding for sericin**,** the glue-like protein that binds fibroin filaments together.

In non-spinning silkworms, mutations or deletions in these genes lead to absence or malfunction of silk protein synthesis**.** For example, mutations in the FibH gene result in the inability to produce sufficient fibroin, thus halting cocoon formation. Additionally, upstream regulatory genes such as SGF1 (Silk Gland Factor 1**)** and POUM2, which controls silk gene transcription, may also be disrupted. Silkworms with such mutations either lack the silk proteins or cannot assemble them correctly within the silk glands.

2. Degeneration of Silk Glands

One of the most notable anatomical features of non-spinning silkworms is the underdeveloped or degenerated silk glands**.** In normal silkworms, the posterior silk glands (PSGs) become highly hypertrophied by the end of the fifth instar, storing massive quantities of fibroin. However, in non-spinning silkworms, these glands are atrophied or fail to enlarge due to lack of protein synthesis. Studies have shown reduced expression of key silk genes and programmed cell death (apoptosis) occurring prematurely in the silk gland cells.

3. Hormonal and Physiological Differences

Cocoon spinning behavior in silkworms is also hormonally regulated, especially by juvenile hormone (JH) and ecdysteroids**.** These hormones orchestrate the transition from the feeding stage to the spinning stage. In non-spinning silkworms, hormonal imbalances often genetically regulated can disrupt the normal onset of spinning behavior. For instance, premature decline in JH or a sharp increase in ecdysone may trigger pupation before silk gland maturity leading to absence of cocoon formation.

4. Behavioral Abnormalities

Normal silkworms, before spinning, exhibit characteristic pre-pupal restlessness, searching for a secure location and beginning head movements to spin the cocoon. Non-spinning silkworms may either lack this behavior or show it incompletely. Even when placed in ideal mountage conditions, they fail to spin or secrete only trace amounts of silk fluid that does not solidify into a cocoon. This indicates a neurophysiological defect in the spinning motor pattern, likely linked to defective silk gland output or signal disruption in the central nervous system.

5. Evolutionary and Experimental Context

Non-spinning silkworms are not typically found in nature but are developed and maintained in laboratories for genetic, physiological and silk protein research. Such strains are important for studying silk gene regulation, transgenic expression and sericin free silk production. They are also used in biomedical and recombinant protein expression studies, where cocoons are unnecessary. In some breeding programs, knockout lines using CRISPR-Cas9 have been developed to specifically inactivate the FibH gene, resulting in non-spinning phenotypes. These models help researchers understand gene function and explore sericulture alternatives beyond silk production.

Reason for non-spinning silkworm

Non-spinning silkworm does not form commercial-grade cocoons. They either:

- Fail to secrete silk entirely
- Secrete very little or low-quality silk
- Form flimsy, loose or deformed cocoons

This phenomenon, once rare is now frequently reported by farmers, especially under suboptimal rearing conditions. Understanding the root causes is keys to addressing the problem.

Causes of Non-Spinning in Silkworms

1. Genetic Factors and Mutations

Some silkworm strains, especially those subjected to long-term inbreeding or hybridization stress, exhibit genetic mutations affecting:

- Silk gland development
- Silk protein synthesis
- Hormonal regulation (ecdysteroids, juvenile hormones)

Mutants like "ns" (non-sericin), "fl" (flaccid larvae) and "csr" (cocoonless silkworm race) have been documented in seribiology labs. Such mutations impair silk filament formation. Furthermore, certain transgenic lines developed for biomedical protein production may lose cocoon-forming traits, especially when fibroin genes are replaced with synthetic ones.

2. Temperature and Humidity Stress

Silkworms are highly sensitive to environmental conditions. Deviations from optimal temperature (23-28°C) or humidity (70-85%) during the late larval and prepupal stages affect:

- Silk gland enzyme activity
- Moisture levels required for smooth secretion
- Larval metabolism

High temperatures (>30°C) can lead to:

- Silk gland degeneration
- Faster larval aging with insufficient time for spinning
- Heat-induced lethargy, preventing spinning behavior

Low humidity dries up silk secretion or causes hardening, leading to incomplete cocoons.

3. Diseases and Pathogens

Non-spinning is often a symptom of underlying infections:

- Viral infections (especially *Bm*NPV or *Bombyx mori* nucleopolyhedrovirus) are notorious for damaging internal organs, including the silk glands and cells of midgut.

- Bacterial and fungal infections (caused by *Serratia*, *Streptococcus* or *Aspergillus*) affect gut health, causing toxemia and metabolic failure.

These pathogens interfere with:

- Hormonal changes needed for spinning behavior
- Nutrient absorption critical for silk synthesis
- Larval health and mobility

Subclinical infections may go unnoticed until spinning failure occurs.

4. Nutritional Deficiency

Quality of mulberry leaves**,** the sole diet of silkworms, plays a pivotal role in cocoon formation.

Leaves that are:

- Deficient in nutrients
- Grown under chemical contamination
- Affected by drought or salinity
- Grown in nutrient-poor soils

result in undernourished larvae with underdeveloped silk glands.

Moreover, poor feeding in the 4th and 5th instars-when silk gland development peaks-has a direct impact on spinning success.

5. Chemical and Environmental Pollution

Irrigation of mulberry with effluents from silk reeling industries, wastewater, or pesticides leads to bioaccumulation of:

- Heavy metals (Zn, Pb, Cd)
- Insecticide and Pesticide drift or residual effect
- pH and salinity imbalances

These toxins damage larval organs, including silk glands and gut linings, and may trigger epigenetic alterations that result in cocoonless or irregular spinning behavior.

6. Mechanical or handling injuries

Silkworms are sensitive during late larval stages. Rough handling, vibration, overcrowding, or delay in mountage installation (spinning frames) causes:

- Stress-induced cocoon retraction
- Wandering without spinning
- Behavioral confusion in spinning posture

Impact of non-spinning silkworms on sericulture

Non-spinning silkworms create multiple challenges in sericulture due to their inability to produce commercial-grade cocoons. Here's a scientific explanation of their impact:

- **Reduced silk yield**: Normally, silk is secreted by specialized silk glands as fibroin and sericin proteins. Non-spinners-due to genetic defects or silk gland atrophy-fail to secrete these proteins, leading to zero filament yield.
- **Increased wastage**: Flimsy or unspun cocoons are biologically unfit for reeling, as the silk filament is either absent or discontinuous. These larvae are often discarded or sold as low-value pupae, increasing post-rearing losses.
- **Loss of farmer income**: Since silk is the primary product, any reduction in cocoon quality directly affects the farmer’s income. Scientifically, poor hormonal regulation or pathogen-induced gland damage in larvae reduces cocoon formation and market value.
- **High rearing costs**: Rearing involves fixed biological inputs-like mulberry leaves rich in proteins and serine-for silk synthesis. When larvae do not spin, all nutritional, labor, and infrastructure efforts are lost, resulting in economic inefficiency.
- **Breeding setbacks**: If the cause is genetic (e.g., “csr” or “fl” mutants), these traits may propagate through seed multiplication if not screened, affecting the genetic purity and productivity of future generations.

Scientific significance and research opportunities

Interestingly, non-spinning silkworms are not just a problem they're a window into deeper biological insights and biotechnological innovations**.**

1. Recombinant protein production

Biotechnologists are using non-spinning strains as platforms to produce valuable pharmaceutical proteins, such as:

- Human collagen
- Antimicrobial peptides
- Industrial enzymes

Since these silkworms don't spin fibroin, their silk glands can be redirected to express custom proteins**,** turning them into living bioreactors.

2. Gene editing research

CRISPR-Cas9 tools have been applied to knockout silk-related genes in *B. mori*, creating purposeful non-spinners for lab studies. These help in:

- Understanding silk biosynthesis pathways
- Studying promoter activity of silk genes
- Identifying mutations responsible for metabolic disorders

3. Nutraceutical and feed applications

Non-spinning silkworm pupae are more accessible for harvest. Rich in proteins, fats, and bioactive compounds, they can be:

- Dried and processed into animal feed
- Used in human dietary supplements (popular in East Asia)
- Explored for antimicrobial and antioxidant compounds

This turns waste into value-added products.

Preventive measures and farm-level management

To reduce the incidence of non-spinning behavior in silkworms, it is essential to manage environmental, nutritional, disease, genetic, and rearing conditions effectively.

a. Environmental management

Silkworm development and silk gland function are highly sensitive to environmental cues like temperature (24–28°C) and relative humidity (70–80**%)**. Extremes in these factors can delay larval development, disrupt hormonal regulation (especially ecdysone), and lead to stress-induced silk gland atrophy.

- Use fans, heaters, and humidifiers/dehumidifiers to stabilize microclimate.
- Ensure cross ventilation to reduce CO_2 buildup and microbial growth.
- Avoid overcrowding, which can cause heat stress and oxygen deficiency.

b. Leaf quality assurance

Mulberry leaves provide essential nutrients like proteins (serine, glycine), carbohydrates, and minerals required for fibroin and sericin biosynthesis. Poor-quality or pesticide-contaminated leaves can impair digestion, reduce silk protein synthesis, and induce toxicity-related gland degeneration.

- Use clean, disease-free, and pesticide-free mulberry.
- Apply balanced NPK and FYM to enhance leaf nutrient content, particularly nitrogen, which boosts protein accumulation.
- Avoid untreated wastewater or reeling effluent, which may contain heavy metals or pathogens that damage the silk glands.

c. Disease prevention

Pathogens such as viruses (e.g., BmNPV), bacteria (e.g., *Serratia marcescens*), and fungi can invade silk glands, impair protein secretion, and lead to non-spinning. These infections spread quickly in unsanitary conditions.

Best practices:

- Regularly disinfect rearing rooms using formalin (2–4%), bleaching powder, or slaked lime, which destroy spores and microbial contaminants.

- Monitor for early signs such as lethargy, vomit, or color change.
- Use serivaccines (e.g., for grasserie) and probiotics (like *Lactobacillus* strains) to enhance disease resistance and gut health.

d. Breeding and race selection

Some silkworm strains carry heritable mutations (e.g., *csr*, *fl*, *nd-s*) associated with non-spinning or weak spinning. If such traits are not removed, they can reduce the genetic fitness and cocoon productivity of subsequent generations.

- Avoid using low-performing races known for high non-spinning rates.
- Conduct performance screening at seed supply units to detect genetic defects.
- Apply selective breeding to eliminate or replace defective lines and maintain race purity.

e. Proper mountage timing

During the last instar, silkworms show a hormonal surge (ecdysone) that triggers spinning. Delayed mountage leads to wandering behavior, mechanical injury, or loss of silk gland integrity, resulting in non-spinning.

- Install mountages at the correct time (usually when silkworms become translucent and show reduced feeding).
- Provide adequate, soft, and clean space that supports natural spinning behavior and minimizes larval stress.

Future perspectives

As climate change, genetic stress, and environmental degradation increase the frequency of non-spinning, the sericulture sector must evolve:

1. Development of resilient strains

With advancements in genomics, CRISPR-Cas9 gene editing, and marker-assisted selection (MAS), scientists are now able to identify and manipulate genes responsible for thermotolerance, disease resistance, and pollutant detoxification in silkworms. For instance, overexpression of heat shock proteins (HSPs) or upregulation of immune-related genes like PGRP (Peptidoglycan Recognition Proteins) can enhance resistance to environmental stress and pathogens.

Application:

- Development of multivoltine or bivoltine hybrid strains that can withstand temperature fluctuations.
- Selection of genotypes with robust silk gland development, even under abiotic stress (e.g., high CO_2 or heavy metals).
- Use of transgenic or gene-edited lines to improve silk yield and larval survival under adverse conditions.

2. Adoption of Seribiotechnology

Non-spinning larvae can be harnessed through seribiotechnological innovations. For example:

- Silk genes like fibroin heavy chain (FibH) and sericin are being cloned into microbial or insect cell systems for recombinant silk protein production.
- Non-spinning mutants with high body protein content can be used for edible pupae products, rich in amino acids, lipids, and vitamins.
- Biotechnology can also create biodegradable silk-based biomaterials for use in cosmetics, sutures, and drug delivery.

Application:

- Transforming waste (non-spinners) into high-value nutraceuticals or biopolymer sources.
- Launching recombinant silk production platforms that bypass traditional cocoon reeling.

3. Integrated Sericulture Models

Integrated models aim to diversify outputs from sericulture to ensure economic sustainability. Silkworm pupae, especially from non-spinners, are a rich source of protein (55–65%) and oil, useful in:

- Animal feed, poultry supplements, and fishmeal industries.
- Pharmaceuticals, including pupal oil used in anti-aging and skincare products.

Application:
- Linking rearing units with pupal processing industries for additional income.
- Creating circular economy models where both silk and pupal byproducts are marketed.

4. Digital Monitoring and AI

The use of IoT (Internet of Things) devices, machine learning, and AI-driven image analysis can revolutionize rearing practices by offering real-time insights into larval health, environmental conditions, and early warning for diseases.
- Sensors monitor temperature, humidity, CO_2, and leaf moisture.
- AI models trained on silkworm behavior can detect deviations like excessive movement or early lethargy—signs of stress or infection.

Application:
- Farmers receive mobile alerts on when to mount, feed, or intervene.
- Reduction in non-spinning through precision rearing practices.
- Better disease prediction reduces antibiotic overuse and enhances cocoon productivity.

Conclusion

The emergence of non-spinning silkworms represents a multifaceted barrier to the sustainability and profitability of sericulture. As these larvae fail to spin cocoons-either due to genetic mutations, environmental stress, disease or nutritional deficiencies-they directly reduce silk yield and disrupt the value chain. For farmers, this leads to economic loss; for researchers, it signals the need for urgent scientific inquiry; and for policymakers, it calls for renewed focus on supporting the backbone of rural silk economies.

Understanding etiology of non-spinning behavior is essential. Whether it's due to high temperature and humidity fluctuations, poor mulberry leaf quality, pathogen invasion or inherent genetic anomalies, each contributing factor must be systematically studied and addressed. Modern tools like molecular diagnostics, genomics and CRISPR-based gene editing offer new avenues for developing robust silkworm breeds resistant to Non-spinning. At the same time, promoting good rearing practices, disease surveillance, and rearing environment management at the farm level is vital.

Furthermore, capacity building among farmers, timely government interventions and supportive sericultural extension services can enhance early detection and control of non-spinning outbreaks. The integration of seri-biotechnology with potential applications of non-spinning larvae in recombinant protein production, pharmaceuticals or food industries, can also transform this challenge into an opportunity. In conclusion, while non-spinning silkworms currently stand as a critical barrier to cocoon production, they also present a chance to rethink, reform, and future-proof sericulture. A coordinated, multidisciplinary effort combining traditional knowledge with cutting-edge science is imperative to ensure that the golden thread of silk continues to weave economic security and rural prosperity across generations.

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