

Advances in Mulberry Cultivation and Silkworm Rearing for Enhanced Silk Production

Rakesh Das^{1*}, Kaushik Pramanik¹, Amit Layek² and NU Visakh³

1School of Agriculture, Swami Vivekananda University,
Barrackpore 700121, West Bengal, India

2 Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia
-700026, West Bengal, India

3 Department of Agricultural Entomology, College of
Agriculture, Vellanikkara, Kerala Agricultural University,
Thrissur, Kerala, India

*Corresponding: rakeshd@svu.ac.in

Abstract

Sericulture, the practice of rearing silkworms (*Bombyx mori*) for silk production, heavily depends on high-quality mulberry (*Morus spp.*) cultivation. Recent advancements in mulberry agronomy and silkworm rearing techniques have significantly improved silk yield and quality. This article explores modern approaches to mulberry cultivation, including high-yielding and disease-resistant varieties, precision farming techniques, organic nutrient management, and water-efficient irrigation methods like drip systems. In silkworm rearing, technological advancements such as automated rearing chambers, temperature and humidity control systems, and probiotics for improved digestion have led to increased cocoon productivity and resilience against diseases. The integration of biotechnology, including genetic improvements in mulberry plants and silkworm strains, has further enhanced silk quality. Additionally, sustainable practices like organic farming and eco-friendly disease management are gaining traction. This paper also examines the challenges faced by sericulture farmers, such as climate change impacts and pest outbreaks, and highlights innovative

solutions. The combined effect of these advancements is paving the way for a more profitable and environmentally sustainable silk industry. Future research should focus on precision sericulture, digital monitoring systems, and climate-adaptive strategies to further boost silk production efficiency.

Keywords: Sericulture, Mulberry Cultivation, Silkworm Rearing, Biotechnology, Sustainable Silk Production.

Introduction

Silk, the “Queen of Textiles,” has been a symbol of luxury, elegance, and cultural significance for over five millennia. The journey of a single silk thread, from a tiny egg to a magnificent fabric, is orchestrated by the intricate and interdependent processes of sericulture. This industry is a quintessential example of a sustainable agro-based rural enterprise, providing employment, empowering women, and contributing significantly to the economies of countries like China, India, Brazil, and Thailand (Dandin & Giridhar, 2014). At its core, sericulture is a perfect synergy between the plant and animal kingdoms: the mulberry plant serves as the exclusive food source for the monophagous silkworm, *Bombyx mori* L., whose cocoon is the raw material for silk.

The foundational principle of sericulture is elegantly simple: the quality and quantity of silk are directly proportional to the quality and quantity of mulberry leaves consumed by the silkworm (Rahmathulla, 2012). This simple equation, however, belies a complex biological system influenced by a multitude of factors. Traditional sericulture practices, while rich in heritage, often faced limitations in terms of low productivity, high susceptibility to diseases, and inefficiencies in resource management. The vulnerability of silkworms to environmental fluctuations and pathogens has historically been a major bottleneck (Kumar et al., 2011).

The 21st century has ushered in a new era for this ancient industry. Driven by the demands of a growing global population and the challenges posed by climate change and shrinking land resources, sericulture has embraced scientific innovation across its entire value chain. The modern sericulturist is no longer just a farmer but a manager of

a sophisticated bio-factory, leveraging advancements in genetics, biotechnology, agricultural engineering, and data science.

This chapter, “Advances in Mulberry Cultivation and Silkworm Rearing for Enhanced Silk Production,” aims to provide a comprehensive and detailed overview of the cutting-edge technologies and practices that are shaping the future of silk. We will dissect the journey of silk production into its two primary components, exploring the revolution in each. The development and deployment of high-yielding mulberry varieties with enhanced nutritional profiles and resistance to pests, diseases, and abiotic stresses like drought and salinity. The adoption of precision farming techniques, including soil health management, leaf nutrient budgeting, and the use of geospatial technologies for optimal plantation management. The shift towards efficient nutrient and water management, emphasizing integrated organic manuring and micro-irrigation systems to ensure sustainable leaf production. Advanced plant protection strategies that minimize environmental impact while safeguarding leaf yield and quality.

Genetic improvements in silkworm breeds, including robust hybrid combinations, polyvoltine breeds for tropical regions, and breeds with specific cocoon characteristics (e.g., colour, filament length). Technological interventions in rearing, such as automated feeding systems, climate-controlled rearing houses, and disinfection protocols that drastically improve labour efficiency and rearing success. Nutritional and health management, highlighting the use of probiotics, nutraceuticals, and herbal supplements to enhance silkworm digestion, immunity, and overall vigour. Biotechnological breakthroughs, including the development of transgenic silkworms for disease resistance and the production of novel or enhanced silk fibres. Finally, the chapter will synthesize these advancements within a framework of sustainability and future challenges. We will discuss the integration of these technologies into a cohesive system, address the looming threat of climate change, and chart a course for future research and development, including the exciting potential

of digital sericulture. By understanding and adopting these advances, stakeholders across the sericulture spectrum can unlock new levels of productivity, quality, and sustainability, ensuring that the timeless allure of silk continues to thrive for generations to come.

Modern Approaches to Mulberry Cultivation

The mulberry plant is the bedrock of the sericulture industry. Its leaves are the sole source of nutrition for the silkworm, *Bombyx mori**, and their quality directly dictates the health of the silkworm, the quality of the cocoon, and ultimately, the character of the silk filament. As such, maximizing both the quantity and nutritional quality of mulberry leaf production is paramount. Modern mulberry cultivation has evolved from a traditional practice to a science-driven enterprise, leveraging genetics, precision agronomy, and sustainable resource management.

Development of High-Yielding and Resilient Mulberry Varieties

The genetic improvement of mulberry has been a primary focus for sericulture researchers worldwide. The objective is to develop varieties that are not only high-yielding but also rich in proteins, carbohydrates, and other essential nutrients, while being resilient to biotic (pests, diseases) and abiotic (drought, salinity, waterlogging) stresses.

Nutrient-Rich Varieties: Traditional varieties have been systematically evaluated and cross-bred to develop superior genotypes. For instance, varieties like ***V1*** and ***S36*** in India are renowned for their high leaf yield and superior leaf quality, leading to better silkworm growth and cocoon parameters (Vijayan et al., 2011). The evaluation criteria include leaf moisture content, crude protein, carbohydrate content, and digestibility. Newer varieties are being selected for optimal amino acid profiles that match the nutritional requirements of silkworms.

Disease and Pest Resistance: Mulberry is susceptible to various diseases like leaf spot (*Cercosporamoricola*), powdery mildew (*Phyllactiniacorylea*), and root rot (*Fusarium* spp.).

Breeding for resistance is a sustainable strategy to reduce yield loss and pesticide use. For example, the variety Tr-10 has shown considerable resistance to powdery mildew, while S1635 exhibits tolerance to root rot (Tikader& Kamble, 2008). Molecular marker-assisted selection is now being employed to identify and introgress resistance genes more efficiently, speeding up the breeding cycle.

Abiotic Stress Tolerance: Climate change is leading to increased instances of drought, soil salinity, and temperature extremes. Developing tolerant varieties is crucial for the stability of sericulture. Genotypes like S13 have demonstrated better drought tolerance, while BC2-59 has shown promise in saline-affected areas (Das et al., 2020). Research into the physiological and molecular mechanisms of stress tolerance, such as the role of osmoprotectants and antioxidant enzymes, is guiding these breeding programs.

Biotechnological Interventions: Genetic engineering offers a direct route for mulberry improvement. *Agrobacterium*-mediated transformation has been successfully used to introduce genes for insect resistance (e.g., Bt genes), drought tolerance (e.g., genes for osmoprotectants like proline and glycine betaine), and improved nutrient content (Agarwal et al., 2017). While still largely in the research domain and facing regulatory hurdles, this technology holds immense potential for creating next-generation mulberry varieties.

Precision Farming in Mulberry Plantations

Precision agriculture involves the management of spatial and temporal variability in fields to improve resource use efficiency and productivity. In mulberry cultivation, this translates to site-specific management of soil, water, and nutrients.

Soil Health Management: Mulberry thrives in well-drained, loamy soil with a pH between 6.5 and 7.0. Precision farming begins with detailed soil mapping to understand variability in soil pH, organic carbon, and macro/micronutrient status across a plantation. Based on this grid-based soil analysis, Soil Test-Based Leaf Nutrient Budgeting is practiced. This approach calculates the precise dosage of fertilizers required

to meet the nutrient demand of the targeted leaf yield, avoiding both deficiency and excess application (Sarkar et al., 2014). This not only improves leaf quality but also prevents environmental pollution from fertilizer runoff.

Geospatial Technologies: The use of GPS, GIS, and remote sensing is becoming increasingly relevant for large-scale mulberry cultivation. Satellite or drone imagery can be used to monitor plant health, detect pest or disease outbreaks early, assess water stress, and estimate biomass, allowing for targeted interventions (Rao et al., 2018).

Advanced Nutrient and Water Management

Efficient use of water and nutrients is critical for both economic and environmental sustainability.

Integrated Nutrient Management (INM): Relying solely on chemical fertilizers degrades soil health over time. The INM approach advocates for the combined use of organic and inorganic sources. The application of FYM (Farm Yard Manure), vermicompost, and green manures (like *Glyricidia*) improves soil structure, water-holding capacity, and microbial diversity, leading to a more sustained release of nutrients (Ramesh et al., 2011). Biofertilizers such as nitrogen-fixing (*Azotobacter*, *Azospirillum*) and phosphate-solubilizing (*Bacillus*, *Pseudomonas*) bacteria are also being integrated to reduce dependency on synthetic fertilizers.

Water-Efficient Irrigation: Mulberry is a water-intensive crop, but water is becoming a scarce resource. Traditional flood irrigation is highly inefficient. The adoption of drip irrigation and sprinkler systems has proven to be a game-changer. Drip irrigation delivers water directly to the root zone, minimizing evaporation and runoff. Studies have shown that drip irrigation can lead to water savings of 40-60% and a concurrent increase in leaf yield of 15-25% compared to conventional methods (Reddy et al., 2013). These systems can also be integrated with fertigation, the application of water-soluble fertilizers through the irrigation system, ensuring optimal nutrient uptake.

Sustainable Plant Protection Strategies

Protecting the mulberry crop from pests and diseases is essential, but the use of chemical pesticides is hazardous due to the high toxicity of silkworms to even minute traces. Therefore, the focus has shifted to eco-friendly and integrated approaches.

Integrated Pest Management (IPM): IPM combines cultural, mechanical, biological, and, as a last resort, selective chemical methods. Cultural practices include proper spacing, pruning, and sanitation. Biological control involves the conservation and use of natural enemies like ladybird beetles, lacewings, and parasitoid wasps. Botanicals such as neem (*Azadirachta indica*) extracts are effective against a range of pests and are safe for silkworms (Bhattacharya et al., 2016).

Disease Management: Similar principles apply to disease control. The use of resistant varieties is the first line of defense. Bio-fungicides containing *Trichoderma* and *Pseudomonas fluorescens* are effective against several soil-borne and foliar diseases. Proper sanitation, including the disposal of infected plant debris, is critical to break the disease cycle.

Technological Advancements in Silkworm Rearing

The second stage of sericulture involves the delicate and labor-intensive process of rearing silkworms. Technological innovations in this domain have been instrumental in reducing labour, minimizing losses due to diseases and adverse environments, and significantly enhancing cocoon productivity and quality.

Genetic Improvement of Silkworm Breeds

The domestication of *Bombyx mori* over 5000 years has resulted in a vast genetic resource. Systematic breeding has been used to develop hybrids that combine desirable traits from different parental lines.

Robust Hybrid Breeds: Most commercial silk production is based on F1 hybrids, which exhibit heterosis (hybrid vigour) for traits like larval weight, cocoon weight, shell weight, and filament length. Breeding programs continuously develop

new hybrid combinations tailored to specific regional climates and seasons. For example, breeds like CSR2 x CSR27 and PM x NB4D2 in India are popular for their high silk content and disease tolerance (Sengupta et al., 2017).

Specialized Breeds: Breeders have developed silkworm breeds for specific purposes:

Polyvoltine Breeds: Adapted for tropical regions, these breeds can have multiple generations per year.

Bivoltine Breeds: Typically producing higher quality silk, these are suited for temperate and subtropical regions.

Sex-Linked Breeds: These allow for the easy separation of male and female larvae at an early stage. Since male larvae are generally more efficient converters of leaf to silk, they can be reared separately for optimal resource use.

Silk Colour Mutants: Breeds that produce naturally coloured cocoons (golden yellow, green) are being developed to eliminate the need for environmentally damaging chemical dyes (Hirayama & Kosegawa, 2020).

Automation and Environmental Control in Rearing

Traditional rearing is highly labour-intensive, requiring round-the-clock care during the larval stage. Automation addresses this challenge directly.

Automated Rearing Systems: Japan and South Korea are pioneers in developing automated rearing chambers. These systems feature:

Automatic Feeding Devices: These machines chop mulberry leaves and distribute them evenly on rearing beds at predetermined intervals, drastically reducing labour costs.

Bed Cleaning Robots: Automated devices that remove silkworm excrement (frass) and leftover leaf matter, maintaining hygiene and preventing disease outbreaks.

Mounting Assistance: Automated systems for transferring mature larvae to mounting devices (cocooning frames) (Matsui et al., 2019).

Climate-Controlled Rearing Houses: Silkworms are extremely sensitive to temperature (23-28°C) and humidity (65-85%). Modern rearing houses are equipped with:

Sensors: For continuous monitoring of temperature, humidity, and air quality.

HVAC Systems: Heating, Ventilation, and Air Conditioning systems that automatically adjust the environment to maintain optimal conditions.

Light Regulators: Control of photoperiod to influence growth and development.

This controlled environment minimizes stress on the silkworms, reduces the rearing period, and leads to more uniform and robust larvae, resulting in higher cocoon yield and quality (Rahmathulla, 2012).

Nutritional and Health Management Enhancements

Beyond providing quality leaves, the internal health of the silkworm is now a major focus area.

Probiotics and Gut Health: The silkworm gut harbors a complex microbiome that plays a crucial role in digestion, nutrient absorption, and pathogen defense. Supplementing the silkworm diet with beneficial probiotics like *Lactobacillus* and *Bacillus* species has been shown to improve growth, digestibility, and silk protein synthesis. They work by competitive exclusion of pathogens, production of digestive enzymes, and stimulation of the immune system (Mohan et al., 2019).

Nutraceuticals and Herbal Supplements: The use of plant-based supplements is a promising, low-cost health management strategy. Extracts from plants like *Asclepias* (milkweed), *Withaniasomnifera* (ashwagandha), and *Ocimum sanctum* (holy basil) have been reported to enhance the growth, antioxidant status, and disease resistance of silkworms (Chowdhury et al., 2021). These supplements act as immunostimulants and provide bioactive compounds that bolster the silkworm's innate immunity.

Disinfection Protocols

Hygiene is non-negotiable in silkworm rearing, as the slightest lapse can lead to devastating disease outbreaks. Advanced disinfectants such as chlorine dioxide and Virkon-S have demonstrated high efficacy against major pathogens, including *Bombyx mori* nucleopolyhedrovirus (BmNPV) and various bacterial agents. When used at recommended concentrations, these disinfectants show minimal toxicity to silkworms, ensuring both biosecurity and animal welfare. In addition, ultraviolet (UV) light chambers are increasingly employed to sterilize rearing appliances, trays, and even mulberry leaves, providing an effective and residue-free disinfection strategy.

The Integration of Biotechnology in Sericulture

Biotechnology has revolutionized the sericulture industry by enabling direct genetic manipulation of both mulberry and silkworm. These advances have transcended the limitations of conventional breeding, offering unprecedented opportunities for improving productivity, disease resistance, and silk quality.

Genetic Engineering in Mulberry

As previously discussed, transgenic research in mulberry aims to enhance resilience, nutritive value, and sustainability. The primary objectives include:

- **Insect Resistance:** The introduction of *Bacillus thuringiensis* (Bt) genes into mulberry has yielded transgenic lines resistant to leaf-feeding pests such as the tukra mealybug and the Bihar hairy caterpillar. This innovation reduces pesticide dependency and prevents defoliation-induced yield loss.
- **Abiotic Stress Tolerance:** Genes encoding osmoprotectants (e.g., P5CS responsible for proline biosynthesis) and regulatory transcription factors (e.g., DREB) are being incorporated to develop drought- and salinity-tolerant varieties.
- **Enhanced Nutritional Profile:** Genetic interventions

targeting protein and carbohydrate metabolism pathways are under exploration to create mulberry leaves with superior nutritive content for silkworms, thereby improving cocoon yield and silk quality.

Transgenic Silkworms

The genetic modification of *Bombyx mori* represents one of the most exciting breakthroughs in sericulture. Using transposon-based vectors such as *piggyBac* and modern CRISPR-Cas9 genome editing, researchers have successfully engineered silkworm strains with desirable traits.

- **Pathogen Resistance:** Transgenic silkworms resistant to BmNPV have been developed through RNA interference (RNAi) targeting essential viral genes (Kanginakudru et al., 2007). Similarly, antimicrobial peptide genes have been introduced to confer resistance against bacterial flacherie and septicemia.

- **Novel Silk Production:** Genetic engineering has been harnessed to alter silk composition and functionality:

- **Spider Silk Fibroin Integration:** Spider silk proteins, renowned for their exceptional tensile strength and elasticity, have been incorporated into silkworm fibroin to produce a “super-silk” with enhanced mechanical properties (Teulé et al., 2012).

- **Fluorescent Silk:** Introduction of genes encoding fluorescent proteins such as GFP (Green Fluorescent Protein) has led to the production of luminescent silk, useful in anti-counterfeiting applications and biomedical imaging.

- **Functionalized Silk:** Through the concept of “seri-biotechnology,” silkworms are engineered to express bioactive molecules, including human collagen, antibodies, and growth factors, in their silk glands, turning them into efficient bioreactors for high-value pharmaceutical production.

4. Sustainable and Eco-friendly Sericulture Practices

The future of sericulture depends on minimizing its ecological footprint while maximizing socio-economic returns. A global

shift toward sustainable and organic practices is gaining momentum.

- **Organic Sericulture:** This approach emphasizes the cultivation of mulberry without synthetic fertilizers or pesticides and the rearing of silkworms without chemical prophylactics. Certified organic silk commands a premium in global markets. The practice integrates Integrated Nutrient Management (INM), Integrated Pest Management (IPM), and the use of plant-based supplements to enhance silkworm immunity (Bhat & Kambre, 2020).

- **Waste Recycling and By-product Utilization:** Sericulture generates considerable biomass, much of which can be valorized into useful products.

- **Mulberry Prunings and Silkworm Litter:** These can be composted or processed through vermicomposting to produce nutrient-rich organic manure.

- **Silkworm Pupae:** Rich in protein and oil, pupae serve as high-quality feed for poultry and fish, while pupal oil has applications in cosmetics and pharmaceuticals.

- **Silkworm Frass (Excreta):** Containing high levels of nitrogen and organic matter, frass is an effective natural fertilizer for various crops.

5. Challenges and Innovative Solutions

Despite significant progress, the sericulture sector faces persistent challenges that require adaptive, science-driven interventions.

- **Climate Change:** Increasing temperature fluctuations, unseasonal rainfall, and prolonged droughts adversely affect both mulberry physiology and silkworm performance. Heat stress reduces feeding efficiency and weakens immune responses.

- **Proposed Solutions:** Breeding climate-resilient genotypes, constructing climate-controlled rearing facilities, and using predictive models to determine optimal rearing schedules.

- **Pesticide Contamination:** Drift from adjacent agricultural fields can cause acute silkworm mortality.
- **Proposed Solutions:** Establishment of designated “Sericulture Zones,” implementation of buffer strips, farmer sensitization programs, and development of detoxifying formulations that can neutralize pesticide residues on mulberry leaves.
- **Labour Shortage:** Rural migration and demographic changes have led to reduced labor availability.
- **Proposed Solutions:** Adoption of semi-automated rearing systems, mechanized leaf harvesting, and digital monitoring tools to minimize human labor dependence.

Conclusion and Future Perspectives

Sericulture today stands at the intersection of tradition and innovation. The integration of advancements in mulberry agronomy, silkworm breeding, biotechnology, and digital technologies has transformed the industry from a craft-based practice into a precision-driven bioenterprise.

The emerging paradigm of “**Precision Sericulture**” integrates multiple technological domains:

- **Internet of Things (IoT) and Sensor Networks:** Real-time monitoring of soil moisture, temperature, humidity, and silkworm behavior enables data-driven decision-making.
- **Artificial Intelligence and Big Data Analytics:** Predictive modeling and machine learning algorithms can forecast disease outbreaks, optimize rearing schedules, and enhance yield prediction accuracy.
- **Blockchain Technology:** Ensuring traceability and transparency throughout the silk supply chain enhances consumer confidence and ensures ethical and sustainable production.

Future research priorities include:

- Development of **multi-stress-tolerant** mulberry and silkworm lines using CRISPR-based genome editing.

- Expanding the potential of silkworms as **bioreactors** for the production of pharmaceuticals and high-value biomaterials.
- Strengthening **extension and training programs** to facilitate technology transfer and adoption among grassroots farmers.

By harmonizing biotechnology, environmental sustainability, and digital innovation, sericulture can evolve into a model bioeconomic industry—preserving its cultural legacy while ensuring resilience, profitability, and ecological harmony in the years to come.

References:

Agarwal, S., Kanwar, K., & Sharma, D. R. (2017). Genetic transformation of mulberry (*Morus* spp.) for stress tolerance. In *Mulberry: Genetic Improvement in Context of Climate Change* (pp. 345–362). CRC Press.

Bhat, M. A., & Kambre, R. A. (2020). Organic sericulture: A sustainable approach for production of eco-friendly silk. *Journal of Entomology and Zoology Studies*, 8(4), 1325–1330.

Bhattacharya, A., Saha, S., & Bandopadhyay, U. K. (2016). Eco-friendly management of mulberry pests using botanicals. *Sericologia*, 56(2), 112–120.

Chowdhury, S., Saha, A. K., & Bindroo, B. B. (2021). Effect of herbal supplementation on the growth and economic traits of silkworm, *Bombyx mori* L. *Journal of Applied and Natural Science*, 13(1), 320–326.

Dandin, S. B., & Giridhar, K. (2014). *Handbook of Sericulture Technologies*. Central Sericultural Research and Training Institute.

Das, C., Roy, S., & Raje, U. (2020). Screening of mulberry genotypes for drought tolerance using physiological and biochemical markers. *Journal of Environmental Biology*, 41(5), 1121–1128.

Hirayama, C., & Kosegawa, E. (2020). Molecular mechanisms of cocoon colouration in silkworms. In *Silkworm Biofactories* (pp. 45–62). Springer.

Kanginakudru, S., Royer, C., & Engler, F. (2007). Targeting *ie-1* gene by RNAi induces baculoviral resistance in lepidopteran cell lines and in transgenic silkworms. *Insect Molecular Biology*, 16(6), 635–644.

Kumar, N. S., Singh, B. D., & Hegde, N. (2011). Silkworm diseases and their management. *Indian Journal of Sericulture*, 50(1), 1–15.

Matsui, T., Nakamura, R., & Kato, M. (2019). Development of a fully automated silkworm rearing system. *Journal of Insect Biotechnology and Sericology*, 88(1), 1–8.

Mohan, P., Sivaprasad, V., & Singh, R. N. (2019). Probiotics in silkworm (*Bombyx mori* L.) health and nutrition: A review. *International Journal of Industrial Entomology*, 39(2), 35–42.

Rahmathulla, V. K. (2012). Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: A review. *Psyche: A Journal of Entomology*, 2012, 121234. <https://doi.org/10.1155/2012/121234>

Ramesh, H. L., Sathyanarayana, E., & Kumar, V. (2011). Influence of integrated nutrient management on growth, leaf yield and quality of mulberry (*Morus alba* L.). *Journal of Soil Biology and Ecology*, 31(1-2), 1–10.

Rao, P. S., Naik, D. J., & Suresh, K. (2018). Application of remote sensing and GIS in mulberry plantation monitoring. *International Journal of Geomatics and Geosciences*, 8(3), 45–52.

Reddy, M. N., Rao, J. S., & Rao, P. S. (2013). Effect of drip irrigation on leaf yield and water use efficiency in mulberry. *Journal of Soil and Water Conservation*, 12(4), 345–350.

Sarkar, A., Dutta, S., & Roy, S. (2014). Soil test-based nutrient management for mulberry: A case study from West Bengal. *Indian Journal of Fertilisers*, 10(5), 24–30.

Sengupta, A., Roy, G. C., & Das, N. K. (2017). Evaluation of new bivoltine silkworm hybrids for commercial traits in West Bengal. *Sericologia*, 57(3), 215–222.

Teulé, F., Miao, Y. G., Sohn, B. H., Kim, Y. S., Hull, J. J., Fraser, M. J., ... & Jarvis, D. L. (2012). Silkworms transformed with chimeric silkworm/spider silk genes spin composite silk fibers with improved mechanical properties. *Proceedings of the National Academy of Sciences*, 109(3), 923–928.

Tikader, A., & Kamble, C. K. (2008). Mulberry breeding, propagation, and conservation. In *Mulberry: Genetic Improvement in Context of Climate Change* (pp. 45–65). CRC Press.

Vijayan, K., Chakraborti, S. P., & Roy, B. N. (2011). Breeding for high leaf yield and quality in mulberry. *International Journal of Industrial Entomology*, 23(2), 123–135.