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Advances in Host Plant Nutrition and their Effects on Silkworm Productivity

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ABSTRACT

The silkworm, Bombyx mori, relies solely on mulberry leaves (Morus spp.) for nutrition, making leaf quality pivotal for sericulture productivity. Advances in mulberry nutrition, including optimized soil fertilization, biofertilizers, foliar sprays, and biotechnological interventions like transgenic and CRISPR-edited varieties, have enhanced leaf nutritional profiles, boosting silkworm growth, cocoon yield, and silk quality. Balanced NPK fertilization increases leaf protein by 18.5%, raising cocoon weight by 10.3%, while biofertilizers elevate leaf nitrogen by 14.6%, extending silk filament length by 11.2%. Transgenic and CRISPR-edited mulberry reduce anti-nutritional factors, improving feed efficiency by 10.2% and larval growth by 8.3%. These advancements yield 20–26% higher farmer incomes and 18–21% lower environmental impacts. Challenges like transgenic costs and soil variability persist, but precision agriculture and climate-resilient cultivars promise sustainable sericulture.

Keywords: *Bombyx mori, Morus spp.RNAi, CRISPR, cocoon yield, silk quality.*

INTRODUCTION

Sericulture, the cultivation of silkworms (*Bombyx mori*) for silk production, is a vital agro-industry with significant economic, cultural, and ecological implications worldwide. As a monophagous species, *B. mori* depends exclusively on mulberry leaves (*Morus* spp.) for its nutritional needs, making leaf quality a critical determinant of larval growth, cocoon production, and silk quality.

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The nutritional composition of mulberry leaves directly influences silkworm development, silk protein synthesis, and cocoon yield, which in turn affect the profitability and sustainability of sericulture. Over the past decade, remarkable advancements in mulberry nutrition have revolutionized sericulture by optimizing leaf nutrient content through innovative approaches, including soil nutrient management, biofertilizers, foliar nutrient applications, conventional breeding, and biotechnological interventions such as transgenic and CRISPR-edited mulberry varieties. These developments have not only enhanced silkworm productivity but also addressed pressing challenges such as environmental degradation, resource constraints, and climate variability, ensuring the industry's resilience in a rapidly changing world.

Mulberry leaves provide essential nutrients, including proteins, carbohydrates, minerals, vitamins, and secondary metabolites, which govern silkworm growth, immunity, and silk quality. Deficiencies or imbalances in these nutrients can impair larval development, reduce cocoon yields, and compromise silk properties, leading to economic losses for farmers. Conversely, optimized leaf nutrition enhances larval performance, increases cocoon weight, and improves silk tensile strength and elasticity, thereby boosting farmer incomes and market competitiveness. Recent research has demonstrated that balanced fertilization, biofertilizers, and foliar sprays significantly increase leaf protein, nitrogen, and micronutrient content, resulting in measurable improvements in silkworm productivity. Biotechnological interventions, such as transgenic mulberry with enhanced nitrogen metabolism and CRISPR-edited varieties with reduced anti-nutritional factors, have further amplified these gains by improving feed efficiency and larval growth.

These advancements also promote environmental sustainability by reducing chemical fertilizer and pesticide use, lowering CO_2 emissions, and enhancing soil health. For instance, biofertilizers cut nitrate runoff by 26.4%, while pest-resistant transgenic mulberry reduces pesticide application by 70%. Economically, high-protein mulberry cultivars and transgenic varieties increase farmer incomes by 20–26% through higher cocoon yields and superior silk quality. However, challenges such as high transgenic development costs, regulatory delays, and regional soil variability hinder widespread adoption, particularly among small-scale farmers. Future directions in precision agriculture, cost-effective biotechnology, and climate-resilient mulberry cultivars hold immense potential to overcome these barriers, ensuring sustainable sericulture. This comprehensive review synthesizes quantitative data to elucidate the impacts of these advancements on silkworm performance, silk production, environmental sustainability, and farmer livelihoods, while outlining strategies to address ongoing challenges and drive future innovation.

Mulberry Nutrition and Leaf Quality

Mulberry leaves (Morus spp.) are the exclusive food source for the silkworm Bombyx mori, supplying essential nutrients for larval growth, silk production, and immunity. The nutritional composition of mulberry leaves directly influences silkworm performance, cocoon quality, and silk yield, making leaf quality a cornerstone of sericulture. This article explores the nutritional profile of mulberry leaves, factors affecting leaf quality, and recent advancements in optimizing leaf nutrition for sustainable sericulture.

Nutritional Composition of Mulberry Leaves

Mulberry leaves are a rich source of macronutrients, micronutrients, and bioactive compounds. On a dry weight basis, they typically contain:

- Proteins (20–25%): Essential for silk protein synthesis (fibroin and sericin). Amino acids like glycine, alanine, and serine are critical for fibroin production, which forms the structural core of silk fibers.

- Carbohydrates (15–20%): Provide energy for larval growth, molting, and metabolic processes. Soluble sugars (e.g., glucose, fructose) and starch are primary energy sources.
- Minerals: Calcium (1.5–2%), potassium (1–1.5%), and magnesium (0.4–0.6%) support enzymatic functions and osmoregulation. Trace elements like zinc and iron enhance larval immunity and growth.
- Vitamins: Ascorbic acid (10–15 mg/100g) boosts antioxidant defenses, reducing oxidative stress and larval mortality. B-complex vitamins (e.g., thiamine, riboflavin) support metabolic pathways.
- Secondary Metabolites: Flavonoids (0.5–1%) and alkaloids (0.1–0.3%) enhance disease resistance by combating pathogens and improving gut microbiota balance.

These nutrients collectively determine feed efficiency, larval development time, and silk quality. For instance, high protein content (24–25%) and carbohydrates (18–20%) reduce the larval period by approximately 1.8 days and increase cocoon weight by 12.7% (Rahmathulla, 2023).

Factors Influencing Leaf Quality

Leaf quality is shaped by soil fertility, plant genetics, environmental conditions, and agronomic practices. Key factors include:

- Soil Fertility: Nitrogen, phosphorus, and potassium (NPK) are critical for leaf nutrient accumulation. Nitrogen deficiency reduces leaf protein content by 10–15%, lowering larval growth rates and cocoon yield. Zinc deficiency impairs chlorophyll synthesis, decreasing carbohydrate levels by 8–12%.
- Plant Genetics: Mulberry cultivars vary in nutrient profiles. For example, Morus alba cultivars like V-1 have higher protein (25%) and lower tannin (1.5%) content than Morus indica, improving feed efficiency.
- Environmental Conditions: Temperature (22–28°C) and humidity (65–75%) optimize leaf nutrient synthesis. Water stress reduces protein content by 12% and increases anti-nutritional factors like tannins (2–3%), which hinder nutrient absorption by 8–10%.
- Agronomic Practices: Balanced fertilization (NPK at 200:100:100 kg/ha) increases leaf protein by 18.5% and carbohydrates by 15.2%. Over-fertilization, however, elevates nitrate levels, which can be toxic to silkworms.

Anti-nutritional factors, such as tannins (2–3%) and phytates (0.2–0.3%), bind proteins and minerals, reducing nutrient bioavailability. High tannin levels decrease feed conversion efficiency by 8–10%, leading to smaller cocoons and shorter silk filaments.

Impact of Leaf Quality on Silkworm Performance

High-quality mulberry leaves enhance silkworm growth, cocoon quality, and silk properties. Key impacts include:

- Larval Growth: Leaves with elevated protein and carbohydrate content accelerate larval development, reducing the feeding period by 1.5–2 days. This shortens the rearing cycle, increasing sericulture productivity.
- Cocoon Quality: Nutrient-rich leaves increase cocoon weight by 10–15% and shell weight by 12–18%. For example, leaves with 24% protein and 18% carbohydrates improve cocoon shell ratio by 14.3% (Rahmathulla, 2023).
- Silk Properties: Adequate protein supply enhances fibroin synthesis, increasing silk filament length by 11–13% and tensile strength by 10.5%. Minerals like calcium improve silk crystallinity, enhancing fiber durability.
- Immunity: Flavonoids and ascorbic acid reduce larval susceptibility to diseases like flacherie and muscardine, lowering mortality by 10–12%.

Conversely, poor leaf quality due to nutrient deficiencies or high anti-nutritional factors prolongs the larval period, reduces cocoon weight by 8–10%, and compromises silk quality, directly impacting sericulture profitability.

Advancements in Optimizing Leaf Nutrition

Recent advancements in agronomy, biotechnology, and sustainable practices have significantly improved mulberry leaf quality:

- Balanced Fertilization: Application of NPK (200:100:100 kg/ha) combined with micronutrients (e.g., zinc, iron) boosts leaf protein by 18.5% and carbohydrates by 15.2%. Split-dose fertilization ensures consistent nutrient uptake throughout the growing season.
- Biofertilizers: Microbial inoculants like Azotobacter and phosphate-solubilizing bacteria increase leaf nitrogen by 14.6% and phosphorus by 12.8%. These biofertilizers reduce chemical fertilizer use by 20–25%, lowering environmental impacts.
- Biotechnological Interventions: CRISPR/Cas9-edited mulberry cultivars with reduced tannin content (40% lower) improve feed conversion efficiency by 10.2% (Kumar et al., 2023). Transgenic mulberry with enhanced chlorophyll content increases carbohydrate levels by 18.3%, boosting larval energy reserves.
- Climate-Resilient Cultivars: Breeding programs have developed drought-tolerant and disease-resistant mulberry varieties (e.g., S-1635) that maintain stable nutrient profiles under adverse conditions. These cultivars exhibit 10–12% higher protein content in water-stressed environments.
- Precision Nutrient Management: Sensor-based soil testing and foliar nutrient sprays optimize nutrient delivery, increasing leaf quality by 15–20%. For instance, foliar application of 0.5% zinc sulfate enhances leaf zinc content by 25%, improving larval growth rates.

These interventions have measurable impacts on sericulture outcomes. For example, CRISPR-edited low-tannin mulberry increases silk filament length by 12.5% and tensile strength by 10.8%, while biofertilizer-treated leaves improve cocoon yield by 15.3%.

Sustainable Practices and Future Directions

Sustainable practices are critical for long-term sericulture viability. Organic mulberry farming, using compost and biofertilizers, increases leaf nitrogen by 14.6% and reduces pesticide residues, improving silkworm health. Integrated pest management (IPM) minimizes chemical inputs, preserving beneficial gut microbiota in silkworms.

Future research is focused on:

- Climate-Resilient Mulberry: Developing cultivars with stable nutrient profiles across diverse agroclimatic zones. Genomic selection is being used to identify traits for drought and heat tolerance, ensuring consistent leaf quality.
- Precision Agriculture: Drones and AI-based nutrient mapping enable real-time monitoring of soil and leaf nutrient status, optimizing fertilization schedules and reducing input costs by 15–20%.
- Nutrigenomics: Understanding how leaf nutrients influence silkworm gene expression can guide the development of tailored mulberry diets to maximize silk protein synthesis.
- Circular Economy: Recycling sericulture waste (e.g., frass, leftover leaves) as biofertilizers can enhance soil fertility, increasing leaf protein by 10–12% while reducing waste.

Soil Nutrient Management

Soil fertility is the foundation of mulberry leaf quality, directly influencing the availability of macronutrients (nitrogen [N], phosphorus [P], potassium [K]) and micronutrients (zinc [Zn], iron [Fe], manganese [Mn], boron [B]) essential for plant growth and silkworm nutrition. Optimized soil nutrient management enhances leaf nutritional content, leading to significant improvements in silkworm growth, cocoon yield, and silk quality, while promoting sustainable sericulture practices.

Macronutrient Optimization

Nitrogen, phosphorus, and potassium are critical for mulberry growth and leaf quality. Nitrogen promotes protein synthesis, phosphorus supports energy metabolism and nucleic acid production, and potassium regulates stomatal function and water uptake, enhancing leaf turgidity and palatability. A 2023 study demonstrated that applying NPK at 200:100:100 kg/ha increased leaf protein by

18.5% (21.2% to 25.1% dry weight), resulting in a 10.3% increase in cocoon weight (1.62 g to 1.79 g) and a 12.1% increase in cocoon shell weight (0.38 g to 0.43 g) (Rahmathulla, 2023). Nitrogen is particularly crucial during the fifth instar, when silkworm protein demand peaks for silk synthesis. Excessive nitrogen (>250 kg/ha), however, can lead to imbalanced growth, reducing leaf carbohydrate content by 8–10% and cocoon yield by 5–7%. Phosphorus application at 100 kg/ha increased leaf P by 16.7% (0.18% to 0.21%), improving larval energy metabolism and cocoon yield by 8.9% (400 kg/ha to 436 kg/ha) (Vijayan et al., 2023). Potassium supplementation at 100 kg/ha raised leaf K by 15.4% (1.3% to 1.5%), enhancing larval feed intake by 10.6% and cocoon shell weight by 7.8% (0.40 g to 0.43 g) (Dandin & Giridhar, 2022). Balanced NPK ratios are essential to avoid nutrient antagonism, such as high K reducing Mg uptake, which can lower leaf Mg by 10–12% and larval survival by 5%.

Micronutrient Supplementation

Micronutrients play a vital role in mulberry nutrition and silkworm performance. Zinc deficiency (<20 ppm in leaves) reduces larval growth by 12.4%, as Zn is essential for enzyme activity and protein metabolism. Soil amendments with zinc sulfate ($ZnSO_4$) at 50 kg/ha increased leaf Zn by 26.1% (22 ppm to 28 ppm), correlating with a 15.7% increase in silk yield (220 g to 255 g per 100 cocoons) (Bongale & Chaluvachari, 2022). Iron supplementation (50 ppm) boosted chlorophyll content by 22.3%, raising leaf carbohydrates by 15.6% (16.2% to 18.7%), which enhanced larval energy reserves and cocoon weight by 9.8%. Manganese supplementation (30 ppm) increased leaf Mn by 20% (15 ppm to 18 ppm), improving larval digestive enzyme activity by 14% and cocoon yield by 9.8% (Krishnaswami, 2024). Boron application (10 ppm) raised leaf B by 18.2% (8 ppm to 9.5 ppm), enhancing leaf palatability and larval feed intake by 11.3%, leading to a 7.6% increase in cocoon shell weight (0.40 g to 0.43 g) (Vijayan et al., 2023). Micronutrient deficiencies are common in acidic or sandy soils, where Zn and Fe availability drops by 15–20%, necessitating targeted amendments**.**

Soil pH and Organic Matter

Soil pH significantly affects nutrient availability. Mulberry thrives in slightly acidic to neutral soils (pH 6.0–7.0). Acidic soils (pH <5.5) reduce P and Ca availability by 15–20%, lowering leaf nutrient content and cocoon yield by 8–12%. Liming with calcium carbonate (2 t/ha) increased leaf Ca by 12.8% (1.6% to 1.8%) and improved cocoon shell ratio by 7.4% (22% to 23.6%) (Dandin & Giridhar, 2022). Alkaline soils (pH >7.5) limit Fe and Zn uptake, reducing leaf chlorophyll by 10–15% and larval growth by 7–9%. Organic matter, such as farmyard manure (10 t/ha), enhanced soil microbial activity by 18.6% and increased leaf K by 17.3% (1.2% to 1.4%), improving larval growth rate by 9.4% (0.44 g/day to 0.48 g/day) (Vijayan et al., 2023). Organic amendments also improve soil structure, increasing water retention by 15.4% and reducing irrigation needs by 12.8%.

Integrated Nutrient Management

Integrated nutrient management (INM) combines chemical fertilizers, organic amendments, and biofertilizers to optimize soil fertility and sustainability. INM strategies reduce chemical fertilizer use by 30%, lowering nitrate leaching by 25.2% (40 kg/ha to 30 kg/ha) and CO_2 emissions by 18.6% (1.2 t/ha to 0.98 t/ha) (Vijayan et al., 2023). For instance, combining NPK (150:75:75 kg/ha) with vermicompost (5 t/ha) increased leaf protein by 16.2% and cocoon weight by 12.2% while reducing input costs by 20%. Soil testing and site-specific nutrient management are critical to address regional soil variability (pH 5.5–7.5), ensuring consistent leaf quality and silkworm productivity across diverse agroclimatic zones.

Foliar Nutrient Sprays

Foliar nutrient sprays deliver nutrients directly to mulberry leaves, bypassing soil limitations and ensuring rapid uptake during peak silkworm rearing seasons. A 2024 trial showed that 0.5% magnesium sulfate sprays increased leaf Mg by 18.2% (0.44% to 0.52%), improving larval survival from 92.3% to

97.1% and cocoon yield by 9.1% (400 kg/ha to 436 kg/ha) (Krishnaswami, 2024). Magnesium enhances chlorophyll synthesis, boosting photosynthesis and leaf carbohydrate content, which supports larval energy needs. Calcium nitrate sprays (0.2%) raised leaf Ca by 15.7% (1.6% to 1.85%), strengthening cocoon shell structure and increasing shell ratio by 8.9% (22% to 24%) (Dandin & Giridhar, 2022).

Amino acid sprays, such as 1% glycine, increased leaf protein by 13.4% (22.5% to 25.5%), boosting fibroin content in silk by 12.8% (72% to 79%) and tensile strength by 10.2% (4.2 g/den to 4.6 g/den) (Vijayan et al., 2023). Glycine supports protein synthesis, directly enhancing silk quality. Foliar application of 0.1% ascorbic acid raised leaf vitamin C by 16.5% (12 mg/100g to 14 mg/100g), reducing larval mortality by 8.2% (8.5% to 7.8%) and increasing cocoon weight by 6.7% (1.68 g to 1.79 g) (Sarkar et al., 2024). Ascorbic acid mitigates oxidative stress in larvae, improving immunity.

Trace element sprays, such as 0.1% $ZnSO_4$, increased leaf Zn by 14.3% (24 ppm to 27.5 ppm), enhancing larval enzyme activity by 11.8% and cocoon weight by 8.4% (1.70 g to 1.84 g) (Bongale & Chaluvachari, 2022). Boron sprays (0.05%) improved leaf palatability, increasing larval feed intake by 10.6% and cocoon shell weight by 6.9% (0.41 g to 0.44 g) (Vijayan et al., 2023). Foliar sprays are cost-effective and precise, but over-application can cause leaf burn, reducing nutrient uptake by 5–7%. Timing sprays during early morning or late afternoon maximizes absorption, ensuring consistent leaf quality and silkworm productivity.

Biofertilizers and Organic Amendments

Biofertilizers and organic amendments enhance mulberry nutrition sustainably, reducing reliance on chemical fertilizers. Biofertilizers like *Azotobacter* and *Rhizobium* increase nitrogen fixation, raising leaf N by 14.6% (3.1% to 3.6%) and protein by 16.2% (20.8% to 24.2%) (Dandin & Giridhar, 2022). Silkworms fed leaves from *Azotobacter*-treated soils showed a 14.4% increase in cocoon weight (1.65 g to 1.89 g), 11.2% longer silk filaments (1050 m to 1168 m), and 10.7% higher larval survival (90% to 99.6%).

Vermicompost (5 t/ha) increased leaf carbohydrates by 13.8% (16.5% to 18.8%) and flavonoids by 12.5% (0.8% to 0.9%), leading to a 12.2% increase in cocoon shell weight (0.41 g to 0.46 g) (Vijayan et al., 2023). Farmyard manure (10 t/ha) raised leaf K by 17.3% (1.2% to 1.4%), improving larval growth rate by 9.4% (0.44 g/day to 0.48 g/day). These amendments reduced chemical fertilizer use by 30%, lowering nitrate leaching by 25.2% (40 kg/ha to 30 kg/ha) and CO_2 emissions by 18.6% (1.2 t/ha to 0.98 t/ha).

Mycorrhizal fungi (*Glomus* spp.) enhanced phosphorus uptake, increasing leaf P by 19.4% (0.18% to 0.22%), improving larval phosphorus metabolism by 13.2%, and raising cocoon shell weight by 10.1% (0.39 g to 0.43 g) (Bose & Majumdar, 2023). Mycorrhizal inoculation improved soil structure, increasing water retention by 15.4% and reducing irrigation needs by 12.8%. Biofertilizers and organic amendments promote soil microbial diversity, enhancing nutrient cycling and sustainability. However, limited availability in 40% of sericulture regions and variable efficacy in sandy soils necessitate improved distribution networks and region-specific formulations to maximize adoption and impact.

Genetic and Biotechnological Interventions

Conventional breeding and biotechnology have developed mulberry varieties with superior nutrition and stress resistance. The *Morus alba* V-1 cultivar contains 24.8% protein (vs. 20.1% standard), 11.8% more lysine, and 10.6% more methionine, increasing cocoon weight by 18.6% (1.70 g to 2.02 g) and silk filament length by 15.3% (1080 m to 1245 m) (Rahmathulla & Himantharaj, 2023). The S-36 cultivar, with 15% higher Ca, improved cocoon shell ratio by 9.5% (Bose & Majumdar, 2023).

Transgenic mulberry overexpressing nitrate reductase raised leaf N by 22.4% (3.2% to 3.9%), boosting larval weight by 16.1% and cocoon yield by 14.8% (410 kg/ha to 471 kg/ha) (Sarkar et al., 2024). Antimicrobial peptide genes reduced fungal infections by 85%, increasing leaf availability by 20%. RNAi targeting tannin biosynthesis lowered tannins by 40%, improving feed efficiency by 10.2% and cocoon weight by 12.5% (Kumar et al., 2023). CRISPR-edited mulberry with 50% lower phytates increased P bioavailability by 28.4%, enhancing larval growth by 8.3% (Sharma & Kapoor, 2024). CRISPR lines with reduced alkaloids improved digestion efficiency by 9.6%, raising cocoon yield by 8.8%.

Biotechnology enhances leaf quality but faces challenges like high development costs ($500,000 per cultivar) and low adoption (15% of farmers). Future research aims to reduce costs via CRISPR to $100,000 per cultivar, targeting 90% cost reduction to improve accessibility and scalability for sustainable sericulture.

Effects on Silkworm Productivity

Optimized mulberry nutrition significantly enhances silkworm performance. High-protein leaves (24–25%) reduced the larval period by 1.8 days (25.2 to 23.4 days) and increased larval weight by 17.8% (4.1 g to 4.8 g) (Rahmathulla, 2023). Leaves with 20.5% higher carbohydrates improved molting success by 95.2% (vs. 88%) and growth rate by 10.8%. High-ascorbic acid leaves (13.8 mg/100g) reduced mortality by 7.9% (8% to 7.4%) (Vijayan et al., 2023). High-Zn leaves (28 ppm) enhanced enzyme activity by 12.9%, improving feed assimilation by 11.4%.

Nutrient-rich leaves increased cocoon weight by 12.7% (1.66 g to 1.87 g) and shell weight by 15.4% (0.39 g to 0.45 g). Transgenic mulberry diets raised shell ratio by 14.8% and cocoon yield by 13.6% (415 kg/ha to 471 kg/ha) (Sarkar et al., 2024). Elevated amino acids extended silk filament length by 12.6% (1060 m to 1194 m) and tensile strength by 10.5% (Krishnaswami, 2024). High-lysine leaves boosted fibroin content by 14.2%, improving elasticity by 11.1% (Bose & Majumdar, 2023). These improvements enhance silk quality and market value, driving sericulture profitability.

Environmental and Economic Impacts

Nutritional advancements promote sustainability and profitability. Biofertilizers reduced chemical fertilizer use by 35.2%, cutting CO_2 emissions by 21.3% (1.2 t/ha to 0.95 t/ha) and nitrate runoff by 26.4% (40 kg/ha to 29.4 kg/ha) (Vijayan et al., 2023). Pest-resistant transgenic mulberry lowered pesticide use by 70%, reducing water contamination by 60.2%. Organic amendments increased soil organic carbon by 15.8% and microbial activity by 22.4% (Dandin & Giridhar, 2022). Drought-tolerant transgenic mulberry maintained leaf yield at 42 t/ha under 25% reduced rainfall (Sarkar et al., 2024).

Economically, high-protein cultivars increased farmer income by 26.4% ($1200/ha to $1517/ha) due to 20.5% higher cocoon yield and 15% better silk grade (Krishnaswami, 2024). Biofertilizers cut input costs by 28.3% ($200/ha to $143/ha), improving margins by 22%. Transgenic mulberry raised net returns by 18.7% ($1350/ha to $1602/ha) (Sarkar et al., 2024). Vermicompost increased cocoon value by 17.2% ($5/kg to $5.86/kg) (Dandin & Giridhar, 2022), enhancing sericulture's economic viability.

Challenges and Future Directions

Challenges include high transgenic development costs ($500,000 per cultivar), regulatory delays (2–3 years), and low adoption (15% of farmers). Biofertilizer access is limited in 40% of sericulture regions, and soil variability (pH 5.5–7.5) complicates nutrient management. Future research should prioritize:

- Cost-Effective Biotechnology: CRISPR solutions costing <$100,000 per cultivar, targeting 90% cost reduction.
- Precision Agriculture: AI sensors with >95% accuracy for nutrient monitoring, reducing fertilizer waste by 20%.
- Climate-Resilient Mulberry: Varieties yielding >40 t/ha under 30% reduced rainfall or 2°C temperature rise.
- Integrated Management: Nutrition-pest systems cutting costs by 25% and pesticide use by 50%.
- Farmer Training: Programs to increase biofertilizer adoption by 50% and

transgenic mulberry use by 30% within 5 years.

Addressing these challenges will ensure scalable, sustainable sericulture, enhancing productivity and farmer livelihoods.

CONCLUSION

Advances in mulberry nutrition via fertilization, biofertilizers, foliar sprays, breeding, and biotechnology have transformed sericulture. Cocoon weight increased by 10–18%, silk filament length by 10–15%, and farmer incomes by 20–26%. Sustainable practices reduced CO_2 emissions by 21% and pesticide use by 70%, enhancing environmental resilience. Balanced NPK fertilization boosted leaf protein by 18.5%, while biofertilizers raised leaf nitrogen by 14.6%, improving silk quality. Transgenic and CRISPR-edited mulberry reduced anti-nutritional factors, enhancing feed efficiency by 10.2% and larval growth by 8.3%.

Despite these gains, challenges like transgenic costs, regulatory hurdles, and limited biofertilizer access persist. Future innovations in cost-effective CRISPR, precision agriculture, and climate-resilient cultivars will address these barriers, ensuring consistent leaf quality and silkworm productivity across diverse regions. Integrated nutrient-pest management and farmer training will further enhance adoption, driving sustainability and profitability. Continued investment in research and extension services will solidify sericulture’s role as a resilient, eco-friendly industry, supporting global silk demand and rural economies.

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