



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(6): 213-217
Received: 17-02-2026
Accepted: 26-03-2026

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Artificial intelligence-driven prediction of mulberry leaf quality for enhanced silkworm performance and silk yield

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6Sc.5772>

Abstract

The success of sericulture largely depends on the quality of mulberry leaves, which directly influences silkworm growth and silk production. Traditional methods of assessing leaf quality are time-consuming, labor-intensive, and often subjective. In this study, an artificial intelligence (AI)-based predictive model was developed to evaluate mulberry (*Morus* spp.) leaf quality and its impact on silkworm (*Bombyx mori*) performance and silk yield. Data on leaf biochemical parameters such as protein, chlorophyll, moisture, and phenolic content were collected alongside environmental variables including temperature, humidity, and soil nutrients. Machine learning algorithms, including Random Forest and Support Vector Machine (SVM), were trained to predict leaf quality and correlate it with silkworm growth and cocoon parameters. The results demonstrated that AI models could accurately predict leaf quality with high precision ($R^2 > 0.90$). Leaves classified as high-quality by the model resulted in significantly improved larval weight, survival rate, cocoon weight, and silk productivity. The integration of AI in sericulture provides a rapid, reliable, and scalable approach for optimizing mulberry cultivation and improving silk yield. This study highlights the potential of AI-driven decision-making systems in modernizing sericulture and promoting sustainable silk production.

Keywords: Artificial intelligence, mulberry leaf quality, sericulture

1. Introduction

Sericulture is a highly specialized agro-based industry that integrates the cultivation of mulberry plants with the rearing of silkworms for the production of natural silk. It plays a vital role in the rural economy by generating employment opportunities, supporting small and marginal farmers, and contributing significantly to the textile sector. The domesticated silkworm, *Bombyx mori*, is entirely dependent on mulberry (*Morus* spp.) leaves as its sole source of nutrition. Consequently, the growth, development, and silk-producing efficiency of silkworms are directly influenced by the quality and nutritional composition of mulberry leaves. Ensuring consistent and high-quality leaf production is therefore fundamental to the success and sustainability of sericulture.

Mulberry leaf quality is determined by a combination of biochemical and environmental factors, including protein content, chlorophyll concentration, moisture levels, and the presence of secondary metabolites. These components play a critical role in silkworm physiology, as proteins are essential for silk synthesis, carbohydrates provide energy for metabolic activities, and moisture content affects leaf palatability and digestibility. Variations in these parameters can significantly impact silkworm growth, survival rate, cocoon formation, and ultimately silk yield. However, maintaining optimal leaf quality remains a challenge due to fluctuating environmental conditions, soil variability, and inconsistent agronomic practices.

Traditionally, the assessment of mulberry leaf quality has relied on laboratory-based biochemical analyses and visual inspection. While these methods are reliable, they are often time-consuming, labor-intensive, and require specialized equipment and expertise. Moreover, such approaches are not suitable for real-time decision-making in field conditions, where rapid and accurate evaluation is necessary to guide farming practices. The lack of timely and precise

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information can lead to suboptimal feeding strategies, reduced silkworm performance, and lower silk productivity. In recent years, advancements in artificial intelligence (AI) and machine learning (ML) have opened new avenues for transforming agricultural practices. AI technologies enable the analysis of large and complex datasets to identify patterns, make predictions, and support data-driven decision-making. In agriculture, AI has been successfully applied for crop monitoring, yield prediction, disease detection, irrigation management, and precision farming. These applications have demonstrated significant improvements in efficiency, productivity, and resource utilization.

The integration of AI into sericulture presents a promising opportunity to overcome the limitations of traditional methods and enhance overall productivity. Machine learning algorithms can process diverse datasets, including environmental parameters, soil characteristics, and plant biochemical traits, to predict mulberry leaf quality with high accuracy. By leveraging these capabilities, AI-based systems can provide real-time insights into crop health and nutrient status, enabling farmers to optimize cultivation practices and improve leaf quality.

One of the key advantages of AI-driven approaches is their ability to handle non-linear relationships and complex interactions among variables. In the context of mulberry cultivation, factors such as temperature, humidity, soil nutrients, and irrigation practices interact dynamically to influence leaf quality. Machine learning models, such as Random Forest, Support Vector Machine (SVM), and neural networks, can capture these interactions and generate accurate predictions. These models can also be continuously updated with new data, improving their performance over time.

The application of AI in predicting mulberry leaf quality has significant implications for silkworm rearing. High-quality leaves identified through AI models can be selectively used for feeding, ensuring optimal nutrition for silkworm larvae. This targeted feeding approach can enhance larval growth, improve survival rates, and increase cocoon yield. Additionally, AI-based predictions can help in scheduling harvesting time, optimizing fertilizer application, and managing environmental conditions to maintain consistent leaf quality.

Beyond leaf quality prediction, AI technologies can also be extended to other aspects of sericulture, such as monitoring silkworm health, detecting diseases, and predicting cocoon quality. The integration of AI with sensor technologies and the Internet of Things (IoT) can further enable real-time monitoring of environmental conditions and automate decision-making processes. Such advancements pave the way for the development of smart sericulture systems that are efficient, sustainable, and economically viable.

Despite the growing potential of AI in agriculture, its application in sericulture is still in its early stages. Limited research has been conducted on the development and validation of AI-based models specifically tailored for mulberry cultivation and silkworm performance. There is a need for comprehensive studies that integrate plant biochemical data, environmental

variables, and silkworm performance metrics to establish robust predictive models. Such studies can provide valuable insights into the relationship between mulberry leaf quality and silk production, facilitating the adoption of AI-driven practices in sericulture.

Furthermore, the use of AI in sericulture aligns with the broader goals of sustainable agriculture. By enabling precise and efficient resource utilization, AI can reduce dependency on chemical inputs, minimize environmental impact, and improve soil health. It also enhances productivity without compromising ecological balance, making it an essential tool for future agricultural systems.

In this context, the present study aims to develop an artificial intelligence-based predictive model for assessing mulberry leaf quality and to evaluate its impact on silkworm performance and silk yield. By integrating machine learning techniques with biochemical and environmental data, the study seeks to establish a reliable and efficient framework for improving sericulture productivity. The findings are expected to contribute to the advancement of smart farming technologies and promote the adoption of AI-driven solutions in the sericulture industry.

2. Materials and Methods

The study was conducted under controlled field and laboratory conditions using healthy mulberry plants and silkworm larvae. Data collection involved both plant and environmental parameters to develop a comprehensive dataset for AI modeling. Mulberry leaves were sampled at different growth stages and analyzed for key biochemical parameters, including protein content, chlorophyll concentration, moisture content, and total phenolic content. Environmental data such as temperature, humidity, soil pH, and nutrient levels were recorded simultaneously using digital sensors and standard soil testing methods.

The collected dataset was preprocessed to remove missing values and normalize the data for machine learning analysis. Feature selection techniques were applied to identify the most relevant variables influencing leaf quality. The dataset was then divided into training and testing sets in an 80:20 ratio.

Machine learning models, including Random Forest and Support Vector Machine (SVM), were developed using Python-based libraries. These models were trained to predict leaf quality based on input variables and were evaluated using performance metrics such as accuracy, mean squared error (MSE), and coefficient of determination (R^2).

For validation, mulberry leaves classified by the AI model as high, medium, and low quality were used to feed silkworm larvae. Standard rearing practices were followed, and parameters such as larval weight, survival rate, cocoon weight, shell weight, and silk productivity were recorded.

Statistical analysis was performed to compare the performance of silkworms fed with leaves from different quality categories. The results were used to validate the predictive capability of the AI models.

Table 1: Performance of AI Models for Predicting Mulberry Leaf Quality

Model	Accuracy (%)	R ² Value	Mean Squared Error (MSE)	Precision (%)	Recall (%)
Random Forest	93.5 ± 1.2	0.92	0.015	92.8	93.2
Support Vector Machine (SVM)	89.7 ± 1.5	0.88	0.022	88.9	89.3
Decision Tree	85.4 ± 1.8	0.83	0.030	84.6	85.0
K-Nearest Neighbors (KNN)	82.6 ± 2.0	0.80	0.035	81.5	82.1

Table 2: AI-Based Classification of Mulberry Leaf Quality

Leaf Quality Category	Protein (mg/g)	Chlorophyll (mg/g)	Moisture (%)	Phenolic Content (mg/g)
High Quality	280 ± 8	2.80 ± 0.07	75.5 ± 1.5	45.2 ± 1.2
Medium Quality	250 ± 7	2.45 ± 0.06	72.0 ± 1.3	38.6 ± 1.0
Low Quality	210 ± 6	2.10 ± 0.05	68.5 ± 1.2	30.4 ± 0.9

Table 3: Effect of AI-Classified Leaf Quality on Silkworm Growth

Leaf Quality	Larval Weight (g)	Larval Duration (days)	Survival Rate (%)
High Quality	4.05 ± 0.12	23 ± 1	96.2 ± 1.0
Medium Quality	3.65 ± 0.11	25 ± 1	91.8 ± 1.2
Low Quality	3.20 ± 0.10	26 ± 1	87.5 ± 1.5

Table 4: Effect of AI-Predicted Leaf Quality on Cocoon and Silk Yield

Leaf Quality	Cocoon Weight (g)	Shell Weight (g)	Shell Ratio (%)	Silk Productivity (%)
High Quality	1.90 ± 0.06	0.40 ± 0.01	21.0 ± 0.5	20.8 ± 0.6
Medium Quality	1.65 ± 0.05	0.34 ± 0.01	20.6 ± 0.4	19.2 ± 0.5
Low Quality	1.45 ± 0.04	0.28 ± 0.01	19.3 ± 0.5	17.6 ± 0.6

3. Results

The application of machine learning techniques in this study demonstrated a high level of accuracy in predicting mulberry (*Morus* spp.) leaf quality and its subsequent impact on silkworm (*Bombyx mori*) performance and silk yield. Among the models evaluated, the Random Forest algorithm exhibited superior performance compared to the Support Vector Machine (SVM), Decision Tree, and K-Nearest Neighbors (KNN) models. The Random Forest model achieved a coefficient of determination (R^2) of 0.92, indicating a strong correlation between predicted and observed values, along with a lower mean squared error (MSE), reflecting high prediction precision. The SVM model also showed good predictive capability but was slightly less accurate, with an R^2 value of 0.88. These results highlight the effectiveness of ensemble learning techniques in handling complex agricultural datasets with multiple interacting variables. Feature importance analysis revealed that protein content, chlorophyll concentration, and soil nutrient availability were the most influential factors in determining mulberry leaf quality. Environmental variables such as temperature and humidity also contributed to model performance but to a lesser extent. The ability of the model to identify these key variables underscores the advantage of AI-based approaches in uncovering hidden patterns and relationships that may not be easily detectable through conventional analytical methods. Based on the trained model, mulberry leaves were categorized into three quality classes: high, medium, and low. Leaves classified as high quality exhibited significantly higher protein content, averaging above 280 mg/g, along with elevated chlorophyll levels and improved moisture content. These characteristics indicate enhanced photosynthetic efficiency and better metabolic activity within the plant. In contrast, medium-quality leaves showed moderate levels of these biochemical parameters, while low-quality leaves exhibited reduced protein and chlorophyll content, along with lower moisture levels, suggesting suboptimal growth conditions.

The nutritional superiority of AI-classified high-quality leaves had a pronounced effect on silkworm growth and development. Silkworm larvae fed with these leaves demonstrated significantly higher larval weight compared to those fed with medium- and low-quality leaves. The increased larval weight can be attributed to the higher protein availability, which supports rapid tissue growth and efficient nutrient assimilation.

Additionally, the improved chlorophyll content in the leaves contributes indirectly to better carbohydrate synthesis, providing sufficient energy for metabolic processes in the larvae. Another important observation was the reduction in larval duration in silkworms fed with high-quality leaves. These larvae completed their developmental cycle faster than those fed with lower-quality leaves, indicating enhanced metabolic efficiency and optimal nutrient utilization. The survival rate of silkworms was also significantly higher in the high-quality leaf group, reaching over 95%, compared to lower percentages observed in other groups. This suggests that improved nutrition not only supports growth but also enhances resistance to stress and disease. The positive effects of leaf quality on silkworm performance were further reflected in cocoon characteristics. Silkworms fed with high-quality leaves produced cocoons with significantly higher weight and shell weight, indicating greater silk deposition. Cocoon weight is a direct indicator of larval biomass accumulation, while shell weight represents the actual silk content. The increase in these parameters confirms that improved leaf nutrition leads to enhanced silk production capacity.

The shell ratio, which represents the proportion of silk fiber relative to total cocoon weight, also showed a noticeable increase in silkworms fed with high-quality leaves. Although the increase was moderate, it indicates improved efficiency in silk synthesis. Silk productivity, a critical parameter for evaluating sericultural performance, was highest in the group fed with AI-classified high-quality leaves. This demonstrates that the use of AI-based predictions can directly contribute to improving economic returns in sericulture, silkworms fed with low-quality leaves exhibited reduced growth performance, lower survival rates, and inferior cocoon characteristics. These larvae showed slower development, reduced larval weight, and lower cocoon and shell weights, highlighting the negative impact of poor leaf quality on silkworm productivity. The results clearly establish a strong correlation between mulberry leaf quality and silkworm performance, emphasizing the importance of accurate and timely assessment of leaf quality, the findings of this study validate the effectiveness of AI-driven models in predicting mulberry leaf quality and demonstrate their practical applicability in sericulture. The ability to accurately classify leaf quality and predict its impact on silkworm growth and silk yield provides a powerful tool for optimizing mulberry cultivation and improving sericultural outcomes. The integration of AI into traditional sericulture practices can significantly enhance efficiency, reduce resource wastage, and ensure consistent production of high-quality silk.

4. Discussion

The present study demonstrates the significant potential of artificial intelligence (AI)-driven approaches in predicting mulberry (*Morus* spp.) leaf quality and enhancing silkworm (*Bombyx mori*) performance and silk yield. The results clearly indicate that machine learning models, particularly the Random Forest algorithm, can effectively analyze complex interactions among biochemical, environmental, and soil-related parameters to provide accurate predictions of leaf quality. This represents a substantial advancement over traditional assessment methods, which are often labor-intensive, time-consuming, and limited in their capacity to integrate multiple influencing factors simultaneously. The superior performance of the Random Forest model observed in this study can be attributed to its ensemble learning structure, which combines multiple decision trees to improve predictive accuracy and reduce overfitting. Unlike

single-model approaches, Random Forest is capable of capturing non-linear relationships and interactions among variables, making it particularly suitable for agricultural systems where numerous dynamic factors influence plant growth and quality. The relatively high R^2 value (0.92) achieved by this model indicates a strong predictive capability, reinforcing its applicability in real-world sericulture practices. One of the key findings of this study is the identification of protein content, chlorophyll concentration, and soil nutrient availability as major determinants of mulberry leaf quality. These parameters are closely associated with plant physiological processes such as photosynthesis, nutrient assimilation, and metabolic activity. Protein content, in particular, plays a crucial role in determining the nutritional value of mulberry leaves, as it directly influences the synthesis of silk proteins in silkworms. Similarly, chlorophyll content serves as an indicator of photosynthetic efficiency and plant health, which in turn affects the production of carbohydrates and other essential metabolites. The classification of leaves into high, medium, and low-quality categories using AI models provides a practical framework for targeted feeding strategies in sericulture. The results clearly demonstrate that silkworms fed with high-quality leaves exhibit superior growth performance, including increased larval weight, higher survival rates, and reduced developmental duration. These improvements can be explained by the enhanced nutritional profile of high-quality leaves, which ensures efficient digestion and assimilation of nutrients. The availability of adequate proteins supports rapid tissue growth and silk gland development, while carbohydrates provide the energy required for metabolic processes.

The observed reduction in larval duration among silkworms fed with high-quality leaves is particularly significant from a production perspective. A shorter developmental cycle allows for increased cropping frequency, thereby improving overall productivity and economic returns. Additionally, higher survival rates indicate improved larval health and resistance to environmental stress, which are critical factors in maintaining consistent silk production. These findings highlight the importance of optimizing mulberry leaf quality to achieve efficient and sustainable sericulture. The positive impact of leaf quality on cocoon characteristics further validates the effectiveness of AI-based predictions. The increase in cocoon weight and shell weight observed in the high-quality leaf group indicates enhanced silk synthesis and deposition. Since silk fibers are primarily composed of protein, the higher protein content in mulberry leaves directly contributes to improved cocoon quality. The slight increase in shell ratio suggests improved efficiency in converting ingested nutrients into silk, which is a key determinant of economic value in sericulture.

Silk productivity, which integrates multiple performance parameters, was significantly higher in silkworms fed with AI-classified high-quality leaves. This demonstrates that AI-driven decision-making can lead to tangible improvements in sericultural output. By enabling early identification of high-quality leaves, AI systems allow farmers to optimize feeding practices and allocate resources more efficiently. This targeted approach reduces wastage, enhances productivity, and ensures consistent quality of silk. The results also highlight the detrimental effects of low-quality leaves on silkworm performance. Silkworms fed with low-quality leaves exhibited reduced larval weight, longer developmental duration, and lower survival rates, along with inferior cocoon characteristics. These findings emphasize the critical role of leaf quality in determining sericultural success and underscore the need for accurate and

timely assessment methods. AI-based models provide a reliable solution to this challenge by offering rapid and precise predictions that can be applied in real-time field conditions. From a broader perspective, the integration of AI into sericulture aligns with the principles of precision agriculture and sustainable farming. AI technologies enable efficient use of resources by providing data-driven insights into crop management practices. For instance, farmers can use AI predictions to optimize fertilizer application, irrigation scheduling, and harvesting time, thereby improving leaf quality while minimizing environmental impact. This approach not only enhances productivity but also contributes to long-term sustainability by reducing dependency on chemical inputs and preserving soil health, the use of AI in sericulture opens new avenues for technological innovation and digital transformation in the agricultural sector. The integration of machine learning models with sensor technologies and the Internet of Things (IoT) can facilitate real-time monitoring of environmental conditions and plant health. Such systems can provide continuous feedback to farmers, enabling proactive decision-making and reducing the risk of crop failure. In the context of sericulture, this can lead to the development of smart rearing systems that optimize both plant and insect performance, the promising results, certain limitations of the study should be acknowledged. The accuracy of AI models depends on the quality and quantity of input data, and variations in environmental conditions across different regions may affect model performance. Therefore, further research is needed to validate and refine these models under diverse agro-climatic conditions. Additionally, the integration of more advanced deep learning techniques and larger datasets may further improve predictive accuracy and robustness, the study highlights the transformative potential of AI in improving mulberry cultivation and sericulture outcomes. The strong correlation between AI-predicted leaf quality and silkworm performance demonstrates the practical applicability of machine learning models in this field. By enabling precise and efficient management of mulberry resources, AI-driven approaches can significantly enhance silk production, improve economic returns, and promote sustainable sericulture practices.

5. Conclusion

The present study highlights the significant potential of artificial intelligence (AI) in transforming traditional sericulture practices through accurate prediction of mulberry (*Morus* spp.) leaf quality and its direct impact on silkworm (*Bombyx mori*) performance and silk yield. The findings clearly demonstrate that machine learning models, particularly the Random Forest algorithm, can effectively analyze complex datasets and provide reliable predictions of leaf quality based on key biochemical and environmental parameters. The study establishes a strong relationship between AI-classified leaf quality and silkworm growth performance. Silkworms fed with high-quality leaves exhibited enhanced larval weight, higher survival rates, and reduced developmental duration, indicating improved physiological efficiency and better nutrient utilization. These improvements were further reflected in cocoon characteristics, where significant increases in cocoon weight, shell weight, and silk productivity were observed. Such outcomes confirm that superior leaf quality plays a crucial role in maximizing silk production. The integration of AI into mulberry cultivation offers a practical and efficient solution for real-time decision-making. By enabling early and precise identification of leaf quality, AI systems can assist farmers in optimizing feeding strategies, improving resource utilization, and minimizing

production losses. This approach not only enhances productivity but also contributes to sustainable agricultural practices by reducing dependency on conventional, labor-intensive assessment methods, the adoption of AI-driven technologies in sericulture aligns with the broader goals of precision agriculture and digital farming. It opens new opportunities for innovation, including the development of smart monitoring systems and automated decision-support tools. Although further research is required to validate these models under diverse environmental conditions, the present study provides a strong foundation for the application of AI in sericulture, AI-based prediction systems represent a promising advancement for improving mulberry leaf quality, enhancing silkworm performance, and ensuring sustainable and efficient silk production.

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