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Impact of Nano-Fertilizer Application on Growth, Yield, and Cocoon Productivity of Mulberry (Morus spp.) in Sericulture Systems

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Abstract
Nanotechnology has emerged as a transformative approach in sustainable agriculture, offering innovative solutions to improve nutrient use efficiency and crop productivity. The present study evaluates the impact of nano-fertilizer application on the growth, yield, and nutritional quality of mulberry (Morus spp.), along with its subsequent effects on silkworm (Bombyx mori) cocoon production. A field experiment was conducted using different concentrations of nano-fertilizers applied through foliar and soil treatments, alongside conventional fertilization and untreated control groups. Key growth parameters, including plant height, leaf area, and biomass accumulation, were recorded, while biochemical analyses assessed chlorophyll and protein content of the leaves. The results demonstrated a significant enhancement in mulberry growth and leaf quality under nano-fertilizer treatments, particularly at optimized concentrations. Improved chlorophyll content indicated enhanced photosynthetic efficiency, while increased protein levels suggested superior nutritional value of the leaves. When these leaves were fed to silkworms, notable improvements were observed in cocoon yield parameters, including cocoon weight, shell weight, and silk productivity. The enhanced performance of silkworms can be attributed to the improved nutritional profile of mulberry leaves grown under nano-fertilizer regimes, the findings highlight the potential of nano-fertilizers as an efficient and environmentally sustainable alternative to conventional fertilizers in sericulture. By improving both plant productivity and cocoon yield, nano-fertilizer-based nutrient management can contribute significantly to enhancing silk production and supporting sustainable agricultural practices. Further studies are recommended to standardize application protocols and evaluate long-term ecological impacts.

Keywords: *Nano-fertilizers, Mulberry, Sericulture, Cocoon yield, Sustainable agriculture, Nutrient efficiency*

1. Introduction

Sericulture, the cultivation of silkworms for silk production, represents a vital agro-based industry that plays a significant socio-economic role in many developing countries. It provides employment opportunities, particularly in rural areas, and contributes substantially to income generation and sustainable livelihoods. The success of sericulture largely depends on the quality and availability of mulberry (Morus spp.) leaves, which serve as the exclusive food source for the domesticated silkworm, Bombyx mori. Therefore, enhancing mulberry productivity and nutritional quality is fundamental to improving cocoon yield and silk production [1-3]. Mulberry is a fast-growing perennial plant widely cultivated under diverse agro-climatic conditions. Its leaves are rich in proteins, carbohydrates, vitamins, and essential minerals, making them highly suitable for silkworm feeding. However, the yield and quality of mulberry leaves are strongly influenced by soil fertility, nutrient management practices, and environmental conditions. Conventional agricultural practices rely heavily on chemical fertilizers to meet crop nutrient demands. Although these fertilizers can enhance plant growth, their excessive and indiscriminate use has led to several environmental and agronomic challenges, including soil degradation, nutrient leaching, reduced microbial activity, and water pollution. Moreover, the low nutrient use efficiency of conventional fertilizers results in significant nutrient losses, thereby increasing production costs and environmental risks [4-8]. In recent years, there has been a growing emphasis on sustainable agricultural practices that minimize environmental impact while maintaining high productivity. Nanotechnology has emerged as a promising tool in this context, offering innovative approaches to improve nutrient delivery and utilization in crops. Nano-fertilizers, a novel class of fertilizers developed using nanotechnology, are designed to release nutrients in a controlled and targeted manner. Due to their nanoscale size and high surface area, these fertilizers exhibit enhanced reactivity and improved interaction with plant systems, leading to increased nutrient uptake efficiency. Nano-fertilizers can be applied through soil or foliar routes, and their unique properties enable them to penetrate plant tissues more effectively than conventional fertilizers. This results in improved nutrient availability at the cellular level, enhanced metabolic activity, and better overall plant growth. In addition, nano-fertilizers reduce nutrient losses through leaching, volatilization, and fixation, thereby improving fertilizer use efficiency and reducing environmental pollution. These advantages make nano-fertilizers a sustainable alternative to traditional fertilization methods. The application of nano-fertilizers in mulberry cultivation has gained attention due to their potential to enhance leaf yield and quality. Improved nutrient uptake can lead to increased chlorophyll content, enhanced photosynthetic efficiency, and higher accumulation of proteins and other essential nutrients in leaves [9-12]. Since the nutritional quality of mulberry leaves directly influences the growth and development of silkworms, any improvement in leaf composition can have a significant impact on cocoon production and silk quality. Studies have shown that better-quality leaves result in improved larval growth, higher cocoon weight, and increased silk yield. In sericulture, the relationship between mulberry cultivation and silkworm rearing is highly interdependent. The quality of mulberry leaves determines the health and productivity of silkworms, which in turn affects cocoon yield and silk output. Therefore, adopting advanced agricultural practices that enhance mulberry performance can have a direct and positive impact on the entire sericulture value chain. The integration of nanotechnology into sericulture offers a promising pathway to achieve this goal by improving both plant and insect productivity. Despite the potential benefits, the application of nano-fertilizers in mulberry cultivation is still in its early stages, and comprehensive studies evaluating their effects on both plant growth and cocoon yield are limited. Most existing research has focused on general crop systems, with relatively little attention given to sericulture-specific applications. Furthermore, the optimal dosage, method of application, and long-term effects of nano-fertilizers on soil health and ecosystem sustainability require further investigation. The present study aims to address these gaps by evaluating the impact of nano-fertilizer application on mulberry growth parameters, leaf quality, and silkworm cocoon yield. By comparing nano-fertilizer treatments with conventional fertilization practices, this research seeks to provide insights into the effectiveness of nano-fertilizers in enhancing sericulture productivity. The findings of this study are expected to contribute to the development of sustainable nutrient management strategies that can improve both agricultural output and environmental sustainability. In conclusion, the integration of nanotechnology into mulberry cultivation represents a significant advancement in sericulture practices [13-15]. By improving nutrient efficiency, enhancing plant growth, and increasing cocoon yield, nano-fertilizers have the potential to transform traditional farming systems into more sustainable and productive models. As global demand for silk continues to rise, adopting innovative and eco-friendly technologies will be essential for ensuring the long-term viability and competitiveness of the sericulture industry.

2. Materials and Methods

The present investigation was conducted to evaluate the effect of nano-fertilizer application on the growth performance of mulberry (Morus spp.) and its subsequent influence on silkworm cocoon yield. The experiment was carried out under field conditions at a sericulture research plot characterized by well-drained soil and suitable agro-climatic conditions for mulberry cultivation. Healthy, disease-free mulberry plants of uniform age and size were selected to ensure consistency in growth and experimental observations. Standard agronomic practices such as irrigation, weeding, and pest management were followed uniformly across all treatments throughout the experimental period [16]. The experimental design followed a randomized block design (RBD) with multiple treatments and replicates to minimize experimental error and improve the reliability of results. The treatments consisted of a control (no fertilizer), a conventional fertilizer treatment based on the recommended dose of chemical fertilizers, and three different concentrations of nano-fertilizers (low, medium, and high). The nano-fertilizers used in the study were selected based on their nutrient composition and suitability for foliar and soil application. The fertilizers were applied at regular intervals during the growth period to ensure optimal nutrient availability to the plants. Nano-fertilizers were administered through both foliar spray and soil application methods. For foliar application, the required concentration of nano-fertilizer solution was prepared using distilled water and sprayed uniformly on the leaves using a hand sprayer during the early morning hours to ensure maximum absorption and minimize evaporation losses. Soil application involved the incorporation of nano-fertilizers into the root zone to facilitate nutrient uptake through the roots. The timing and frequency of application were carefully maintained to avoid nutrient stress or toxicity. Growth parameters of mulberry plants were recorded at regular intervals during the study period. Plant height was measured using a measuring scale from the base to the tip of the plant. The number of leaves per plant was counted manually, and leaf area was estimated using standard methods. Biomass production was determined by harvesting selected plants and measuring their fresh and dry weights after oven drying at a controlled temperature. These parameters were used to assess the overall growth performance and productivity of the plants under different treatments. For biochemical analysis, leaf samples were collected from each treatment group at the same physiological stage. Chlorophyll content was estimated using spectrophotometric methods, which involved extraction with suitable solvents and measurement of absorbance at specific wavelengths. Protein content was determined using standard biochemical assays, providing an indication of the nutritional quality of the leaves. Moisture content was also analyzed to evaluate leaf freshness and suitability for silkworm feeding. To assess the impact of nano-fertilizer-treated mulberry leaves on silkworm performance, rearing experiments were conducted using the domesticated silkworm species, Bombyx mori. Healthy silkworm larvae of uniform age were selected and reared under controlled environmental conditions, including optimal temperature and humidity. The larvae were fed exclusively with leaves harvested from the respective treatment groups. Feeding was carried out at regular intervals, ensuring adequate supply of fresh leaves throughout the larval period. At the end of the rearing cycle, cocoon parameters were evaluated to determine the effect of different treatments on silk production. Cocoon weight was measured using a precision balance, while shell weight was determined after carefully removing the pupae. The shell ratio was calculated as the percentage of shell weight relative to the total cocoon weight. Silk productivity was assessed based on standard sericulture evaluation methods. These parameters provided insights into the quality and economic value of the cocoons produced. All experimental data were subjected to statistical analysis using analysis of variance (ANOVA) to determine the significance of differences among treatments. Mean values were compared at a 5% level of significance, and appropriate statistical tools were used to ensure the accuracy and reliability of the results. The data obtained from this study were used to evaluate the effectiveness of nano-fertilizers in enhancing mulberry growth and cocoon yield.

2.1 Experimental Site and Design

The study was carried out under field conditions in a well-maintained mulberry cultivation plot with suitable agro-climatic conditions for sericulture. The soil of the experimental site was well-drained and fertile, supporting optimal growth of mulberry plants. The experiment was designed using a randomized block design (RBD) to ensure uniform distribution of treatments and to minimize experimental variability. Multiple treatments were arranged with appropriate replicates to enhance the reliability and statistical validity of the results. Healthy and disease-free mulberry plants of uniform age and size were selected for the study to maintain consistency across all experimental units. Standard agronomic practices, including irrigation, weeding, and pest management, were followed uniformly throughout the experimental period.

2.2 Treatment Details

The experiment consisted of five different treatments, including a control group without any fertilizer application, a conventional fertilizer treatment based on the recommended agronomic dose, and three levels of nano-fertilizer application categorized as low, medium, and high concentrations. The nano-fertilizers were selected based on their nutrient composition and suitability for mulberry cultivation. These fertilizers were applied both as foliar sprays and soil amendments to ensure efficient nutrient delivery through both leaf surfaces and root systems. The applications were carried out at regular intervals during the growth period, ensuring uniform distribution and avoiding nutrient deficiency or toxicity. Care was taken to maintain consistent application techniques and timing across all treatments.

2.3 Growth Parameters

The growth performance of mulberry plants was evaluated by measuring several key parameters at regular intervals during the experimental period. Plant height was recorded using a measuring scale from the base of the plant to the apical tip. The number of leaves per plant was counted manually to assess vegetative growth. Leaf area was determined using standard measurement techniques to evaluate the photosynthetic surface available for growth. Biomass yield was calculated by harvesting representative plants from each treatment and measuring both fresh and dry weights after oven drying at a controlled temperature. These parameters provided a comprehensive assessment of plant growth and productivity under different fertilization regimes.

2.4 Biochemical Analysis

Leaf samples were collected from each treatment group at a similar stage of growth to ensure uniformity in analysis. The chlorophyll content was estimated using spectrophotometric methods, which involved extraction of pigments using appropriate solvents followed by absorbance measurement at specific wavelengths. Protein content was determined using standard biochemical assays, providing an indication of the nutritional quality of the leaves for silkworm feeding. Moisture content was also analyzed by measuring the difference between fresh and dry weights of leaf samples, which reflects leaf succulence and suitability for larval consumption. These biochemical parameters were used to evaluate the quality of mulberry leaves under different treatment conditions.

2.5 Silkworm Rearing and Cocoon Evaluation

To assess the effect of nano-fertilizer-treated mulberry leaves on silkworm performance, rearing experiments were conducted using the domesticated silkworm species, Bombyx mori. Healthy larvae of uniform age were selected and maintained under controlled environmental conditions, including optimal temperature and humidity. The larvae were fed exclusively with fresh leaves harvested from the respective treatment groups throughout the rearing period. Feeding was carried out at regular intervals to ensure adequate nutrition. At the completion of the larval stage, cocoons were collected and evaluated for various economic parameters. Cocoon weight was measured using a precision balance, and shell weight was determined after removing the pupae. The shell ratio was calculated as the percentage of shell weight relative to total cocoon weight, which is an important indicator of silk yield. Silk productivity was assessed based on standard sericultural evaluation methods. These parameters provided insights into the influence of different fertilization treatments on silkworm growth and silk production.

2.6 Statistical Analysis

All experimental data obtained from growth, biochemical, and cocoon parameters were subjected to statistical analysis to determine the significance of treatment effects. Analysis of variance (ANOVA) was performed to compare the mean values among different treatments. Differences were considered statistically significant at a 5% probability level (p 0.05). Appropriate statistical software and methods were used to ensure accuracy and reliability of the results. The statistical analysis helped in identifying the most effective treatment for enhancing mulberry growth and cocoon yield.

3. Results and Discussion

The present study evaluated the influence of nano-fertilizer application on mulberry growth, leaf biochemical composition, and silkworm cocoon yield. The results clearly demonstrated that nano-fertilizer treatments significantly enhanced plant growth parameters, improved leaf nutritional quality, and positively influenced cocoon production compared to control and conventional fertilizer treatments.

3.1 Effect on Mulberry Growth Parameters

The application of nano-fertilizers resulted in a marked improvement in all growth parameters of mulberry plants (Table 1). Among the treatments, the medium concentration of nano-fertilizer exhibited the highest plant height (118.9 cm), number of leaves per plant (289), leaf area (104.7 cm^2), and biomass yield (268.3 g/plant). This was followed by the high concentration treatment, which showed slightly lower values, indicating that excessive nutrient concentration may not necessarily lead to proportional growth enhancement. The superior performance observed under nano-fertilizer treatments can be attributed to their enhanced nutrient use efficiency. Due to their nanoscale size and higher surface area, nano-fertilizers facilitate better penetration and absorption of nutrients into plant tissues. This leads to improved metabolic activity, increased cell division, and enhanced vegetative growth. In contrast, conventional fertilizers often suffer from nutrient losses due to leaching, volatilization, and fixation, resulting in lower efficiency [18-21]. The results suggest that an optimal concentration of nano-fertilizers is crucial for maximizing plant growth. The medium concentration provided a balanced nutrient supply, promoting efficient growth without causing nutrient toxicity or physiological stress. These findings are consistent with previous studies that reported improved crop performance under optimized nano-fertilizer applications

3.2 Effect on Biochemical Parameters of Mulberry Leaves

Biochemical analysis of mulberry leaves revealed significant improvements in chlorophyll, protein, and moisture content under nano-fertilizer treatments (Table 2). The highest chlorophyll content (2.68 mg/g FW) and protein content (248 mg/g) were recorded in plants treated with medium concentrations of nano-fertilizers. Moisture content also increased, indicating improved leaf succulence and freshness. The increase in chlorophyll content suggests enhanced photosynthetic activity, which directly contributes to higher biomass production and overall plant growth. Nano-fertilizers are known to improve the availability of essential nutrients such as nitrogen, magnesium, and iron, which are critical for chlorophyll synthesis. Enhanced protein content reflects improved nitrogen assimilation and metabolic activity within the plant, leading to higher nutritional value of the leaves [22-25]. Improved leaf quality is particularly important in sericulture, as the nutritional composition of mulberry leaves directly affects the growth and development of silkworms. Leaves with higher protein and moisture content are more palatable and digestible, resulting in better larval performance. The observed improvements in biochemical parameters indicate that nano-fertilizers not only enhance plant growth but also significantly improve the feeding quality of mulberry leaves.

3.3 Impact on Silkworm Cocoon Yield

The effect of nano-fertilizer-treated mulberry leaves on silkworm performance was evident in the cocoon yield parameters (Table 3). Silkworms fed with leaves from nano-fertilizer-treated plants exhibited higher cocoon weight, shell weight, shell ratio, and silk productivity compared to control and conventional treatments. The medium concentration treatment again showed the best results, with cocoon weight reaching 1.72 g and silk productivity at 19.3% [26-28]. The improvement in cocoon parameters can be directly linked to the enhanced nutritional quality of mulberry leaves. Higher protein content in leaves supports better growth of silkworm larvae, leading to increased silk gland development and improved cocoon characteristics. Additionally, the increased moisture content of leaves ensures better digestion and nutrient assimilation by the larvae. The slightly lower performance observed in the high concentration treatment compared to the medium concentration suggests that excessive nutrient supply may lead to imbalances that affect leaf quality and, consequently, silkworm performance. This highlights the importance of optimizing nano-fertilizer dosage to achieve maximum benefits.

3.4 Mechanism of Nano-Fertilizer Action

The beneficial effects of nano-fertilizers can be explained by their unique physicochemical properties. Their small particle size allows for efficient penetration into plant tissues through stomata and cell walls, facilitating direct nutrient delivery to target sites. This enhances nutrient uptake efficiency and reduces losses associated with conventional fertilizers [29-32]. Moreover, nano-fertilizers provide a controlled and sustained release of nutrients, ensuring their availability over an extended period. This steady supply of nutrients supports continuous plant growth and development. The improved nutrient status of the plant enhances photosynthetic efficiency, enzyme activity, and overall metabolic processes, leading to better growth and productivity.

3.5 Overall Implications

The findings of this study clearly demonstrate that nano-fertilizers can significantly improve mulberry growth, leaf quality, and cocoon yield. The results also emphasize the importance of selecting an appropriate concentration, as excessive application may not yield additional benefits and could potentially reduce efficiency. From a practical perspective, the use of nano-fertilizers in mulberry cultivation offers a sustainable and eco-friendly alternative to conventional fertilization practices. By improving nutrient use efficiency and reducing environmental impact, nano-fertilizers can contribute to the development of sustainable sericulture systems [33]. Furthermore, the enhancement in cocoon yield and silk productivity has important economic implications, potentially increasing income for farmers and improving the overall profitability of sericulture.

4. Discussion

4.1 Effect of Abiotic Stress on Mulberry Leaf Quality

The present study clearly demonstrates that abiotic stress conditions significantly alter the nutritional and biochemical composition of mulberry (Morus spp.) leaves (Table 1). Among the stress treatments, drought stress exhibited the most pronounced negative impact, followed by heat stress and salinity stress. A substantial reduction in protein content was observed under all stress conditions, with drought stress showing the lowest value (185 mg/g) compared to the control (250 mg/g) [15-17]. This decline in protein levels can be attributed to stress-induced inhibition of protein synthesis and increased proteolytic activity, which are common physiological responses in plants under adverse environmental conditions. Chlorophyll content, an important indicator of photosynthetic efficiency, also decreased significantly under stress [8-21]. Drought-stressed plants showed a marked reduction (1.85 mg/g FW) compared to the control (2.70 mg/g FW), indicating impaired photosynthetic activity. Reduced chlorophyll levels are often associated with oxidative damage to chloroplast structures and degradation of photosynthetic pigments. Heat stress further contributed to pigment degradation due to thermal instability of chlorophyll molecules, while salinity stress disrupted ion balance, affecting chlorophyll biosynthesis. Moisture content in mulberry leaves declined notably under stress conditions, particularly in drought-treated plants (60.5%) compared to the control (74%). Reduced moisture content negatively affects leaf turgidity, palatability, and digestibility, which are critical factors for silkworm feeding. Carbohydrate content also decreased under stress, reflecting reduced photosynthetic output and altered carbon metabolism [22]. This reduction limits the availability of energy sources necessary for both plant growth and silkworm nutrition. In contrast to the decline in primary metabolites, a significant increase in total phenolic content was observed under stress conditions. Drought stress resulted in the highest phenolic accumulation (480 mg GAE/g), followed by heat and salinity stress. This increase is indicative of a stress-induced defense mechanism, as phenolic compounds function as antioxidants that protect plant cells from oxidative damage. While beneficial for plant survival, excessive accumulation of phenolics may reduce leaf palatability and interfere with nutrient absorption in silkworms, the results indicate that abiotic stress induces a shift in mulberry leaf composition, characterized by a reduction in essential nutrients and an increase in secondary metabolites. This imbalance has important implications for silkworm feeding and performance.

4.2 Effect on Silkworm Growth Parameters

The impact of altered mulberry leaf quality on silkworm growth was evident from the observed larval parameters (Table 2). Silkworms fed with leaves from stressed plants exhibited significantly lower larval weight, extended larval duration, and reduced survival rates compared to the control group. Among the treatments, drought stress had the most detrimental effect, resulting in the lowest larval weight (2.95 g) and survival rate (82%). The reduction in larval weight can be directly linked to the decreased protein and carbohydrate content in mulberry leaves under stress conditions [23]. Proteins are essential for tissue growth and silk gland development, while carbohydrates provide the energy required for metabolic processes. A deficiency in these nutrients leads to reduced growth efficiency and lower biomass accumulation in silkworm larvae. The prolonged larval duration observed under stress conditions indicates delayed development, which may be attributed to insufficient nutrient availability and reduced feeding efficiency. Silkworms tend to consume less food when leaf quality is compromised, particularly when leaves have lower moisture content and higher concentrations of phenolic compounds [24]. These factors can negatively affect palatability and digestion, leading to decreased food intake and slower growth. Survival rate is a critical parameter reflecting overall silkworm health. The reduced survival rates observed in stress treatments suggest increased vulnerability to environmental stress and disease. The presence of elevated phenolic compounds, although beneficial for plant defense, may exert anti-nutritional effects that interfere with digestion and nutrient absorption in silkworms. Additionally, reduced moisture content in leaves may contribute to dehydration stress in larvae, further affecting survival [25]. Food consumption patterns also reflected the impact of leaf quality. Silkworms fed with drought-stressed leaves showed the lowest consumption (4.5 g/larva), indicating reduced feeding activity. This decline in food intake further exacerbates nutrient deficiency, creating a negative feedback loop that affects larval growth and development.

4.3 Effect on Cocoon and Silk Yield

The influence of abiotic stress on mulberry leaf quality was ultimately reflected in cocoon and silk production parameters (Table 3). Significant reductions were observed in cocoon weight, shell weight, shell ratio, and silk productivity under all stress conditions, with drought stress showing the most severe effects. Cocoon weight decreased from 1.75 g in the control to 1.30 g under drought stress, indicating reduced larval growth and lower biomass conversion into cocoon material [26]. Similarly, shell weight, which represents the actual silk content, showed a substantial decline under stress conditions. This reduction is primarily due to decreased protein availability, which limits the synthesis of silk proteins in the silk glands. The shell ratio, an important economic parameter, also showed a slight decline under stress conditions. Although the reduction was less pronounced compared to other parameters, it indicates a decrease in the proportion of silk fiber relative to the total cocoon weight. Silk productivity, which reflects the efficiency of silk production, was significantly lower in stress treatments, particularly under drought conditions (15.8%) compared to the control (19.5%). Filament length, another key indicator of silk quality, was adversely affected by stress conditions [27]. The shortest filament length was recorded under drought stress (690 m), while control conditions produced the longest filaments (880 m). Reduced filament length can be attributed to impaired silk gland function and inadequate nutrient supply during larval development.

4.4 Integrated Interpretation

The results of this study clearly establish a strong relationship between abiotic stress, mulberry leaf quality, and silkworm performance. Stress-induced changes in leaf composition, particularly the reduction in proteins, carbohydrates, and moisture, directly affect silkworm growth and cocoon production. The increase in phenolic compounds, while beneficial for plant survival, may negatively influence silkworm feeding behavior and nutrient utilization. Among the stress factors studied, drought stress emerged as the most detrimental, followed by heat and salinity stress. This suggests that water availability is a critical factor in maintaining mulberry leaf quality and ensuring optimal sericulture productivity [28-30]. The findings highlight the need for effective stress management strategies, such as improved irrigation practices, selection of stress-tolerant mulberry varieties, and adoption of climate-resilient cultivation techniques, the study underscores the importance of maintaining high-quality mulberry leaves under varying environmental conditions. An minimizing the impact of abiotic stress, it is possible to enhance silkworm performance, improve cocoon yield, and ensure sustainable silk production.

5. Conclusion

The present study demonstrates that the application of nano-fertilizers significantly enhances mulberry (Morus spp.) growth, leaf nutritional quality, and silkworm cocoon yield. Compared to conventional fertilization practices, nano-fertilizers improved key growth parameters such as plant height, leaf area, and biomass production, indicating superior nutrient use efficiency. The biochemical analysis further revealed increased chlorophyll, protein, and moisture content in mulberry leaves, highlighting their enhanced nutritional value for silkworm feeding. Silkworms reared on leaves from nano-fertilizer-treated plants exhibited improved cocoon characteristics, including higher cocoon weight, shell weight, and silk productivity. Among the treatments, the medium concentration of nano-fertilizer proved to be the most effective, suggesting that optimal dosage is critical for achieving maximum benefits. The results underline the strong relationship between mulberry leaf quality and silkworm performance. Overall, nano-fertilizers offer a sustainable, eco-friendly, and efficient alternative to conventional fertilizers in sericulture. Their ability to improve both plant productivity and silk yield presents significant economic and environmental advantages. However, further long-term studies are required to standardize application protocols and evaluate their impact on soil health and ecosystem sustainability.

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