REVIEW ARTICLE

Review on Nanotechnology Applications in Sericulture

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ABSTRACT

Recent decades have witnessed the transformative impact of nanotechnology across various technology and industry sectors, ushering in significant improvements and, in some cases, revolutionary changes. Nanotechnology integrates progress achieved in chemistry, physics, materials science, and biotechnology to craft innovative materials with distinctive properties attributable to their structuring at the nanometer scale. Sectors such as information technology, energy, environmental science, and transportation are all benefiting from nano-technological advancements. The study investigated *Spirulina*-mediated titanium dioxide nanoparticle's effects on silkworm economic traits. Characterization revealed uniform nanoparticles with a size of 97 nm. Silkworms fed with 50 ppm concentration showed improved weight, cocoon traits, silk quality, and reduced renditta. This suggests the potential benefits of nanoparticle-treated mulberry leaves in sericulture.

Keywords: Nanotechnology, *Spirulina,* Titanium dioxide, Silkworm growth and Development.

INTRODUCTION

Sericulture, the cultivation of silkworms for the production of silk, has been an integral part of various cultures for centuries, weaving itself into the fabric of ancient traditions and contemporary industries. As technology continues to advance, the integration of nanotechnology into sericulture has emerged as a promising avenue, propelling this age-old practice into the realms of cutting-edge innovation. Nanotechnology, the manipulation of matter at the nanoscale, holds unprecedented potential to revolutionize the sericulture industry by enhancing silk production processes, improving textile properties, and introducing novel functionalities.

This review aims to explore and evaluate the diverse applications of nanotechnology in sericulture, examining how nanomaterials and nanotechnological approaches can address challenges and unlock new possibilities within this age-old craft. From the molecular-level interactions between nanomaterials and silkworms to the development of advanced silk-based nanocomposites, the convergence of nanotechnology and sericulture offers a myriad of opportunities for sustainable and high-performance silk production. The integration of nanotechnology into sericulture not only promises advancements in silk quality and quantity but also opens doors to environmentally conscious and economically viable practices. Understanding the potential benefits, challenges, and ethical considerations of this emerging field is paramount as we navigate the intricate web of science, tradition, and innovation.

In this review, we delve into the current state of research, exploring the key achievements, ongoing studies, and future prospects of nanotechnology applications in sericulture. By doing so, we aim to contribute to the collective knowledge that guides the responsible and effective integration of nanotechnology into this timeless craft. This introduction provides a brief overview of sericulture and nanotechnology,

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establishes the motivation for the review, and outlines the key areas that will be explored in the subsequent sections. Adjustments can be made based on the specific focus and scope of your review

Role of nanoparticles in the agricultural and Sericulture field

Nanoparticle-bound drugs provide targeted delivery and high drug loading due to their large surface area (Panyam and Labhasetwar, 2003; Han *et al*., 2007). Various synthesis methods, including biological processes (Singaravelu *et al*., 2007; Ray *et al*., 2011) and chemical approaches (Zhang *et al*., 2016), contribute to nanoparticle production. Titanium dioxide nanoparticles exhibit antibacterial properties and find applications in various fields (Chai *et al*., 2006). Modifying nanoparticle size and surface properties enhances drug delivery effectiveness (Sahoo *et al*., 2007; Chen *et al*., 2007). Nanotechnology impacts multiple sectors, offering applications ranging from water treatment to biotechnology (Murphy *et al*., 2011; Dhillon *et al*., 2012). Nanoparticles are classified as inorganic and organic types, with titanium dioxide nanoparticles widely used in pharmaceuticals, orthopedics, and dental fields (Ni *et al*., 2015; Tian *et al*., 2016). Biofabrication methods utilize natural sources from unicellular to multicellular organisms (Asmathunisha *et al*., 2012; Aritonang *et al*., 2019). TiO2 nanoparticles synthesized through thermal decomposition were characterized using various techniques (Viana *et al*., 2010). Gunasundari *et al*. (2016) synthesized and characterized silver, chromium, iron, lead, and zinc nanoparticles, highlighting chromium and zinc nanoparticles' antimicrobial activity. Dharanipriya and Thangapandiyan (2019) observed improved economic traits and nutrient efficacy in mulberry leaves treated with chemically mediated Ag nanoparticles and *Spirulina*. Aravind *et al*. (2021) synthesized TiO2NPs using jasmine flower extract in green synthesis and analyzed their properties.

Nanoparticle characterization

The characterization of nanoparticles is performed to learn more about the averagesize, size distribution and changes that occur when the particles are stored (for example, crystal growth and agglomeration). Nanoparticles and nanomaterials characteristics include their size, shape, surface area and disparity (Jiang *et al*., 2009). The most common methods for characterizing nanoparticles are UV-visible absorbance Spectroscopy (UV), Particle SizeAnalyzer (PSA), Fourier Transform Infrared Spectroscopy (FTIR), Powder X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) (Mittal *et al*., 2013).

Ultraviolet-Visible Absorbance Spectroscopy

The green synthesis method, employing ultrasonic-assisted *Spirulina platensis* as a reducing agent, proves effective, non-toxic, and eco-friendly for producing metal nanoparticles like AgNPs, CrNPs, PbNPs, ZnNPs, and FeNPs. Confirmation of nanoparticle formation was achieved using UV-visible spectroscopy (Gunasundari *et al*., 2016). Subhapriya *et al*. (2018) utilized an aqueous leaf extract of *Trigonella foenumgraecum* to biosynthesize TiO2 NPs, characterized and exhibited significant antimicrobial activity against various microorganisms. Vasanth *et al.* (2023) confirmed the formation of nanoparticles using UV-Vis absorbance spectroscopy, with confirmation observed at a wavelength of 300 nm.

Particle Size Analyzer

Photocatalytic degradation of methyl orange dye using silver (Ag) nanoparticles synthesized from *Ulva lactuca* showed a negative zeta potential value of −34 mV suggesting that the nanoparticles are highly stable in colloidal solution (Kumar *et al.,* 2013). The green synthesized *Azadirachta indica* mediated with TiO_2NPs showed the zeta potential at the rate of -24 mV and particle size distribution was 124 nm (Sankar *et al.,* 2015). Vasanth *et al.* (2023) conducted an analysis using a particle size analyzer, revealing a uniform distribution of particles with a narrow size distribution, measured at 97 nm. Additionally, the zeta potential was determined to be -20.08 mV.

Fourier Transform Infrared (FTIR) Spectroscopy analysis

Infrared radiation (IR) is heat radiation, and its frequency ranges from 10^{14} to 10^{11} Hz on the electromagnetic spectrum. The energy differences between various molecular vibrational modes are equivalent to the energy differences of infrared radiation. The vibrational absorption spectra are clearly made up of bands rather than lines.

The IR spectral bands are narrower in the solid state and at low temperatures. The spectrum of infrared light is plotted as a function of wave number, which is the reciprocal of wavelength.

Wave number = 1/λ cm-1

The FT-IR method measures the vibrations of bonds within chemical functionalgroups and produces a spectrum that can be interpreted as the sample's biochemical or metabolic "fingerprint." It may be possible to detect minor changes in primary and secondary metabolites by obtaining IR spectra from plant samples (McCann *et al*., 1992). Meenakshi *et al*. (2012) reported the FT-IR spectrum of *S. wightii* and *U. lactuca* samples, with the wave number of peaks lying between 449.32 cm-1 and 3495.89 cm-1 and 462.89 cm-1 and 3407.05 cm-1, respectively. Devi and Gayathri (2014) demonstrated FTIR analysis of TiO_2NPs to determine their functional groups. The results indicated the spectrum of titanium dioxide nanoparticles in which the peaks at 3400 and 1631.78 cm -1 spectra were due to stretching and bending vibrations of the –OH groups. The peaks such as 435.91 cm-1, 466.77 cm-1 to 700 cm-1 showed the bending and stretching mode of titanium dioxide. Kannan (2014) determined the frequency of functional groups in brown algae (*S. wightii*) and red algae (*Gracilaria corticata*) using the FT-IR technique. N-H/O-H, C-H, and C-O stretching vibrations in various amines, hydroxyl groups, and carboxylic groups are represented by the bands at 3371 cm-1, 2924 cm-1, and 2358 cm-1, respectively. Krishnasamy *et al*. (2015) used FTIR spectroscopy to determine the substances responsible for the formation and stabilisation of titanium nanoparticles using *Azadirachta indica*. The FTIR spectrum of the materials produced by biosynthesis peaks in the concentration of titanium nanoparticles was found at 3421.63, 1640.53, 1083.76, and 775.38. 3421.63, and 1637.73 can refer to either the C=C groups of aromatic rings or the C=O stretching of amide. O-H stretching of phenolic compounds and alcohols were indicated at 3421.63, and these values are both possible for amide. The absorption band at 1083.76 indicates that alcohols and carboxylic acids have C-O vibrations. Thakur *et al.* (2019) utilized A. indica leaf extract for the synthesis of titanium dioxide nanoparticles, followed by analysis using FTIR. The results showed peaks at 3581.96, 1166.92, 1091.86, and 709.62 in the FTIR spectrum of the titanium dioxide nanoparticles. Aromatic ring C=C groups are responsible for the peak at 1166.92, while the peak at 3581.96 is caused by alcohols and phenolic compounds stretching their O-H bonds. Peak 709.62 represents the stretching vibration of titanium dioxide nanoparticles (Ti-O-Ti), whereas Peak 1091.86 represents the vibration of carboxylic acid (C=O).

Powder X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) analysis is a crucial technique for characterizing the crystal structure of nanomaterials (Sun *et al.,* 2000). Bragg's law, $\sin\theta = n\lambda/2d$, is employed to determine the spacing between diffractional lattice planes (Porter *et al.,* 2008). XRD provides rapid identification of crystalline phases and unit cell dimensions (Pattabhi and Gautham, 2009). Shameli *et al*. (2010) utilized XRD to confirm the formation of Ag-NPs on talc surfaces without disrupting the mineral clay's lamellar structure. Mashael (2013) observed similar 2θ and d-spacing values in both Talc and Talc/polypropylene (TPP), indicating talc's preserved crystal structure in the nanocomposite. Rajeshkumar (2019) synthesized titanium dioxide nanoparticles from *Cassia fistula* leaves and analyzed their crystalline nature and particle size using XRD. The XRD patterns revealed different Bragg's reflections corresponding to various lattice planes, indicating the face-centered cubic (FCC) crystalline nature of the TiO_2 nanoparticles (Vijayakumar *et al*., 2017).

Scanning Electron Microscopy (SEM) analysis

Electron microscopy, as highlighted by Cao (2004), is a prominent method for nanoparticle characterization, offering insight into materials ranging from nanometer to millimeter scales. Various microscopy techniques such as optical light microscopes, scanning electron microscopes (SEM), transmission electron microscopes (TEM), and atomic force microscopes (AFM) facilitate detailed analysis (AFM).

SEM is particularly valuable for high-resolution surface imaging, utilizing electrons scattered from the sample and accelerating them with a shorter wavelength electric potential than photons. This technique can magnify images up to 20,000 times, enabling precise size distribution determination of nanoparticles (Schaffer *et al*., 2009). Kalantari *et al*. (2013) utilized high-magnification SEM to analyze the external surface of talc/Fe_3O_4 nanocomposites, revealing the presence of small Fe_3O_4 nanoparticles that aggregate and form larger particles, altering surface shininess. Santhoshkumar *et al*. (2014) employed FESEM to study the *Psidium guajava* extract-based green synthesis of titanium dioxide nanoparticles, observing smooth, spherical nanoparticles. FESEM images provided valuable insights into physical morphology, particle size, and aspect ratio at various magnifications, aiding in comprehensive nanoparticle characterization.

Transmission Electron Microscopy (TEM) analysis

Transmission electron microscopy (TEM) boasts a 10,000-fold higher resolution compared to scanning electron microscopy (SEM) (Eppler *et al*., 2000). Kalantari *et al*. (2013) utilized TEM to analyze talc/ Fe_3O_4 nanocomposites, revealing nanoparticles with diameters ranging from 1.2 to 3.2 nm. Similarly, Shameli *et al*. (2010) reported mean diameters and standard deviations of talc and Ag-NCs ranging from approximately 7.60 ± 2.62 nm to 13.11 ± 4.58 nm. TEM analysis of neem leaf-mediated titanium dioxide NPs by Krishnasamy *et al*. (2015) showed spherical nanoparticles with smooth surfaces, ranging in size from 15 to 45 nm.

Silkworm growth and development in Nano-formulation

The utilization of nanoparticles, particularly silver (Ag) and titanium dioxide (TiO_2), has demonstrated significant effects on silkworm (*Bombyx mori*) growth, development, and cocoon quality. Govindaraju *et al*. (2011) found that Ag nanoparticles synthesized with *Spirulina platensis* showed strong antiviral activity, enhancing total haemocyte count and differential haemocyte count in silkworms. Similarly, TiO_2 nanoparticles have been associated with increased ecdysone synthesis, affecting growth and antiviral capabilities (Jiang *et al*., 2014), as well as improving feeding efficiency and silk protein synthesis (Ni *et al*., 2015). *Spirulina* supplementation in silkworm rearing has also shown growth stimulant activity, enhancing larval, cocoon, and pupal weights, as well as shell ratio (Kumar and Balasubramanian, 2014). Studies by Ni *et al*. (2014) and Zhang *et al*. (2014) highlighted the positive effects of TiO_2 nanoparticles on silkworm development, including faster ovary and testis development, increased gamete differentiation, improved food conversion efficiency, and enhanced cocoon quality and silk filament yield. Furthermore, Cai *et al*. (2015) demonstrated that TiO_2 nanoparticles could improve the mechanical properties of silk, particularly its breaking strength and elongation, as well as its ultraviolet resistance. Li *et al*. (2016) observed that low concentrations of TiO_2 nanoparticles improved feed efficiency and cocoon characteristics, although higher concentrations exhibited inhibitory effects on silkworm growth. Pandiarajan *et al*. (2016) found that exposure to low doses of Ag nanoparticles enhanced larval growth and cocoon weight. Tian *et al*. (2016) investigated the effects of TiO_2 nanoparticles on silkworm nutrient metabolism, revealing activation of the insulin signalling pathway and enhanced carbohydrate, protein, and fat metabolism. Yang *et al*. (2017) studied the effects of various nanoparticles on silk production, observing increased copper content in silk and significant changes in silk morphology and structure. Alipanah *et al*. (2021) reported increased cocoon weight and feeding efficiency in TiO_2 nanoparticle-fed silkworms. Soliman *et al*. (2021) investigated the enrichment of mulberry leaves with *Spirulina* extracts, noting improvements in various biological parameters of silkworms. These studies collectively underscore the potential of nanoparticles, particularly Ag and TiO_2, in enhancing silkworm growth, cocoon quality, and silk production efficiency.

In the study by Vasanth *et al.* (2023), larvae fed mulberry leaves treated with *S. platensis* mediated TiO_2NPs at a concentration of 50 ppm exhibited notable effects on various parameters compared to the control group. Specifically:

- Larval weight increased to 4.34 g.
- Larval duration extended to 203 hours.
- Efficiency of the rearing process (ERR) improved to 92.22%.
- Larval mortality decreased to 8.89%.

Furthermore, significant enhancements were observed in silk gland parameters, including silk gland weight and silk productivity, among larvae fed with leaves treated with *S. platensis*-mediated TiO_2NPs at a concentration of 50 ppm. These findings suggest the potential beneficial effects of *S. platensis*-mediated TiO2NPs on silkworm rearing and silk production.

Gut microbial diversity in silkworm

Silkworm gut microbes play a pivotal role in various aspects of the host's biology, including interaction with environmental factors, diet, developmental stages, and phylogeny. Studies have identified diverse bacterial species inhabiting the gut of silkworms, shedding light on their diversity and potential functions. Kalpana *et al*. (1995) identified *Micrococcus* sp. *Staphylococcus* and sp. in the gut of silkworm crossbreeds, while Neelu Nangia *et al*. (1999) found higher bacterial loads in bivoltine breeds compared to others. Roy *et al*. (2000) reported the presence of bacteria in the gut of mulberry silkworms. Chowdary *et al*. (2002) investigated the bacterial flora in the midguts of Pure Mysore and NB_4D_2 silkworms, revealing substantial populations and enzymatic activities. Tandon and Mishra (2003) isolated various bacterial species from the gut of indigenous silkworm breeds, including *Enterobacter, E. coli,* and *Bacillus* sp. Mohanraj *et al*. (2009) identified common gut bacterial flora, including *B. subtilis, S. aureus, and Pseudomonas* sp., across different silkworm breeds. Sekar *et al*. (2010) assessed bacterial colonization in mulberry leaves and silkworm intestines, observing the dominance of *Bacillus cereus* and other species like *Enterobacter, Lactococcus lactis,* and *Staphylococcus lactis*. Notably, the foregut harbored a greater bacterial population, likely originating from mulberry phyllosphere microbes. These studies collectively underscore the complex relationship between silkworms and their gut microbiota, impacting various aspects of silkworm biology and potentially offering avenues for enhancing sericulture practices.

Changes in gut microflora due to fortification

Khyade and Doshi (2012) demonstrated that herbal drug-treated mulberry leaves significantly improved protein levels and the velocities of biochemical reactions in silkworms across instars 3 to 5, enhancing midgut protease and amylase activities. Additionally, Ni *et al*. (2015) found that exposure to TiO_2NPs affected the biological functions of B. mori, influencing digestion, absorption, growth, and immune function. Gunasundari *et al*. (2016) synthesized various metallic nanoparticles via green synthesis, with chromium and zinc nanoparticles exhibiting notable antimicrobial activity against common pathogens. Li *et al*. (2016) observed that TiO_2NPs increased dominant bacterial strains and gene expression related to digestion and detoxification in silkworm intestines, enhancing growth and immunity. Similarly, Xie *et al*. (2014) noted TiO_2NPs' role in enhancing resistance against pathogenic bacteria and promoting detoxification processes. Ahmad *et al*. (2020) utilized green-synthesized TiO2 NPs using *Mentha arvensis* leaf extract, demonstrating potent antibacterial and antifungal activity against various microorganisms, including *Staphylococcus aureus, Klebsiella pneumoniae*, and *E. coli*. Their study suggests the potential of green-synthesized TiO_2NPs for environmental and biomedical applications, exhibiting superior antibacterial properties compared to chemically synthesized counterparts (Aravind *et al*., 2021).

CONCLUSION

Nanotechnology holds the potential to revolutionize the realms of Sericulture and agriculture, as highlighted in this paper's review. The replication of natural systems emerges as a particularly promising avenue within this technology, yet scientists face the formidable task of comprehending the intricate complexities inherent in these systems. The field of nanotechnology and nanomaterials is experiencing rapid growth in research, presenting opportunities to leverage novel properties of materials at the nano-scale for industrial benefits. Numerous developments are on the horizon, capable of significantly altering the service life and life-cycle cost of construction infrastructure. In essence, this burgeoning area of study has the power to shape a new world in the future.

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