

Next-Generation Biodegradable Antimicrobial Sanitizers: Driving Sustainable Food Safety and Environmental Innovation

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INTRODUCTION & AIM



Figure 1. Food Waste Iceberg.

The global population is projected to reach 10 billion by 2050, posing a critical challenge of how to feed everyone with limited food resources (1). Each year, nearly one-third of all food produced for human consumption is lost or wasted due to safety and quality issues. This not only limits food availability but also causes serious environmental impacts, contributing to 10% of global greenhouse gas emissions (2,3). Food waste that could feed 1.6 billion people instead consumes 25% of global freshwater resources and ranks as the third largest source of greenhouse gases after China and the United States (2). Figure 1 illustrates the hidden environmental burden of global food waste across the supply chain.

Ensuring food safety while advancing environmental sustainability remains a pressing challenge for the food industry. Conventional chlorine-based sanitizers raise concerns due to their toxicity, environmental persistence, and potential to increase food waste. Moreover, synthetic polymers used in antimicrobial formulations contribute to microplastic pollution, heightening environmental and regulatory pressures.

METHOD

This study details the systematic development and evaluation of a novel biodegradable antimicrobial sanitizer, encompassing material preparation, active agent encapsulation, and comprehensive antimicrobial efficacy assessments.

Silk fibroin, a natural protein polymer, was extracted and purified to form the biocompatible matrix (refer to Figure 2). Thyme essential oil was then encapsulated within this silk fibroin matrix via a rapid, 1-minute, solvent-free sonication method, yielding nanoparticles with 8% w/w thyme oil. This approach enhances stability and controlled release of the active compound (as illustrated in Figure 3).

Post-synthesis, formulations were tested in vitro through antimicrobial assays and evaluated for efficacy on food-contact surfaces against relevant foodborne pathogens.

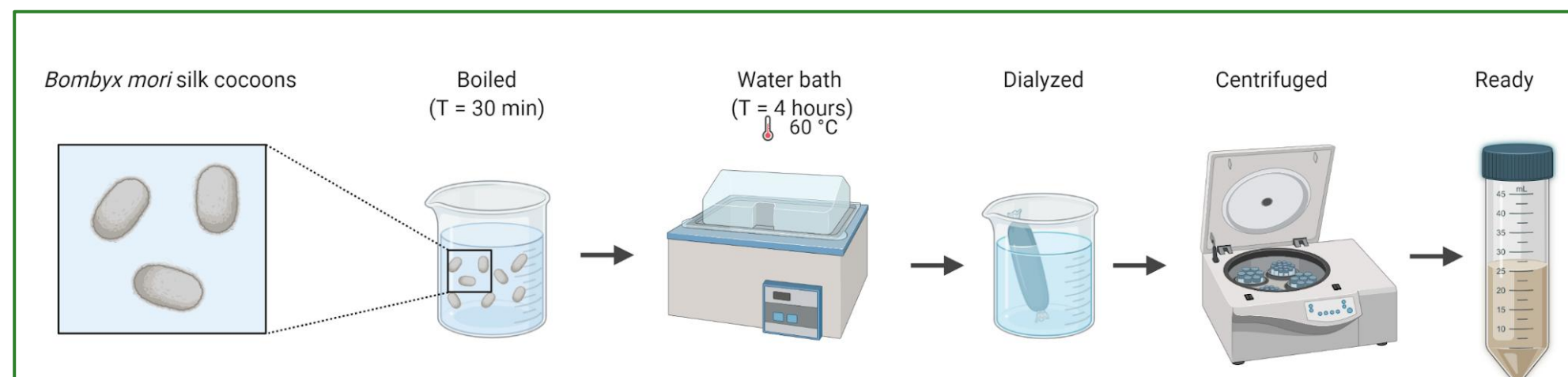


Figure 2. Schematic of silk fibroin regeneration from *Bombyx mori* cocoons.

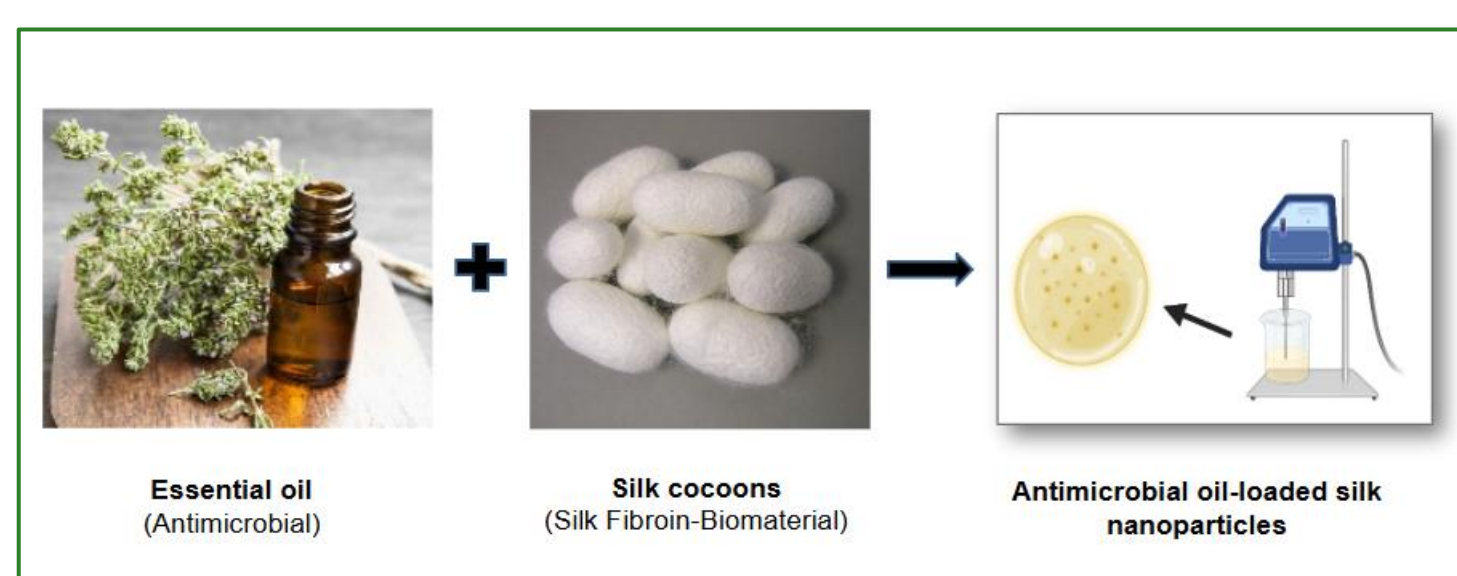


Figure 3. Essential oil-loaded silk nanoparticles production.

RESULTS & DISCUSSION

Our novel biodegradable antimicrobial sanitizer demonstrates superior efficacy and longevity. Nanoparticle characterization and controlled release profiles (Figure 4) confirmed successful encapsulation of thyme essential oil within a silk fibroin matrix, ensuring sustained antimicrobial release for prolonged surface protection.

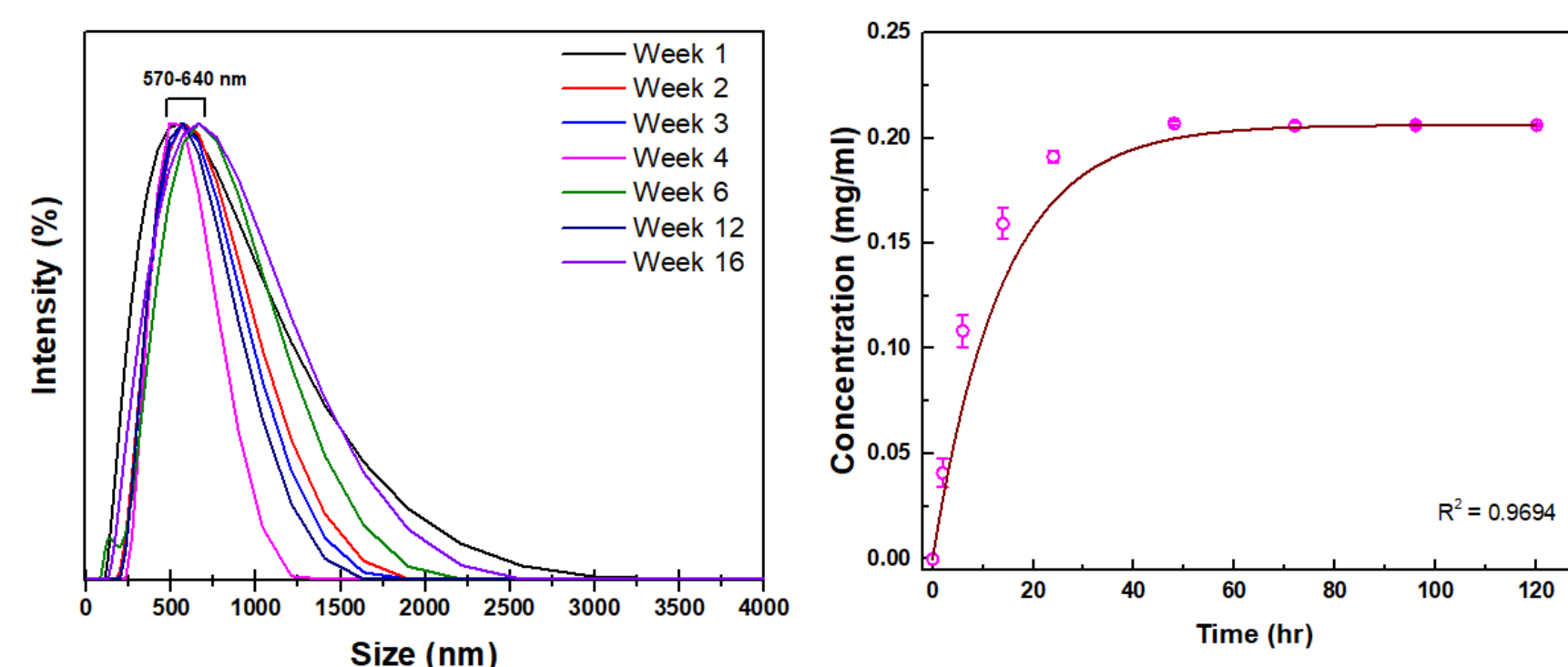


Figure 4. Size characterization of the nanoparticles and controlled drug release of the nanoparticles.

The formulation exhibited potent antimicrobial effects (Figure 5) against major foodborne pathogens like *Salmonella* Typhimurium and *Listeria monocytogenes*. Notably, equivalent efficacy was achieved with approximately ten times less active ingredient compared to unencapsulated oil.

Treatment	<i>Salmonella</i>	<i>Listeria</i>
Free Drug (w/w%)	4	2
NP (w/w%)	0.4	0.4

Figure 5. Antibacterial testing of the nanoparticles.

A 90-day storage study highlighted significant food preservation, with treated samples (Figure 6) maintaining visual acceptability for 90 days. This contrasts sharply with spoiled control samples, underscoring the novel sanitizer's potential to extend shelf life and reduce food waste.



Figure 6. Comparison of Several Treatments on Tomatoes- Day 90.

CONCLUSION

This research demonstrates how biodegradable materials and natural antimicrobials can be integrated into effective sanitation technologies that align with sustainable food system principles. The innovation contributes to reduced foodborne illness, extended shelf life, and environmental responsibility—demonstrating that food safety and sustainability need not be competing objectives.

FUTURE WORK / REFERENCES

- Scale-up studies to evaluate potential for industrial applications
- Testing against additional foodborne pathogens
- Optimization of encapsulation efficiency
- Economic feasibility analysis

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