Valorization of Sericulture By-Products for Non-Textile Applications: A Conceptual Edp-Based Integrated Biorefinery Framework for Circular Rural Enterprise

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Abstract

Sericulture is traditionally organized around the production of silk fibre, but the production and processing chain also generates biologically valuable streams including silkworm pupae, sericin, silk residues, mulberry biomass and organic rearing/reeling residues. These materials contain proteins, lipids, amino acids, phytochemicals and other functional constituents that can support value-added applications beyond textiles. This paper develops a conceptual framework for the valorization of sericulture by-products through an integrated biorefinery model linked with Entrepreneurship Development Programmes (EDPs) and competency-based skill development. The study uses a structured review of secondary literature and institutional documents to map major by-products, their principal constituents, potential non-textile applications, processing pathways and enterprise opportunities. Published evidence supports the potential of silkworm pupae as sources of protein and lipids, sericin as a functional biomaterial, silk fibroin and silk waste as inputs for advanced biomaterials, and mulberry residues as sources of phytochemicals and bioactive compounds. The proposed framework organizes these streams into sequential modules involving collection, stabilization, extraction or conversion, product development, residual biomass recycling, quality assurance and market linkage. An illustrative economic scenario is presented only to demonstrate how multiple product streams may be combined; it is not claimed as a field-validated profitability estimate. The framework provides a research and enterprise roadmap for moving sericulture toward a circular bioeconomy, but pilot-scale process validation, techno-economic analysis, life-cycle assessment, product safety testing and market studies are required before commercial adoption.

Keywords: sericulture; by-product valorization; biorefinery; silkworm pupae; sericin; silk fibroin; mulberry biomass; circular bioeconomy; entrepreneurship; NSQF

1. Introduction

Sericulture is an agro-based production system in which biological resources are transformed into silk and associated products. Although silk remains the principal economic output, the production chain generates several secondary biomass streams. Recent research has increasingly recognized these materials as potential resources rather than unavoidable waste. A major review of silk-industry by-products identified sericin, pupae, litter and mulberry leaves as sources of proteins, lipids and other biomolecules with possible applications extending well beyond conventional silk production [1].

Silkworm pupae are particularly important because their protein and lipid fractions can be recovered for food, feed and other bioproduct applications. Published studies report substantial protein and lipid contents in Bombyx mori pupae on a dry-weight basis, although composition varies with species, sex, diet, developmental stage and analytical method [2,3]. Sericin, which surrounds the fibroin filament, accounts for approximately 20–30% of silk mass and has attracted attention because of its hydrophilicity, biocompatibility and reported antioxidant and biological properties [4,5]. Mulberry (Morus alba L.) biomass also contains diverse phytochemicals, including flavonoids and phenolic compounds, supporting investigation of food, nutraceutical and other applications [6].

At the policy and skills-development level, the concept is compatible with increasing emphasis on value addition, waste utilization, entrepreneurship and competency-based training. ICAR identifies economic utilization of bio-waste and by-products, value addition, biomass utilization and entrepreneurship development among relevant areas [7]. The revised NSQF is an outcome- and competency-based framework that organizes qualifications according to knowledge, skills, aptitude and responsibility, and recognizes entrepreneurship and employment readiness as important elements [8]. The objective of this paper is to develop a conceptual EDP-based integrated biorefinery framework for sericulture by-products, identify technically plausible non-textile applications, and define a research agenda for validating the model.

2. Materials and Methods

This study is a conceptual review and framework-development paper rather than an experimental investigation. The source manuscript used secondary information from Central Silk Board reports, ICAR publications, peer-reviewed literature and NCVET-related documents. For this revision, key technical claims were cross-checked against peer-reviewed literature and official institutional sources. The analysis was organized into five stages: (i) identification of major sericulture by-product streams; (ii) synthesis of reported composition and functional properties; (iii) mapping of non-textile applications; (iv) development of an integrated biorefinery architecture; and (v) identification of skills, enterprise requirements and research gaps. Quantitative values strongly dependent on species, process conditions, location or scale were treated as ranges or contextual values rather than universal constants.

3. Sericulture By-products as Biological Resources

By-product stream	Primary source	Important constituents / characteristics	Potential non-textile pathway
Silkworm pupae	Cocoon processing/reeling	Protein, lipids, amino acids and minerals; composition varies	Feed ingredients, protein/oil recovery, functional ingredients
Sericin	Degumming of silk	Protein rich in hydrophilic amino acids; about 20–30% of silk mass	Cosmetics, films, hydrogels, biomedical research
Silk fibroin / silk waste	Reeling and downstream processing	Fibroin protein; biodegradable and	Films, scaffolds, composites, drug-delivery research

		biocompatible platform	
Mulberry biomass	Harvest, pruning and processing	Polyphenols, flavonoids and other phytochemicals	Functional foods, extracts, nutraceutical research
Rearing/reeling residues	Rearing and processing	Organic matter and nutrients; source-dependent	Composting, vermicomposting, anaerobic digestion

4. Non-textile Valorization Pathways

4.1 Silkworm pupae

Silkworm pupae are among the most promising secondary resources because they contain substantial protein and lipid fractions. Recent reviews describe protein and oil recovery, food and feed incorporation, and production of functional peptides as important directions [2,3]. Human-food applications require careful consideration of processing hygiene, allergenicity, oxidation, contaminants, regulatory requirements and consumer acceptance.

4.2 Sericin

Sericin has moved from being viewed primarily as a degumming residue to a material of interest in biomedical, pharmaceutical, cosmetic and environmental applications. Reviews report antioxidant activity, biocompatibility, biodegradability and potential use in films, hydrogels, scaffolds, wound-related materials and drug-delivery systems [4,5]. Because sericin properties depend strongly on extraction and purification conditions, product development should specify extraction chemistry, molecular-weight distribution, purity and functional testing.

4.3 Silk fibroin and silk waste

Fibroin is the structural protein of silk and has been investigated as a biodegradable and biocompatible material platform. Silk residues can therefore serve as feedstock for films, composites, scaffolds and controlled-release systems.

4.4 Mulberry biomass

Morus alba contains diverse phytochemicals, including flavonoids, phenolic acids, anthocyanins and other bioactive constituents [6]. Mulberry leaves, fruits, branches and other plant parts have consequently been investigated for functional-food and phytochemical applications. Health-related product claims require standardized extraction, chemical characterization, toxicological assessment and appropriate clinical or regulatory evidence.

4.5 Residue recycling and bioenergy

Low-value residues that are not suitable for high-value extraction can be directed to composting, vermicomposting or anaerobic digestion, subject to feedstock characterization. This cascading approach is central to the biorefinery concept: higher-value fractions are recovered first, while remaining organic matter is converted into lower-value but useful products such as soil amendments or energy.

5. Proposed EDP-based Integrated Biorefinery Framework

The proposed framework follows a cascading resource-utilization principle. Multiple streams are routed to the most appropriate processing pathway according to composition, quality, local infrastructure and market demand.

1. Collection, segregation and traceability of by-product streams.
2. Stabilization through drying, chilling or other appropriate preservation methods.
3. Primary processing and fractionation of pupae, sericin, silk residues and mulberry biomass.
4. Recovery of higher-value fractions such as proteins, oils, sericin and phytochemical-rich extracts.
5. Conversion of lower-value fractions into compost, biofertilizer or biogas, where technically appropriate.
6. Quality assurance, packaging, branding and regulatory compliance.
7. Entrepreneurship Development Programme modules covering business planning, costing, market assessment, digital marketing and risk management.
8. Skill certification and progression pathways aligned with the applicable national competency framework, subject to formal qualification validation.
9. Market linkage through cooperatives, Farmer Producer Organizations, start-ups and industry partnerships.

Recommended Figure 1: Sericulture production → by-product segregation → stabilization → fractionation/extraction → high-value products → residual biomass conversion → quality assurance → packaging/branding → market linkage → enterprise income and circular resource recovery.

6. Illustrative Enterprise Scenario

The original manuscript presented an annual gross-income scenario of approximately ₹4.10 lakh from selected streams. Because the underlying quantities, recovery yields, processing costs, capital depreciation, labour costs, utilities and market prices were not experimentally established, the figure should not be reported as a demonstrated economic result. It can be retained only as an illustrative scenario for future techno-economic analysis.

Illustrative input	Assumed quantity	Potential output	Illustrative gross value (₹)
Silkworm pupae	1,000 kg	Feed/protein/oil products	150,000
Sericin-containing stream	500 L	Cosmetic/material ingredient	120,000
Silk waste	300 kg	Biomaterial feedstock	80,000
Mulberry residues	2,000 kg	Compost/bio-input	60,000
Total	—	Multiple product streams	410,000

Note: These are scenario assumptions from the source manuscript, not experimentally validated market returns. A publishable economic analysis should report capital expenditure, operating expenditure, recovery efficiency, product yield, selling price, gross margin, net present value, internal rate of return, sensitivity analysis and break-even period.

7. Skill and Entrepreneurship Dimension

The skills component is a distinctive feature of the proposed framework. The revised NSQF is competency- and outcome-based and provides a structure for qualifications, progression pathways, employability and entrepreneurship [8]. The biorefinery concept can be translated into modular training in raw-material handling, drying, extraction, separation, composting, quality control, occupational safety, packaging, enterprise management and marketing. The source manuscript's direct assignment of specific job roles to NSQF Levels 4 and 5 should, however, be treated as a proposal rather than an officially approved NCVET classification. Formal level assignment requires alignment with an approved qualification specification and assessment requirements.

8. Discussion

The central implication is that sericulture can be viewed as a multi-output biological production system rather than a single-output fibre industry. The scientific literature demonstrates that individual streams have substantial functional potential [1–6], while ICAR identifies biomass utilization, economic use of bio-waste, value addition and entrepreneurship among relevant priorities [7].

The transition from laboratory potential to rural enterprise requires feedstock characterization, contamination control, extraction yield, energy efficiency, product stability, regulatory approval, consumer acceptance and market access. Therefore, the integrated model should be evaluated through pilot-scale demonstrations rather than assumed to be profitable solely from theoretical product values. Cascading utilization may improve resource efficiency, but environmental and economic benefits must be quantified through life-cycle and techno-economic assessment.

9. Research Gaps and Future Directions

- Generate location-specific mass balances for sericulture by-products.
- Standardize feedstock characterization, including moisture, protein, lipid, ash, fibre and contaminants.
- Compare extraction and conversion technologies on yield, energy use, solvent consumption and product quality.
- Conduct pilot-scale techno-economic analysis using measured capital and operating costs.
- Undertake life-cycle assessment to quantify greenhouse-gas, water, energy and waste-reduction benefits.
- Evaluate safety, allergenicity, microbial quality, heavy metals and pesticide residues for food/feed pathways.
- Develop product-specific quality standards and regulatory pathways.
- Validate training curricula and competency standards with industry and relevant awarding/assessment bodies.
- Study market acceptance, willingness to pay, branding and supply-chain feasibility.
- Demonstrate cluster-level or FPO-based pilot units and compare outcomes with conventional sericulture.

10. Limitations

This paper is based on secondary information and conceptual synthesis. It does not report laboratory experiments, field trials, pilot-scale processing, primary economic surveys, life-cycle assessment or consumer studies. Consequently, proposed product pathways and economic scenarios are research hypotheses requiring validation.

11. Conclusions

Sericulture by-products represent a diverse biological resource base with potential applications in food and feed ingredients, biomaterials, cosmetics, phytochemical products, bio-inputs and bioenergy. The evidence supports a shift from a waste-disposal perspective toward a cascading valorization and circular-biorefinery perspective. The EDP-based framework connects resource recovery with entrepreneurship, skills development and market linkage. Its principal contribution is a structured roadmap for integrating scientific valorization with rural enterprise development, not a claim of demonstrated profitability. Future work should prioritize mass-balance studies, pilot validation, techno-economic analysis, life-cycle assessment, safety testing and competency validation before large-scale commercialization.

12. Policy and Enterprise Implications

1. Support pilot-scale sericulture biorefineries through research–industry–extension partnerships.
2. Include sericulture by-product valorization within waste-to-wealth and circular-bioeconomy initiatives.
3. Develop evidence-based training modules for rural youth, women, entrepreneurs and producer organizations.
4. Facilitate shared processing infrastructure for collection, stabilization, extraction, quality testing and packaging.
5. Encourage FPOs, cooperatives, start-ups and private enterprises to develop cluster-based value chains.
6. Create clear quality and regulatory pathways for food, feed, cosmetic, biomedical and bio-input products.

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