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Review

Bio-Nutritional and Pharmacological Applications of Eri Silkworm Pupae *(Samia ricini)*

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ABSTRACT

The eri silkworm (*Samia ricini*) is a major non-mulberry species whose pupae remain an underused byproduct despite their rich nutritional and bioactive profile. Recent studies show they contain high-quality proteins, essential amino acids, polyunsaturated fatty acids, vitamins, and minerals, along with functional compounds such as peptides, sterols, tocopherols, and chitosan. These compounds exhibit diverse biological activities, including antioxidant, anti-inflammatory, antimicrobial, and hypolipidemic effects, supported by both *in vitro* and *in vivo* studies. The nutritional versatility of eri pupae supports their incorporation into functional foods, nutraceuticals, and animal feed formulations, while emerging evidence points to pharmaceutical applications in wound healing, metabolic regulation, and biomaterial development. However, their large-scale utilization is constrained by variability in composition, lack of standardized processing, and limited toxicological or clinical validation. This review synthesizes current knowledge on the nutritional and pharmacological potentials of *Samia ricini* pupae, emphasizing their role as a sustainable bioresource that bridges food and pharmaceutical domains. The strategic integration of advanced bio-processing approaches with cutting-edge bioengineering platforms is poised to substantially augment the functional potential of these biological systems, thereby catalyzing transformative advancements in functional food technology and biomedical innovation.

INTRODUCTION

The eri silkworm, *Samia ricini* (Boisd.), represents a key non-mulberry sericulture species, particularly in the northeastern regions of India, where it has long been reared for its production of Eri silk and, in many cases, the pupae are also used as a food source (Birari *et al*., 2019; Gogoi *et al*., 2024). The life-cycle, host-plant flexibility and favourable rearing traits of *S. ricini* contribute to its sericultural significance. Eco-race evaluations revealed that certain strains achieved superior larval and pupal weights and shell-ratios under local castor-leaf feeding regimes, underscoring the viability of *S. ricini* in integrated sericulture systems (Bora *et al*., 2024; Gogoi *et al*., 2024).

In addition to their conventional utilization in sericulture, *Samia ricini* pupae remain an underexploited biomaterial endowed with high nutritional quality and a broad spectrum of bioactive compounds with potential value for health-promoting applications. Analyses have shown that eri pupae contain high levels of protein, essential amino acids, lipids, vitamins and minerals when compared to conventional protein sources (Das *et al*., 2024; Zhou *et al*., 2022). Quantitative compositional analyses indicate that eri pupae contain approximately 40–55% crude protein (dry-matter basis), 25–33% total lipids and all essential amino acids including lysine, threonine, valine and leucine in nutritionally relevant proportions (Longvah *et al*., 2011; Ray and Gangopadhyay, 2021). Mineral profiling further shows appreciable levels of iron (4.8–6.1 mg/100 g), zinc (5–7 mg/100 g), phosphorus (~280–320 mg/100 g) and B-group vitamins, confirming their value as a micronutrient-dense food ingredient (Hăbeanu *et al*., 2023; Zhou *et al*., 2022).

Recent investigations have further demonstrated that

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the biochemical richness of *S. ricini* pupae aligns with current interests in sustainable bioproduct development, positioning them as promising candidates for food, feed, nutraceutical, and biomaterial applications (Beniwal *et al*., 2024; Rodríguez-Ortiz *et al*., 2024). In fact, in one nutrient-composition study, eri pupae displayed a protein content of ~49 % (dry matter basis) and a broad aminoacid profile, thereby lending support to their valorisation in food and feed sectors (Kongsup *et al*., 2022; Zhou *et al*., 2022). Lipid analyses show that the pupal oil fraction is enriched in polyunsaturated fatty acids (PUFAs), particularly linoleic (C18:2) and α-linolenic acid (C18:3), yielding PUFA:SFA ratios favourable for cardiometabolic health applications (Hăbeanu *et al*., 2023).

Interest in insect-derived ingredients for food, feed and pharmaceutical applications has grown rapidly in recent years, driven by global challenges of sustainability, food security and the need for novel bioactive compounds (Tanga *et al*., 2023; Rodríguez-Ortiz *et al*., 2024). Insects such as *S. ricini* offer advantages of efficient feed-conversion, lower land and water use, and high-quality nutrients, while also presenting unique bioactive constituents such as antioxidant peptides and hypolipidaemic lipids (Sinha and Choudhury, 2025). Sericulture insect pupae therefore represent a valuable avenue for nutritional and pharmaceutical valorization, transforming a low-value waste stream into a high-value bioresource (Rodríguez-Ortiz *et al*., 2024; Kumar *et al*., 2025).

S. ricini pupae contain antioxidant peptide fractions, PUFA-rich oils with measurable hypolipidaemic effects, and chitin/chitosan suitable for developing antimicrobial and wound-healing biomaterials, confirming their functional and biotechnological value (Chukiatsiri *et al*., 2024; Gangopadhyay *et al*., 2022; Hăbeanu *et al*., 2023). Accordingly, this review consolidates experimentally validated evidence on the nutritional composition and pharmacological attributes of *S. ricini* pupae, highlighting their potential as a sustainable and multifunctional bioresource for food, feed, nutraceutical and biomedical applications.

NUTRITIONAL COMPOSITION AND FUNCTIONAL PROPERTIES

Proximate composition

Eri silkworm (*Samia ricini*) pupae are a nutrient-dense biological material with high crude protein and lipid contents, making them attractive for both food and feed uses. Quantitative analyses report pupal protein ranging from 40–55% of dry weight, with defatted pupal meals consistently exceeding 60% protein, reflecting concentration effects during processing. The amino acid profile that contains all indispensable amino acids and a favourable essential to non-essential ratio comparable to conventional animal proteins (Longvah *et al*., 2011; Ray and Gangopadhyay, 2021). Lipid fractions of eri pupae are rich in unsaturated fatty acids, especially linoleic (C18:2, omega-6) and α-linolenic (C18:3, omega-3) acids. Reports indicate PUFA:SFA ratios above 2.0, which is favourable for cardiometabolic health (Hăbeanu *et al*., 2023; Ray and Gangopadhyay, 2021). In one compositional analysis, linoleic acid contributed ~23.4% of total fatty acids and oleic acid ~36.5%, resulting in an overall unsaturated fatty acid fraction exceeding 65%, as summarised in Table I.

Table I. Fatty acid composition of eri silkworm pupal oil.

Fatty acid	Content (% of total lipid)	Classification	Physiological role	Reference
Palmitic acid	24.3	Saturated fatty acid (SFA)	Energy storage; structural lipid component	Das *et al.* (2024)
Stearic acid	5.6	Saturated fatty acid (SFA)	Neutral effect on plasma cholesterol	Longvah *et al.* (2011)
Oleic acid	36.5	Monounsaturated fatty acid (MUFA)	Supports cardiovascular health	Das *et al.* (2024)
Linoleic acid	23.4	Polyunsaturated fatty acid (PUFA)	Essential fatty acid; regulates inflammation	Longvah *et al.* (2011)
α-Linolenic acid	5.8	Polyunsaturated fatty acid (PUFA)	Anti-inflammatory; improves lipid metabolism	Das *et al.* (2024)
Total unsaturated fatty acids	65.7	MUFA + PUFA	Favorable for human nutrition	Das *et al.* (2024)

Table II. Proximate and micronutrient composition of eri silkworm (*Samia ricini*) pupae and their contribution to adult nutrient requirements.

Component	Content (per 100 g dry weight)	Major function	% Recommended dietary allowance (RDA) contribution (adult)	Reference
Protein	49.2 g	Tissue building; enzyme and hormone synthesis	82 %	Kongsup *et al.* (2022); Longvah *et al.* (2011)
Lipid (total fat)	26.4 g	Energy source; carrier of fat-soluble vitamins	53 %	Hăbeanu *et al.* (2023); Zhou *et al.* (2022)
Carbohydrate	8.7 g	Energy metabolism	-	Longvah *et al.* (2011)
Ash (total minerals)	5.3 g	Mineral reserve	-	Longvah *et al.* (2011)
Iron (Fe)	5.0 mg	Oxygen transport; haemoglobin synthesis	29 %	Hăbeanu *et al.* (2023); Ray and Gangopadhyay (2021)
Zinc (Zn)	6.2 mg	Enzyme activation; immune function	52 %	Ray and Gangopadhyay (2021)
Calcium (Ca)	128 mg	Bone and teeth formation; muscle function	13 %	Zhou *et al.* (2022)
Phosphorus (P)	290 mg	Bone mineralisation; energy transfer (ATP)	41 %	Ray and Gangopadhyay (2021); Longvah *et al.* (2011)
Vitamin B_2 (Riboflavin)	1.1 mg	Energy metabolism; redox coenzyme	85 %	Zhou *et al.* (2022); Hăbeanu *et al.* (2023)
Niacin (Vitamin B_3)	11.8 mg	Coenzyme in metabolic reactions	74 %	Hăbeanu *et al.* (2023); Zhou *et al.* (2022)

Micronutrient surveys indicate appreciable levels of B-group vitamins (notably riboflavin and niacin), fat-soluble vitamins in oil fractions, and essential minerals such as iron (~5 mg/100 g dw), zinc (~6.2 mg/100 g dw), calcium (~128 mg/100 g dw), and phosphorus (~290 mg/100 g dw), although values differ according to strain, host plant, and processing variables (Zhou *et al*., 2022; Hăbeanu *et al*., 2023). These nutrient densities position *S. ricini* pupae as a credible alternative to conventional protein sources in regions facing micronutrient deficiencies. The overall proximate and micronutrient composition of *Samia ricini* pupae and their approximate contribution to adult nutrient requirements are presented in Table II.

Functional components

Beyond macronutrients, eri pupae contain several functional constituents with documented bioactivities. Proteolytic hydrolysates yield antioxidant and angiotensin-converting enzyme (ACE)-inhibitory peptides that show *in vitro* radical-scavenging and enzyme-modulating activities, suggesting nutraceutical potential (Zhou *et al*., 2022; Gangopadhyay *et al*., 2022). The lipid fraction is a source of tocopherols and phytosterols, compounds associated with antioxidant protection and cholesterol-modulating effects when included in foods or extracts (Hăbeanu *et al*., 2023; Beniwal *et al*., 2024). The exoskeletal chitin and its deacetylated derivative chitosan, present in pupal cuticle, offer functional properties for food structuring and biomedical applications (wound dressings, delivery matrices) and can be retrived as a value-added co-product (Hăbeanu *et al*., 2023; Beniwal *et al*., 2024).

Determinants of compositional variability: Roles of sex, diet, rearing conditions, and processing

The compositional attributes of eri pupae exhibit intrinsic variability rather than a fixed profile. Biological factors such as sex and developmental stage alter proximate and micronutrient profiles. Males and females may differ in lipid and vitamin content at pupation, and maturation stage affects amino acid concentrations (Ray and Gangopadhyay, 2021; Gangopadhyay *et al*., 2022). The biochemical composition of eri pupae is strongly modulated by environmental and husbandry factors including host plant species, seasonal forage quality, rearing density, and temperature, reflecting the pivotal role of larval diet in determining stored lipids and key micronutrients. (Ray and Gangopadhyay, 2021). Post-harvest processing (drying, blanching, defatting, extraction) profoundly modifies both nutrient retention and functional-compound yield. Defatting consistently increases protein content (on a dry-weight basis), whereas heat treatments may reduce heat-labile vitamins yet enhance microbiological safety (Kongsup *et al*., 2022; Hăbeanu *et al*., 2023). These sources of variability mandate standardised rearing and processing protocols when pupal material is proposed for food or pharmaceutical use.

Assessment of digestibility and nutritional equivalence to conventional animal proteins

Digestibility studies and protein-quality assessments indicate that eri pupal protein is highly bioavailable and often compares favourably with traditional animal proteins. *In vitro* and *in vivo* measures (protein digestibility, PDCAAS/NPU proxies) show good digestibility and an essential amino-acid balance that supports nutritional claims for complementary feeding and feed replacement, although values vary with processing and defatting (Longvah *et al*., 2011; Kongsup *et al*., 2022). Feeding trials in poultry and aquaculture demonstrate that 5–15% inclusion of pupal meal can safely substitute a portion of conventional protein feeds (soybean meal or fishmeal) without compromising growth performance, and sometimes with improved carcass or product quality (Kongsup *et al*., 2022). Nonetheless, controlled human clinical data are limited; therefore, translating *in vitro* and animal-model findings into validated dietary recommendations for humans will require targeted clinical and safety studies.

Bioactive compounds and its mechanisms

Eri silkworm (*Samia ricini*) pupae harbour a concentrated set of bioactive constituents that span peptide fractions, polyunsaturated fatty acids (PUFAs), low-molecular phenolics/flavonoids and chitin-derived polymers (chitosan). Hydrolysates and peptide fractions from pupal proteins contain antioxidant and ACE-inhibitory peptides that scavenge free radicals and modulate key enzymes. Lipid fractions are rich in PUFAs (notably linoleic and α-linolenic acids) and contain tocopherols and sterols that contribute antioxidant and cholesterol-modulating potential. The pupal cuticle and shell are a practical source of chitin and chitosan, which combine structural, antimicrobial and biofunctional properties useful in food and biomedical formulations (Zhou *et al*., 2022; Chukiatsiri *et al*., 2024; Hăbeanu *et al*., 2023).

Biochemically mechanistic insights, suggest that these compounds act through a small set of well-characterised pathways. Antioxidant peptides neutralise free radicals directly and upregulate cellular antioxidant systems (e.g., increased activities of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx)) while lowering lipid peroxidation markers. PUFAs and phytosterols modulate lipid metabolism via effects on hepatic lipid handling and regulatory transcription factors, producing hypolipidaemic outcomes in animal models. Chitosan exerts antimicrobial action through electrostatic interactions with microbial cell envelopes and can enhance wound healing and barrier functions when formulated as films or hydrogels. Phenolic constituents contribute further antioxidant and anti-inflammatory effects through inhibition of pro-inflammatory mediators (e.g., cyclooxygenase [COX], inducible nitric oxide synthase [iNOS]) and suppression of nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) signalling in cell models (Chukiatsiri *et al*., 2024; Zhou *et al*., 2022; Sinha and Choudhury, 2025).

Evidence supporting this has been demonstrated through both *in vitro* and *in vivo* models. *In vitro* work has isolated and characterised antioxidant peptides from silkworm pupae hydrolysates showing DPPH/ABTS scavenging, FRAP activity and cellular ROS attenuation (Chukiatsiri *et al*., 2024; Cermeno *et al*., 2022). *In vivo* studies demonstrate that pupal protein fractions or peptide preparations reduce oxidative stress and inflammatory responses in rodent models (improved enzyme markers, reduced edema and lowered MDA), and topical/supplement formulations have shown protective effects against skin photo-aging and hepatic oxidative injury (Lin *et al*., 2024; Sinha and Choudhury, 2025; Zhou *et al*., 2022). Antimicrobial and antipathogen activity are supported by studies of plasma and chitosan extracts that inhibit bacterial growth *in vitro* and improve infection outcomes in insect infection models; chitosan derived from pupae shows promising activity as an antimicrobial coating in food-preservation assays (Mastore *et al*., 2021; Sagala *et al*., 2024; Hegde and Selvaraj, 2024). Collectively, these data indicate multi-modal bioactivity but also highlight variable potency depending on extraction, fractionation and processing conditions.

Eri pupae provide a rich mix of bioactives such as peptides, polyunsaturated fatty acids, phenolics, and chitosan that act through antioxidant, anti-inflammatory, antimicrobial, and hypolipidemic pathways. While preclinical studies demonstrate strong biological activity, the evidence remains inconsistent. Advancing their use in nutraceuticals and pharmaceuticals will require standardised extraction methods, dose–response evaluations, safety assessments, and clinical validation (Zhou *et al*., 2022; Beniwal *et al*., 2024). The interrelated mechanisms through which peptides, polyunsaturated fatty acids (PUFAs), chitosan, and phenolic compounds from *Samia ricini* pupae exert antioxidant, antimicrobial, lipid-regulatory, and anti-inflammatory effects Figure 1.

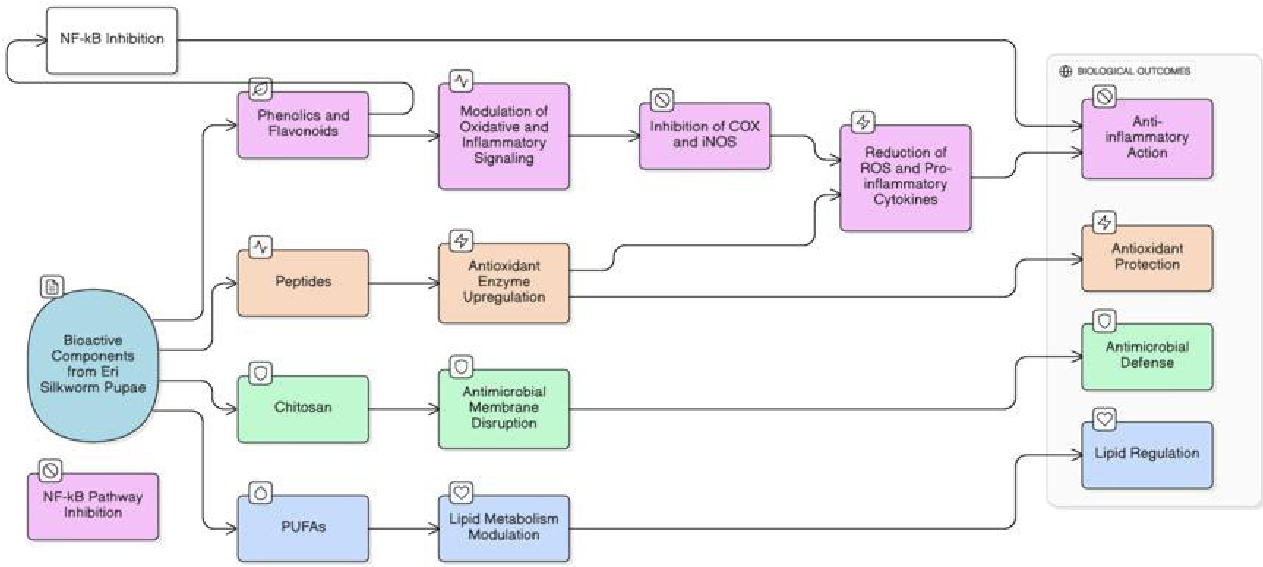

Fig. 1. Bioactivity of eri silkworm pupae.

NUTRITIONAL AND FUNCTIONAL FOOD APPLICATIONS

Eri silkworm (*Samia ricini*) pupae can be processed into several value-added ingredients such as defatted protein powder (pupal meal), pupal oil, and targeted peptide or hydrolysate extracts. These formats are optimized to meet distinct formulation objectives. Protein powders provide concentrated amino acids and functional technofunctional properties (water-holding, emulsification) useful for fortification; oils supply PUFA-rich lipids and fat-soluble antioxidants for nutraceutical use; enzymatic hydrolysates yield antioxidative and bioactive peptides that can be incorporated into supplements or functional beverages (Rodríguez-Ortiz *et al*., 2024; Zhou *et al*., 2022). Recent compositional studies report that defatted *S. ricini* pupae contain ~72–78% crude protein, while whole pupae typically contain 40–55% protein and 25–32% lipids, enabling their use as a concentrated nutrient source in food and feed matrices (Longvah *et al*., 2011; Ray and Gangopadhyay, 2021). The main processing routes and practical food and feed applications of eri silkworm pupae are illustrated in Figure 2.

Practical applications demonstrated fortification of bakery products, spreads and pasta, and partial replacement of conventional proteins in feed formulations. Fortified bakery goods and ready-to-eat pastas with silkworm pupae show higher protein content and acceptable taste at 15–20% inclusion levels. Quantitative sensory trials show that incorporating 10–15% pupae powder increases protein content by 18–30% in bread and spreads, while maintaining hedonic scores above 6.5/9 on consumer panels (Karnjanapratum *et al*., 2022; Piazza *et al*., 2023; David-Birman *et al*., 2022).

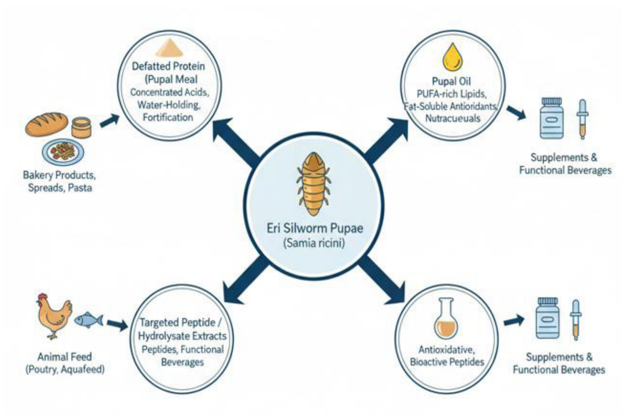

Fig. 2. Nutritional and functional food applications of eri silkworm pupae.

For animal feed, studies on eri pupal meal show promising performance as a partial substitute for fishmeal or soybean meal. Inclusion of 4–8% *S. ricini* pupae in broiler diets supported growth rates comparable to conventional diets, with feed-conversion ratios (FCR) remaining within optimal ranges (1.7–1.9) and no adverse physiological effects. Aquaculture trials have similarly shown that replacing up to 25% fishmeal with fermented pupal meal maintains growth performance and protein efficiency ratio (PER) in carp and tilapia species (Kongsup *et al*., 2022; Bora *et al*., 2025).

Safety, processing and regulatory challenges must be addressed before broad food use. Key issues include allergenicity (cross-reactivity with crustacean/house-dust-mite allergens), microbial safety, heavy-metal monitoring, and standardisation of processing (defatting, heat-treatment, drying) to control lipid oxidation and off-flavours (Herman *et al*., 2022; Hăbeanu *et al*., 2023). Techniques like defatting, enzymatic hydrolysis, and microencapsulation help improve taste and stability, though they raise production costs (Herman *et al*., 2022; Rodríguez-Ortiz *et al*., 2024). Regulatory status also varies regionally, and consumer acceptance remains a major barrier that is eased when insect ingredients are presented as powders or incorporated into familiar products (Okaiyeto *et al*., 2024; Zhou *et al*., 2022). Controlled sensory studies confirm that pupae-fortified cookies retain acceptability at ≤10% inclusion, while pasta fortified at 15% achieves a 25–28% rise in protein content and maintains favourable texture scores when drying and extrusion parameters are optimized (Piazza *et al*., 2023; Akande *et al*., 2020).

Sensory and nutritional studies demonstrates that low-level fortification with pupae powder significantly increases protein, lipid, and micronutrient content, while retaining acceptable sensory quality when flavour and textural parameters are properly optimised. Silkworm-fortified spreads and cookies retained consumer acceptability at low–moderate inclusion levels and improved protein density; similar findings appear for pasta and other staple matrices, where nutritional gains are clear but product optimisation is essential to avoid bitterness or oiliness (Karnjanapratum *et al*., 2022; Akande *et al*., 2020; David-Birman *et al*., 2022). These studies show the technical feasibility of using pupal ingredients in human foods, and they support stepped approaches to product development such as starting with low inclusion levels, masking off-notes, and ensuring proper labelling and safety testing (Karnjanapratum *et al*., 2022; David-Birman *et al*., 2022; Piazza *et al*., 2023).

PHARMACEUTICAL AND BIOMEDICAL PROSPECTS

Eri silkworm (*Samia ricini*) pupae and their derivatives (oil, protein fractions, sericin and chitin/chitosan) have attracted growing attention as sources of pharmacologically active materials with applications that span antioxidant therapy, lipid-modulating nutraceuticals, wound care, immune modulation and metabolic health. Recent studies collectively portray pupal biomass as a multifunctional, low-cost feedstock for developing bioactive extracts and biomaterials for both topical and systemic uses (Zhou *et al*., 2022; Sadat *et al*., 2022; Beniwal *et al*., 2024). Recent research provides quantitative evidence that these bioactive fractions can modulate oxidative stress, inflammatory pathways, tissue regeneration, and metabolic biomarkers.

Antioxidant and hypolipidemic activities

Pupal oil and protein extracts reduce oxidative stress markers and improve lipid profiles in preclinical models. Supplementation with silkworm pupal oil improved serum lipid parameters and lowered markers of oxidative damage in hypercholesterolaemic rats (Zou *et al*., 2017). Oil extraction studies report high contents of α-linolenic and other PUFAs plus tocopherols, which plausibly underlie these effects (Tangsanthatkun *et al*., 2022). Proteolytic hydrolysates or peptide fractions from pupal proteins also demonstrate *in vitro* antioxidant activity and, in some *in vivo* rodent models, reduce lipid peroxidation and improve hepatic oxidative markers (Sinha and Choudhury, 2025; Tangsanthatkun *et al*., 2022).

Wound healing, sericin and biomaterials

Chitosan derived from pupal cuticle are actively explored for wound dressings, barrier films and tissue engineering scaffolds (Li *et al*., 2023; Endrawati *et al*., 2023). Chitosan isolated from silkworm pupae shows antimicrobial action and can be formulated into films or coatings suitable for wound care and controlled-release matrices; recent reviews on chitosan biomaterials summarise its value as a drug-carrier and tissue-engineering polymer (Wang *et al*., 2023; Sagala *et al*., 2024).

Immune modulation and metabolic effects (including anti-diabetic signals)

Preclinical data indicate immunomodulatory and anti-inflammatory actions from pupal protein preparations and modified derivatives. Arginine-modified silkworm-derived formulations demonstrated protective effects on intestinal inflammation *in vivo,* suggesting modulatory effects on mucosal immunity (Yuan *et al*., 2025). Protein hydrolysates/peptides have shown inhibition of carbohydrate-digesting enzymes (α-amylase), antioxidant-driven reductions in inflammatory markers and improvements in experimental models of inflammation and metabolic stress, supporting exploration of pupal extracts as adjuncts for metabolic health (Sinha and Choudhury, 2025; Sadat *et al*., 2022). Quantitative assays show that pupal peptide extracts inhibit α-amylase activity by 41–55%, while reducing TNF-α and IL-6 levels by up to 30% in inflammation-induced rodents (Sinha and Choudhury, 2025).

Table III. Industrial and pharmaceutical applications of eri silkworm (*Samia ricini*) pupae and their derivatives.

Derivative/ Component	Application area	Key function	Representative evidence	References
Pupal oil	Nutraceuticals, functional foods	Antioxidant and lipid-lowering effects	Improved lipid profile and reduced oxidative stress	Zou *et al.* (2017); Tangsanthatkun *et al.* (2022)
Protein hydrolysates/ peptides	Functional foods, nutraceuticals	Antioxidant and ACE-inhibitory activity	Enhanced antioxidant status and enzyme inhibition	Zhou *et al.* (2022); Sinha and Choudhury (2025); Sadat *et al.* (2022)
Defatted pupal meal	Animal feed	Sustainable protein source	Maintained growth and feed efficiency	Kongsup *et al.* (2022); Bora *et al.* (2025)
Sericin	Wound healing, cosmetics	Moisturising and healing properties	Promoted fibroblast growth and wound closure	Li *et al.* (2023); Endrawati *et al.* (2023)
Chitin / Chitosan	Biomedical and packaging uses	Antimicrobial and biocompatible	Inhibited bacterial growth and supported tissue repair	Wang *et al.* (2023); Sagala *et al.* (2024); Beniwal *et al.* (2024)
Pupal oil or peptide encapsulates	Delivery systems	Improved stability and bioavailability	Enhanced oxidative stability and sensory quality	Rodríguez-Ortiz *et al.* (2024); Hăbeanu *et al.* (2023)
Protein hydrolysates (modified)	Metabolic and immune health	Anti-diabetic and anti-inflammatory	Inhibited α-amylase and reduced gut inflammation	Yuan *et al.* (2025); Sinha and Choudhury (2025)
Sericin–chitosan composites	Biomaterials	Drug delivery and scaffold formation	Supported controlled release and cell growth	Wang *et al.* (2023); Beniwal *et al.* (2024)

Applications in drug delivery and nutraceutical formulations

The combined presence of functional proteins, lipids and polysaccharides makes pupal biomass a flexible feedstock for nutraceuticals and delivery systems. Encapsulation of pupal oil or peptides to stabilise PUFAs and mask flavour, and development of chitosan-based nanoparticles or films for controlled release of antimicrobials or growth factors (Wang *et al.*, 2023; Beniwal *et al.*, 2024). These emerging platforms demonstrate that pupal oil microcapsules enhanced oxidative stability, while chitosan nanoparticles enabled sustained-release delivery of therapeutic compounds. Encapsulation studies show that microencapsulated pupal oil increases PUFA stability by nearly 45% during storage, while chitosan nanoparticles provide controlled-release profiles extending up to 72 hours (Tangsanthatkun *et al.*, 2022; Wang *et al.*, 2023). The industrial and pharmaceutical applications derived from eri silkworm pupae and their components is summarised in Table III.

Current evidence highlights diverse pharmacological potentials of eri silkworm pupal derivatives, including antioxidant and hypolipidemic effects from pupal oil, enzyme-inhibitory and anti-inflammatory activities from protein-derived peptides, and antimicrobial and wound-healing properties from sericin- and chitosan-based biomaterials. Emerging studies also indicate immunomodulatory potential in modified pupal formulations (Zou *et al.*, 2017; Tangsanthatkun *et al.*, 2022; Li *et al.*, 2023; Sinha and Choudhury, 2025; Yuan *et al.*, 2025). Despite these promising findings, existing data remain inconsistent due to variations in extraction techniques, dosages, and experimental endpoints. Standardised extraction protocols, dose–response validation, and rigorous toxicity assessments are required before clinical translation.

FUTURE PERSPECTIVES

Eri (*Samia ricini*) pupae should focus on standardizing processing and compositional profiling to ensure reproducibility across different rearing systems and environmental conditions (Rodríguez-Ortiz *et al.*, 2024; Liang *et al.*, 2024). Although current findings highlight their nutritional and pharmacological value, more work is needed to address safety concerns, allergenicity, and regulatory validation for food and pharmaceutical applications (Gao *et al.*, 2018). Integrating multi-omics tools such as proteomics and metabolomics could uncover key bioactive markers and optimize production through selective breeding or feed modification (Ma *et al.*, 2023; Hăbeanu *et al.*, 2023). At the same time, bioprocess engineering approaches like enzymatic hydrolysis, fermentation, and encapsulation can improve the functional stability and bioavailability of eri pupal extracts (Lisboa *et al.*, 2024; Liang *et al.*, 2024). Future advancements in drug delivery technologies, biomaterial development, and nutraceutical design are expected to elevate eri pupae to a high-value, sustainable bioresource with diverse applications that reach well beyond the boundaries of traditional sericulture.

CONCLUSION

Eri silkworm (*Samia ricini*) pupae are a nutrient- and bioactive-rich, underutilized resource with significant pharmacological potential. They offer high-quality proteins, essential fatty acids, and compounds supporting antioxidant, hypolipidemic, anti-inflammatory, and wound-healing activities, making them promising candidates for functional foods, nutraceuticals, and biomedical applications. Industrial and clinical translation is constrained by inconsistent composition, lack of standardized extraction, and limited toxicological data. Integrating omics technologies, optimized bioprocessing, clinical evaluation, and regulatory frameworks will be key to unlocking their value as a sustainable bioresource for nutrition, healthcare, and the circular bioeconomy.

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