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Lac insect *(Kerria lacca)*: Driving sustainable bioeconomic growth through multifaceted applications including pharmaceuticals and cosmetics

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Abstract
Lac insects, primarily *Kerria lacca*, are small, scale insects known for their ability to produce lac, a resinous secretion of significant economic and industrial value. The lac resin, traditionally used in varnishes, sealants, and dyes, has emerged as a sustainable resource for a diverse range of applications, establishing its role in the bio-economy. Beyond traditional uses, lac derivatives exhibit remarkable potential in cosmetics and pharmaceuticals, where their biocompatibility, film-forming properties are highly desired. In the cosmetics sector, lac-based formulations are utilized for hair care, skin care products and nail lacquers, offering natural alternatives to synthetic counterparts. In pharmaceuticals, lac resin serves as an excipient for drug delivery systems, coatings for pills, and encapsulation of bioactive compounds, enhancing stability and controlled release. The natural origin of lac, combined with its biodegradability and safety profile, supports the growing demand for eco-friendly materials in these industries. Lac insects highlight the symbiotic relationship between biodiversity and industrial progress, encouraging a green economy. This review explores the biology and cultivation of lac insects, emphasizing sustainable harvesting practices and their contribution to rural livelihoods, particularly in India. It also examines the chemical composition and properties of lac resin, highlighting its versatility and innovative applications in health and wellness. This article aims to provide a comprehensive understanding of Lac insects' multifaceted role in the bio-economy and their potential to drive sustainable innovation.

Keywords: Lac insects (*Kerria lacca)*, Lac resin, bio-economy, cosmetics, bioresource pharmaceuticals

Introduction
The term "lac" is believed to be originated from the Sanskrit word "laksha", which means "a Lakh," reflecting the huge number of Lac insects required for the production of Lac resin. The "Atharva Veda" quotes references to the Lac insect and the host plant, "*Butea monosperma*" (Lakshataru). Mahabharata narrates the creation of the Lakhshagriha (Lac House) by the Kauravas. Lac insects, particularly *Kerria lacca*, are a critical natural resource known for producing lac resin, a biodegradable and sustainable material with extensive industrial applications. Traditionally utilized in varnishes, dyes, and adhesives, lac has evolved into a valuable asset in the bio-economy due to its natural origin, eco-friendliness, and versatile properties (Bashir NK *et.al*, 2022) [4]. The biology of Lac insects involves a fascinating lifecycle where resin is secreted to form protective encrustations. Females are the primary producers, with resin glands covering their bodies except near the mouth and spiracles. This process sustains the insect population while enabling significant resin yield (Mohanta *et.al.*, 2013) [10]. India leads in global lac production, contributing 55-65% of the total world's supply. States such as Jharkhand, Chhattisgarh, and Bihar are the hubs of this eco-friendly industry, which also supports the livelihoods of rural population (Anmol *et.al,* 2021& Sharma KK, 2023) [2,18].

Female *Kerria lacca* | Female *Kerria lacca* | Male *Kerria lacca*

Pictures from book *Indian Insect Life: A Manual of the Insects of the Plains* by Harold Maxwell-Lefroy

Lac tubes from *Kerria lacca*, secreted by insects, deposited on host plant branches (Pictures from Natural Dye House, Tamil Nadu) https://www.naturaldyehouse.com/lac

Lac-based products offer natural alternatives to synthetic ingredients in cosmetics, particularly in nail polishes, skincare, and hair care formulations. (Rybczyńska-Tkaczyk K *et.al*, 2023) [15]. The film-forming and antimicrobial properties of lac resin make it highly desirable in these industries. Other pharmaceutical applications include its use as a pill-coating agent and an excipient in sustained/controlled release drug delivery systems. Recent advancements highlight its potential in encapsulating bioactive compounds for enhancing controlled release and improving bioavailability (Zabot GL et.al, 2022) [23]. Lac cultivation also plays a significant socio-economic role by providing a source of income to rural communities and promoting biodiversity conservation. However, challenges such as pest infestations, theft and the mortality of insects due to climatic variations persist. Addressing these issues through genetic improvements can make the way for a more sustainable industries (Kewal Krishan Sharma *et.al*. 2023) [8].

This article focuses on the diverse role of lac insects in the bio-economy, highlighting their applications, addressing the challenges, and emphasising their contributions to global sustainable development.

Materials and methods

This study was conducted a comprehensive review of scientific literature and technical reports to gather information on Lac insects (*Kerria lacca*) and their resin products. Key databases such as Scopus, PubMed and Google Scholar were searched using keywords like "Lac insects," "bio-economy," "applications of lac resin," "chemical composition of lac resin," "socio-economic importance of lac," and "cosmetic and pharmaceutical applications of lac," along with related terms. Peer-reviewed articles published up to 2024, focusing on cultivation, socio-economic impact, biology, and applications, were included. Additionally, reports from agricultural extension services in India were examined to highlight regional contributions to global lac production. Statistical data on production trends and economic impact were sourced from websites of Trading Economics and Institutions like the Indian Institute of Natural Resins and Gums (IINRG). Future directions were proposed based on recent advancements in the bio-economy and sustainability goals outlined in policy frameworks.

Results and discussion

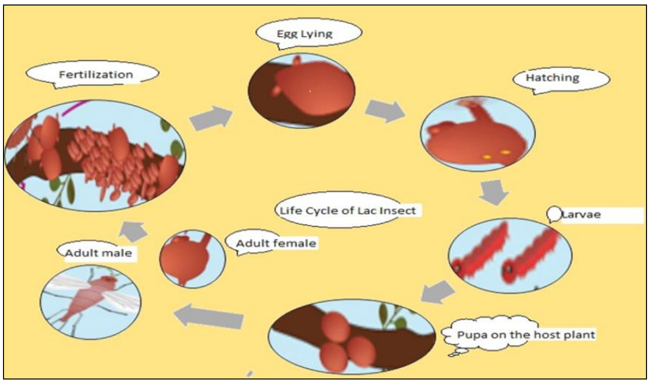
Lac insects in bioeconomy

Lac insects (Kerria lacca and related species) have become significant contributors to the bioeconomy, renowned for producing lac resin—a versatile natural product with broad applications across various industries. *Kerria lacca* (family: Kerriidae), is one of the variety of scale insects known for their resin secretion used in shellac production. They belong to the order Hemiptera and suborder Sternorrhyncha (Ayashaa Ahmad *et.al*., 2012) [3]. These insects exhibit sexual dimorphism (males and females playing distinct roles). Females secrete lac resin while males are non-resin-producing. (Bashir NH *et.al*., 2022) [4]. India Exports of lac, gums, resins was US$956.87 Million during 2023, according to the United Nations COMTRADE database on international trade (Web site; India Exports of lac, gums, resins, Trading Economics) [7]. Lac cultivation received the status of agriculture in the state of Jharkhand on 17th April 2023.

Production of Lac, geographical distribution and contribution of India: India leads in lac production contributing around 80% annually. Lac insects can be referred as a glory of India's insect fauna. More than 400 lac hosts plants are reported globally. In India Ber, Palas (Palash) and Kusum are the common hosts for the commercial production of Lac. These trees are mostly found in Chhattisgarh, Madhya Pradesh, Jharkhand, Maharashtra and West Bengal. East, South and South east countries are also among the contributors in lac production (Pratibha bhatnagar *et.al*., 2022) [14].

Biology and life cycle of lac insects: Lac insects are obligate phloem sap suckers, completing their life cycle on host plants. They exhibit gender-specific roles, with females being productive for resin secretion. Their unique biology and host preferences contribute to local diversity and ecological relations (Kewal Krishan Sharma *et.al*, 2023) [8]. The lifecycle includes egg, nymph and adult stages, with variations depending on climate and region. The life cycle of *Kerria lacca*, consists various key stages that significantly influence the production of lac resin. Understanding these stages is vital for improving lac cultivation and enhancing resin yield. In egg stage, female lac insects lay 160-307 eggs, depending on the generation, with a highest number in the first generation. In Nymph stage**,** the larvae, after hatching, exhibit crowded behaviour and settle on suitable host plants. On the host plants, they start to feed on phloem sap. Their survival and growth are influenced by conditions of host plant and environment. In adult stage, females secrete lac resin with production hitting in the first generation. The lifespan of adults varies; males live for 2-3 days, while females can live between 62-148 days (Mohanta *et al*., 2013) [11].

Life Cycle of *Kerria lacca*



- **Sustainable lac cultivation for environmental benefits:**
  Adopting sustainable lac cultivation practices offers significant environmental benefits, primarily through biodiversity conservation and ecosystem stability. Lac cultivation supports a complex ecosystem that includes various flora and fauna, which are essential for maintaining ecological balance.

- **Biodiversity conservation:** Lac cultivation promotes the preservation of over 400 plant species that serve as host plants for lac insects, which are crucial for maintaining biodiversity. The ecosystem associated with lac insects includes numerous species of predators, parasites, and microorganisms, contributing to a rich biodiversity that is threatened by habitat destruction (Kewal Krishan Sharma*et al*., 2006) [9].

- **Forest conservation:** Sustainable lac practices help to conserve forest areas, preventing deforestation and habitat loss, which are critical for numerous species' survival. By maintaining the natural vegetation involved in lac cultivation, these practices can restore the ecological importance of host plants, countering the trend of indiscriminate cutting for firewood (Biplob Modak & Basu, 2011) [5].

- **Soil health and carbon sequestration:** Sustainable agricultural methods, including those used in lac cultivation, enhance soil health by reducing erosion and increasing organic matter, which in turn improves nutrient supply and moisture retention. These practices also contribute to carbon sequestration, helping mitigate climate change impacts (Amir Kassam & Brammer, 2013) [1].

Cultivation of lac insects

Cultivating lac insects, specifically *Kerria lacca*, involves a series of well-defined practices that ensure optimal growth and resin production. This process is crucial for various industries, particularly in India, where lac cultivation significantly contributes to the economy and provides livelihoods for many farmers. The key steps are given below;

- **Host plant selection and maintenance:** Lac insects thrive on over 400 species of host plants, including Palas, Kusum, and Flemingia (Sharma, 2017) [16]. Proper selection and maintenance of these host trees are essential for encouraging the growth and reproduction of lac insects (Pragati B Patil *et al*., 2024) [12].

- **Cultivation techniques:** Key practices include pruning host plants, inoculating them with lac insect larvae, and managing environmental conditions to promote healthy growth. Farmers utilize traditional tools such as secateurs and sickles for manual operations, which may require modernization for efficiency (Lalita, 2020) [10].

- **Harvesting and processing:** Harvesting involves removing the lac resin from the host plants, followed by scraping and processing to refine the resin into commercially viable products. (Sharma, 2017) [16].

Processed products of lac

Lac, a natural resin undergoes various processing steps to produce numerous valuable products. These processed lac products have applications in industries such as food, cosmetics, pharmaceuticals, and more. Below are the key processed products of lac

- **Seed lac:** Seed lac is the raw lac that has been crushed and sieved to remove impurities like insect parts and twigs. Processing involves washing and drying the raw stick lac to obtain a granular form. This is used in the manufacturing of shellac

- **Shellac:** Shellac is a purified form of lac resin obtained after melting, filtering, and molding seed lac**.** It is available in the form of flakes, powder, or liquid**.** It is used as a coating material in varnishes, wood finishes and polishes for furniture. In food industry it is used as a food-grade glaze for candies, fruits, and pills (designated as E904)**.** In cosmetics it is used in hair sprays, mascaras, and nail polishes**.** In pharmaceuticals it is used for coating tablets and capsules to make them enteric or delay-release**.**

- **Button lac:** A variety of shellac shaped into button-like discs, often created during the refining process**.** The molten resin is spread on a flat surface and cooled into button shapes. It is used in surface coatings and traditional crafts**.**

- **Bleached lac:** It is a decolorized form of shellac achieved through chemical bleaching processes**.** The natural orange color is removed using oxidizing agents like sodium hypochlorite**.** It is used in the food and pharmaceutical industries for coating applications and in cosmetic applications where colorless lac is preferred**.**

- **Lac dye:** It is a natural dye extracted from lac resin**.** Dye extraction involves dissolving the lac in water or alcohol and separating the dye components**.** It is used in textiles to dye especially for silk and wool**.** Traditionally it was used in food colouring also.

- **Dewaxed lac:** It is a resin with its natural wax content removed. It is carried out through solvent extraction process. It is preferred in applications requiring a clearer finish, such as high-quality varnishes and food-grade coatings**.**

- **Aleuritic acid:** It is derivative of lac resin obtained through chemical hydrolysis**.** It is used as a raw material in the production of perfumes and other fine chemicals. It is also used in the synthesis of polymers and resins**.**

- **Lac waxes:** It is a natural wax component separated from lac resin**.** It is extracted during shellac production or purification processes. It is used in cosmetic formulations such as lipsticks and balms. It also has industrial applications like lubrication and polishes**.**

- **Garnet Lac:** It is a dark-colored form of shellac with a deep reddish-brown hue**.** It is often used in high-quality wood finishes and traditional crafts.

- **Stick Lac:** It is the unprocessed form of lac resin that is scraped from the branches of host trees. It is used as a raw material for producing seed lac and other derivatives (Chen Y, 2024

				
Seed Lac	Shellac	Button Lac	Stick Lac	Bleached Lac
				
Lac Dye	Garnet Lac	Dewaxed Lac	Lac waxes	Aleuritic acid

Industrial Applications of Lac obtained from Lac Insects including Pharmaceuticals and Cosmetics (Thombare N,2022; Wadia MS,1969; Yao X, 2024; Yuan Y, 2021; Zabot GL 2022) [19, 20, 21, 22, 23].

Industry	Application	Details
Food industry	Food glaze	Shellac is used as a natural coating (E904) for candies, chocolates, nuts, and fruits to provide a glossy finish and protect against moisture and spoilage.
	Food Packaging	Lac is used in the manufacturing of biodegradable coatings for food packaging to maintain freshness and reduce wastage.
	Dye	Lac dye, a natural red pigment, is used in traditional food coloring (though less common due to synthetic alternatives
Pharmaceuticals	Tablet and Capsule Coatings	Shellac is used as an enteric coating for tablets and capsules, protecting drugs from stomach acid and ensuring release in the intestine.
	Sustained Release Formulations	Provides delayed-release properties for pharmaceuticals, enabling controlled drug delivery
	Adhesive-Medical Applications	Lac resin serves as a natural adhesive in medical products like wound dressings and bandages
Cosmetics	Hair Spray	Shellac is a key ingredient in hair sprays, providing strong hold and shine
	Nail Polishes	Used as a natural film-forming agent in nail polishes for durability and gloss
	Lipsticks and Balms	Dewaxed lac and lac wax are used in formulations for smoothness, consistency and gloss
Woodwork and Furniture	Wood Polishes	Lac-based polishes are used for varnishing and finishing furniture, providing a durable and glossy protective layer.
	Sealers	Used to seal wood and protect it from moisture and damage**.**
Textile Industry	Dyeing	Lac dye is traditionally used for dyeing silk and wool, providing rich red and purple hues
	Printing	Used in fabric printing to create intricate designs with natural pigments
Electrical Industry	Insulating Material	Lac is used to insulate electrical components such as coils, transformers, and capacitors due to its excellent dielectric properties.
Leather Industry	Leather Finishes	Shellac is used as a finishing agent for leather products, enhancing their durability and gloss
Paints and Varnishes	Base Material	Lac serves as a natural resin in varnishes, providing a glossy finish and protection for painted surfaces.
Agriculture	Biodegradable Coatings	Used in protective coatings for seeds and slow-release fertilizers to improve germination and nutrient delivery
Perfumery	Aleuritic Acid	Extracted from lac resin, aleuritic acid is a key component in the synthesis of musk-like fragrances in the perfume industry.
Traditional Crafts	Jewellery and Ornaments	Lac is used in making traditional bangles and other decorative items in regions like India
	Lacquer Ware	Utilized in the production of lacquered goods such as boxes, trays, bangles, toys and artistic crafts
Adhesives	Natural Adhesive	Used in making adhesive formulations for industrial and household applications

Chemical composition of lac: Lac resin contains 70-80% resin, sesquiterpenoic acids, hydroxy fatty acids and their polymers; aleuritic acid (9,10, 16-trihydroxy palmitic acid), shellolic acid, and other long-chain fatty acids which gives lac its characteristic gloss and hardness. Lac also contains 5 -6% wax composed of esters of fatty acids and long-chain alcohols which is responsible for providing flexibility and water resistance property to lac. Other important component is lac dye which comprises 1-2% resin. Dye is composed of red coloured natural anthraquinine derivatives, namely Laccaic acid A, B, C, and E which is used as natural dyes in textiles, cosmetics, and food industries. Other acids isolated are laksholic acid and jalaric acid. Other components are 6-7% protein (presence is from the insect body as an impurity, small amount of sugars derived from the sac of the plant ingested by the lac insect, inorganic salts including magnesium, potassium and calcium salts and 3-5% water. The composition of chemical components varies based on environmental conditions, processing methods and host plants. Resin is soluble in ethanol, ether and acetone; insoluble in water (Wadia MS *et.al*., 1969, Prasad N, 2014, Sharma K.K. *et.al*., 2020) [20, 13, 17].

Economic and environmental impact of culturing lac insects and lac resin production

- **Contribution to rural livelihoods and employment:** Lac resin production plays a pivotal role in improving rural livelihoods, particularly in developing regions where agriculture is the primary source of income. It provides income generation for small-scale farmers offering an additional source of revenue alongside traditional farming.

- **Employment opportunities:** The process of lac cultivation, harvesting, and processing involves labor-intensive steps, creating jobs for rural communities, including marginalized groups and women. Training in lac cultivation enhances technical know-how, enabling farmers to increase productivity and adopt sustainable practices**.**

- **Export potential, market dynamics and global demand:** Lac resin has significant export potential, contributing to national economies, particularly in countries like India, the largest producer of lac. Since Lac is used in a variety of industries, including cosmetics, pharmaceuticals, food coatings, and varnishes, ensuring its consistent demand. By developing high-value derivatives such as shellac and lac dyes, countries can enhance their export revenues. Price volatility in lac resin markets often creates demand-supply imbalances which can be stabilized through marketing strategies and trade agreements.

- **Role in sustainable agriculture and agroforestry:** Lac cultivation aligns with sustainable agricultural practices and contributes positively to the environment. Eco-Friendly Production methods (The cultivation of lac insects does not require chemical fertilizers or pesticides), results in no harm to the environment. Lac cultivation on host trees in agroforestry systems, promotes biodiversity, forest conservation, prevents soil erosion, and improves carbon sequestration.

- **Future prospects of lac production:** The growing demand for sustainable and biodegradable materials creates opportunities to diversify lac applications. Lac products can serve as eco-friendly alternatives to synthetic materials in industries like packaging, coatings, and adhesives, aligning with global sustainability goals. Researchers are exploring lac-based components for bioelectronics, including flexible circuits and sensors, leveraging lac's unique insulating properties. By expanding the range of lac derivatives, such as refined shellac and lac-based polymers, value-added products can be produced to cater to niche markets in high-performance coatings, luxury furniture, and artisan crafts. Lac dyes, being natural colorants, non-toxic and biodegradable, are increasingly favored in food, textiles, and cosmetics industries, replacing synthetic counterparts Integration into Modern Pharmaceuticals and Cosmetics Research. Lac resin and its derivatives have immense potential in the health and beauty sectors. Pharmaceutical applications includes production of sustained-release drug formulations, tablet coatings, capsule shells due to its film forming and moisture resistance. Lac-based ingredients are being incorporated into natural cosmetic formulations such as lipsticks, nail polishes, and skincare products, meeting the demand for clean-label beauty products. Research into bioactive components of lac resin may reveal antimicrobial, antioxidant, and wound-healing properties, opening new avenues for therapeutic uses. As industries seek biodegradable and renewable resources, lac resin serves as an excellent candidate for integration into green chemistry initiatives. Biotechnological innovations hold significant promise for enhancing lac resin production by addressing yield and quality challenges**.** Research on the genetic structure of lac insects could lead to the development of high-yielding and disease-resistant strains.

- **Challenges in lac production:** Major challenges include susceptibility to pest infestations, Climatic dependencies, leading to fluctuating yields and limited technological interventions in harvesting and processing.

Conclusion

The lac insect, *Kerria lacca*, is a sustainable resource driving the bio-economy with diverse applications in textile, varnishing, dying industries including, pharmaceuticals and cosmetics. Its cultivation supports rural livelihoods while promoting environmental sustainability through agroforestry and biodiversity conservation. Lac resin's unique properties, including biodegradability, non-toxicity, and film-forming capabilities, make it ideal for eco-friendly products. It is increasingly utilized in drug delivery systems and natural cosmetics, aligning with consumer-driven markets. Biotechnological advancements offer potential for higher yields, improved resin quality and novel applications. *Kerria lacca* exemplifies the fusion of tradition and innovation, fostering economic growth and environmental stewardship for a sustainable future.

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