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Cynips Gallae-Tinctoriae: An eco-friendly gall-inducing insect as a sustainable source of bioactive phytoconstituents

Marina Gladys D'Souza[1], Vivek V Byahatti[2], Shankar Yelmame[3], Srinivas Nandyala[4], Laxmikanth B Borse[4]
[1] Department of Pharmacognosy, Sandip Foundation's, Sandip Institute of Pharmaceutical Sciences, Mahiravani, Nashik, Maharashtra, India
[2] Department of Pharmacognosy, School of Pharmaceutical Sciences, Sandip University. Mahiravani, Nashik, Maharashtra, India
[3] Department of Pharmaceutical Chemistry, Sandip Foundation's, Sandip Institute of Pharmaceutical Sciences, Mahiravani, Nashik, Maharashtra, India
[4] Department of Pharmacology, Sandip Foundation's, Sandip Institute of Pharmaceutical Sciences, Mahiravani, Nashik, Maharashtra, India

Abstract
Cynips gallae-tinctoriae, a gall-inducing insect of the class Insecta and family Cynipidae, has emerged as a subject of growing interest due to the unique phytochemical-rich galls it forms on oak trees (*Quercus infectoria*). These galls are traditionally valued for their astringent, antimicrobial, antioxidant, and anti-inflammatory properties, finding widespread use in pharmaceutical, cosmetic and dye industries. This article explores the biological interactions between *C. gallae-tinctoriae* and its host plant, emphasizing the eco-friendly nature of gall formation as a natural process devoid of synthetic inputs. The galls are renewable, biodegradable, and can be sustainably harvested, aligning well with the principles of green chemistry and environmental conservation. The article also highlights the potential of these galls as a sustainable reservoir of tannins and other bioactive compounds, their market demand, and scope in modern phytopharmaceutical development. Furthermore, the paper examines the insect's role in biodiversity preservation and ecological balance, underscoring its importance in the future of sustainable drug discovery and environmentally responsible raw material sourcing.

Keywords: *Cynips gallae-tinctoriae*, galls, antimicrobial, antioxidant, anti-inflammatory, environment conservation

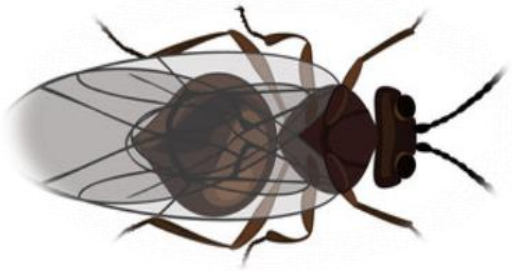
Introduction

Cynips gallae-tinctoriae (Olivier), a gall-inducing insect of the family Cynipidae, is well-known for forming galls on oak species, particularly *Quercus infectoria*. These galls, commonly called "gallnuts," have long been prized in traditional systems of medicine, dyeing, and leather tanning due to their high content of bioactive phytoconstituents, especially hydrolysable tannins and phenolic acids (Tataroğlu *et al*., 2023) [17]. The formation of galls by *C. gallae-tinctoriae* represents a complex plant-insect interaction in which the insect manipulates host tissues to form nutritive and protective structures for its larvae (Gätjens-Boniche, 2019) [6]. This natural biological process also results in the accumulation of secondary metabolites within the gall tissue (Huang *et al*., 2015) [8]. These include gallic acid, ellagic acid, and various other phenolic compounds, which have demonstrated significant antimicrobial, antioxidant, and anti-inflammatory effects (Bilek *et al*., 2022) [4].

Environmentally, the gall harvesting process is considered sustainable and eco-friendly. It is non-destructive to the host tree and does not involve synthetic inputs, making it a renewable, biodegradable, and green resource (Eroğlu, 2004) [5]. This alligns with the principles of green chemistry and sustainable harvesting (Tsai & Schmidt, 2017) [19]. The pharmaceutical and medical relevance of *C. gallae-tinctoriae* galls continues to gain attention due to their potential in drug development and formulation as natural antioxidants and antimicrobials (Giron *et al*., 2007) [7]. Ethnobotanical reports further highlight their applications in traditional remedies for dental, gastrointestinal, and skin conditions (Tooker & De Moraes, 2009) [18]. In addition to pharmaceutical uses, the high tannin content makes these galls valuable in natural dye and ink industries, providing an environmentally safer alternative to synthetic dyes. Studies also indicate that gall-induced tissues may exhibit altered physiological and biochemical profiles that offer insights into plant developmental biology and defence mechanisms (Nogueira *et al*., 2018) [13].

Given their ecological benefits, sustainability, medicinal and industrial applications, *C. gallae-tinctoriae* and its galls represent a valuable resource for future research, conservation, and industrial application. The integration of such natural and renewable sources into mainstream usage supports the broader goals of environmental conservation and sustainable development (Barker *et al*., 2018) [2].

Picture image of *Cynips gallae-tinctoriae*



Phoograph showing Oak galls produced by *Cynips gallae-tinctoriae* on Oak tree

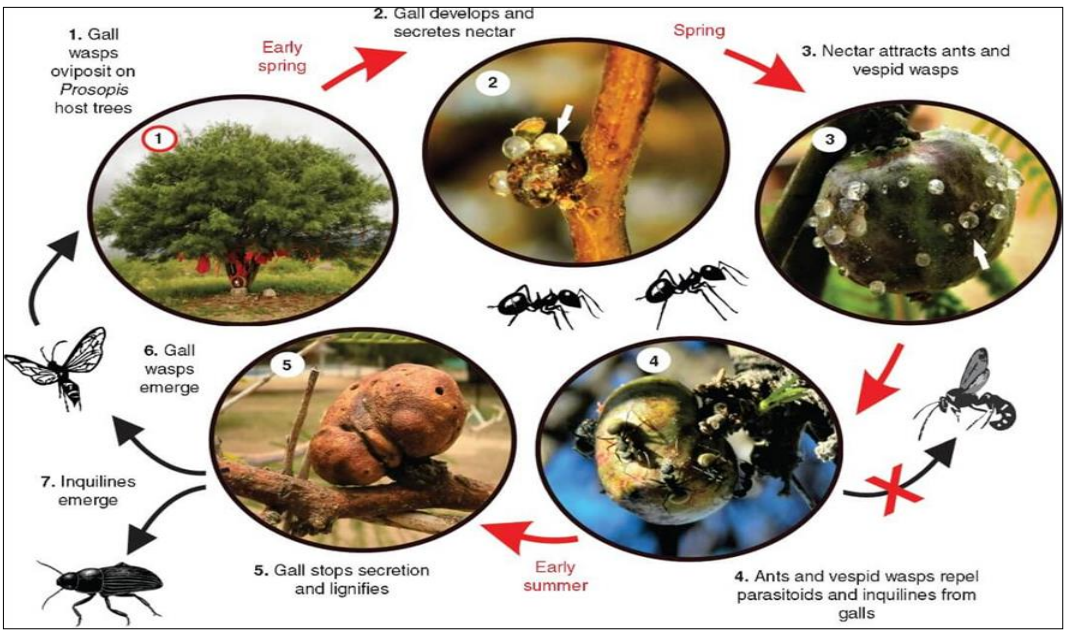
Oak galls produced by insect *C. gallae-tinctoriae*
References: https://stock.adobe.com/search?k=%22cynips+gallae+tinctoriae

Materials and methods

A systematic literature search was conducted using PubMed, Scopus, and Web of Science to gather data on the medicinal, industrial, environmental, and economic significance of gall-inducing insects, especially *C. gallae-tinctoria*

Results and Discussion

Mechanism of Gall Formation: *Cynips gallae-tinctoriae*, a gall wasp belonging to the family Cynipidae, initiates gall formation on the leaves and twigs of *Quercus infectoria* by laying its eggs into plant tissue. The oviposition process, along with secretions from the developing larva, triggers a cascade of physiological changes in the host plant. These changes involve modulation of plant hormone levels, particularly auxins and cytokinins, which lead to abnormal cell division and enlargement (Giron, 2007) [7]. The insect manipulates host gene expression to reprogram plant tissues into forming a nutritive and protective gall structure (Gätjens-Boniche, 2019) [6]. These galls provide food and shelter to the larvae while isolating them from environmental stress and natural enemies. The inner chamber of the gall becomes rich in nutrients and is surrounded by layers of dense tissue, which may also accumulate secondary metabolites as a plant defence response (Stone and Schönrogge, 2003; Nogueira, 2018) [16, 13]. Recent studies also indicate that insect salivary enzymes or effectors may interfere with plant signaling pathways, redirecting normal growth into gall morphogenesis. This insect–plant interaction represents a unique form of biological co-evolution and resource optimization (Tataroğlu, 2023) [17].



(Reference: https://i0.wp.com/botany.one/wpcontent/uploads/2017/12/GallWaspCycle.jpg?ssl=1)

Life cycle of *Cynips gallae-tinctoriae* and production of Galls

Phytoconstituent Profile: The galls formed by *Cynips gallae-tinctoriae* are known for their rich and diverse phytochemical composition. The most dominant group of compounds is hydrolysable tannins, which may constitute up to 50–70% of the gall's dry weight (Bilek et.al., 2022) [4]. Among these, gallic acid, ellagic acid, and methyl gallate are predominant. These compounds contribute significantly to the astringent and antioxidant nature of the galls. Other notable phytochemicals include flavonoids like quercetin and kaempferol, phenolic acids such as ferulic acid and caffeic acid, and small amounts of triterpenoids and organic acids (Huang et.al., 2015) [6]. These bioactive compounds offer multiple pharmacological benefits. Gallic acid is particularly known for its potent antioxidant, anti-inflammatory, and antimicrobial activities. Ellagic acid exhibits chemopreventive and hepatoprotective properties (Barker et.al., 2018) [2]. The synergistic effect of these phytochemicals contributes to the wide therapeutic relevance of gall extracts.

Medicinal Applications: *Cynips gallae-tinctoriae* galls have long been used in traditional medicine systems such as Ayurveda, Unani, and Persian medicine to treat diarrhea, dysentery, wounds, and oral infections due to their strong astringent and antimicrobial effects (Eroğlu, 2004) [5]. Modern studies validate their use, showing antibacterial, antifungal, antiviral, and wound-healing properties (Tsai et.al., 2017) [19]. Their extracts have shown effectiveness against pathogens like *Staphylococcus aureus*, *Candida albicans*, and *Helicobacter pylori*. Additionally, the antioxidant and anti-inflammatory activities of gall constituents make them promising in treating oxidative stress-related conditions (Giron *et.al*., 2007) [7].

Industrial and Commercial Applications: Due to their high tannin content, these galls are used as raw materials in the leather tanning industry and for natural dye production, particularly in the making of iron-gall ink—a historically important black-blue writing ink. The cosmetic industry utilizes gall extracts in tooth powders, anti-acne formulations, and anti-aging creams for their antimicrobial and antioxidant potential.

Environmental and Sustainable Relevance: Gall collection is non-destructive to the host plant, making it an environmentally friendly source of natural products. As they grow without the need for fertilizers or pesticides, gall-based products align with eco-friendly and sustainable harvesting practices. Moreover, the collection and trade of galls provide economic support to tribal and rural communities, especially in Turkey, India, and Iran.

Market Potential: The galls produced by *Cynips gallae-tinctoriae* have garnered increasing commercial interest owing to their high content of tannins and polyphenols, making them valuable raw materials in pharmaceutical, cosmetic, textile, and leather industries. Globally, the demand for natural tannin sources is on the rise due to a shift towards plant-based and eco-conscious formulations in health care and industrial applications (Kaya *et.al*., 2021) [10] In traditional medicine systems like Ayurveda, Siddha, and Unani, these galls are sold as crude drugs or in powdered form for their astringent and antimicrobial properties. The herbal pharmaceutical market utilizes gall extracts in products such as oral care preparations, antidiarrheal formulations, and skin protectants, contributing significantly to the growing phytopharmaceutical sector (Baskaran et.al., 2017) [3]. In the cosmetics sector, the incorporation of tannin-rich gall extracts in anti-aging, anti-acne, and antioxidant-rich creams reflects their commercial promise. These products cater to the increasing consumer demand for natural, preservative-free cosmetics (Kılıçarslan, 2023) [11]. From an industrial viewpoint, gall nuts remain an essential raw material for natural dye and ink production—notably iron-gall ink, which is regaining attention among heritage conservation experts and artists due to its historical significance and eco-compatibility (Vetter, 2019) [20]. Their application in leather tanning as a biodegradable and safer alternative to synthetic tannins has also attracted eco-label-certified brands and manufacturers (Siddiqui, 2020) Given their multipurpose utility and high-value phytochemical yield, *C. gallae-tinctoriae*-derived galls represent a sustainable economic opportunity for both local cultivators and commercial industries.

Environmental Impact: The use and cultivation of *Cynips gallae-tinctoriae* galls align well with environmentally sustainable practices. Unlike synthetic chemicals or monoculture crops, gall harvesting causes minimal ecological disruption as it does not require uprooting the host plant (*Quercus infectoria*) or intensive agricultural inputs (Akbulut, 2022) [1]. The galls naturally fall off or can be manually collected without damaging the plant, making it a renewable and non-destructive resource. Additionally, the absence of pesticide or fertilizer requirements during their growth significantly reduces the environmental footprint, promoting organic and low-impact harvesting systems (Karakoç et.al., 2021) [9]. The biodiversity associated with gall-forming insects and their host trees contributes to the ecological balance of forest ecosystems, enhancing pollinator diversity, supporting trophic networks, and improving microhabitat availability (Melika et.al., 2018) [12]. Cultivation and trade of galls can also support socio-ecological systems, particularly in rural and forested regions of India, Turkey, and Iran, where tribal and local communities depend on non-timber forest products for livelihood. This not only encourages resource conservation but also provides incentives for community-based forest management and biodiversity protection (Yazici, 2020) [21]. Furthermore, replacing environmentally damaging industrial materials with biodegradable gall-based compounds in pharmaceuticals and cosmetics can mitigate long-term pollution, helping industries transition toward green chemistry principles.

Applications, Market Potential, and Environmental Impact of *Cynips gallae-tinctoriae* induced Galls

Aspect	Sub-category	Details
Medicinal Applications	Antidiarrheal	Gall extracts are rich in tannins, which help in reducing intestinal inflammation and secretion, effectively controlling diarrhoea.
	Antimicrobial	Exhibits broad-spectrum activity against Gram-positive and Gram-negative bacteria due to polyphenols and tannins; effective in formulations for infections.

	Anti-inflammatory	Inhibits pro-inflammatory cytokines; used in topical preparations to reduce swelling and pain.
	Oral Ulcer Treatment	Astringent properties help reduce ulceration and promote tissue repair in oral mucosa; used in mouthwashes and dental powders.
	Wound Healing	Promotes tissue contraction and regeneration; used in creams and powders for minor cuts and wounds.
Industrial Applications	Natural Ink Production	Used historically and currently in archival ink production; reacts with iron salts to form durable black inks with historical importance.
	Natural Dye	Galls are used in dyeing textiles, especially for shades of brown and black; also, as mordants in eco-friendly dyeing processes.
	Leather Tanning	Rich in hydrolyzable tannins, essential in vegetable tanning processes to increase leather durability and flexibility.
	Corrosion-resistant Coatings	Tannin-based coatings derived from galls are being explored as eco-friendly, corrosion-inhibiting materials in metallurgy and marine applications.
Market Potential	Herbal Pharmaceuticals	Increasing use in herbal products such as antiseptics, astringents, creams, and dental care products; high relevance in Ayurveda and Unani systems.
	Natural Cosmetics	Used in face packs, scrubs, and anti-acne treatments; valued for astringency and skin-tightening effects.
	Export Value	High-value export commodity, especially to countries in the Middle East, Southeast Asia, and Europe due to traditional and cosmetic uses.
	Economic Impact	Promotes local employment and trade; considered a valuable non-timber forest product for tribal and rural communities.
Environmental Impact	Biodegradability	Natural, non-toxic, and biodegradable material, making it environmentally safe across multiple industries.
	Low Input Farming	Does not require fertilizers or pesticides; gall production is a result of insect-plant interaction requiring minimal human intervention.
	Non-destructive Harvesting	Harvesting galls does not harm oak trees significantly, promoting sustainable collection practices.
	Biodiversity Support	Gall-inducing insects contribute to ecological diversity; the oak ecosystems supporting gall formation host multiple insect and bird species (Raman A et.al., 2020, Siddiqui MA et.al.,) [14, 15].
	Tribal Livelihood Support	Collection and trade of galls is a source of income for forest-dwelling and tribal populations, contributing to social sustainability.

Results and Discussion

The insect *Cynips gallae-tinctoriae* is a gall-inducing wasp that forms characteristic galls on *Quercus infectoria*, significantly enriching the host plant with medicinally valuable phytoconstituents. These insect-induced galls result from oviposition, which triggers localized plant tissue proliferation and differentiation. Phytochemical profiling reveals a high concentration of bioactive compounds such as gallic acid, tannic acid, methyl gallate, ellagic acid, and pentagalloyl glucose. These compounds exhibit potent antimicrobial, anti-inflammatory, and antioxidant properties, validating their long-standing use in traditional medicine. The medicinal and industrial applications of these galls are well documented. Traditionally, they are used to manage wounds, gastrointestinal issues, and infections. Industrially, due to their high tannin content, they are valuable in dyeing, ink production, and leather tanning. Ecologically, this insect supports biodiversity by creating microhabitats for various organisms and plays a vital role in forest ecosystems. Environmentally, gall harvesting is sustainable, with low ecological disturbance. The market potential is notable, with increasing demand for natural and plant-based products, particularly in herbal medicine and cosmetics. The insect contributes to rural economies through the sustainable trade of galls

Conclusion

Cynips gallae-tinctoriae represents a fascinating convergence of insect-plant symbiosis, sustainability, and phytochemical richness. Its galls are an invaluable source of bioactive constituents with wide-ranging pharmaceutical and industrial applications. Environmentally, it supports low-input, non-destructive resource harvesting while preserving forest biodiversity. Economically, it offers livelihood potential for rural communities and serves as a sustainable source of raw material in the global herbal market. Given the current emphasis on eco-friendly bioproducts, further exploration into the cultivation and standardization of gall-based formulations is highly recommended.

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