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Cochineal insects (*Dactylopius coccus*) in cosmetics: An overview of taxonomy, composition, extraction methods, applications, and regulatory perspectives

Sanket R Vakte*, Chinmay P Sonawane, Krupa V Saraf, Shraddha M Kashmire, Jitendra Y Nehete
Department of Pharmacognosy, Mahatma Gandhi Vidyamandir's Pharmacy College, Panchavati, Nashik, Maharashtra, India

Abstract
Cochineal insects (*Dactylopius coccus*), esteemed for their capacity to create carminic acid, have long been utilized as a normal red color in different businesses, especially in beauty care products. Cochineal dye is prized for its dynamic, stable color, making it a favoured choice in lipsticks, blushes, and other beauty items. The extraction of carminic acid has advanced from conventional manual strategies to advanced, economical approaches, tending to environmental concerns. In expansion, the article looks at the regulatory scene encompassing the use of cochineal color, highlighting ethical considerations, especially in light of growing customer request for vegetarian and cruelty-free items. Future trends in research, counting elective sources and biotechnological advances, are discussed to investigate the advancing use of cochineal in the cosmetic industry. This review gives a comprehensive overview of the part of cochineal insects in the cosmetic industry, centering on their taxonomy, chemical composition, extraction methods, applications, and regulatory perspectives.

Keywords: *Dactylopius coccus*, taxonomy, composition, extraction, regulatory perspectives

Introduction

Cochineal insects (*Dactylopius coccus*), a species of scale insect local to tropical and subtropical regions, have been utilized for centuries to create a distinctive red color known as cochineal. This color, basically determined from carminic acid found in the insects' bodies, has been broadly utilized in textiles, food, and cosmetics due to its strongly color and relative steadiness. [1] As customer inclinations move towards common and economical fixings, cochineal color has experienced a resurgence, especially in the beauty care products industry. [2] It utilizes in lipsticks, becomes flushed, eyeshadows, and other corrective items requests to brands that prioritize eco-friendly and clean excellence arrangements. [3]

In any case, the developing application of cochineal color in beauty care products brings forward basic contemplations, such as the sustainability of its production, extraction methods, chemical composition, and safety concerns. [4] Regulatory bodies around the world have set guidelines to guarantee the safe use of cochineal color, and ethical talks about, especially with respect to its use in vegetarian and cruelty-free items, remain important. Understanding these components is fundamental for the proceeded success of cochineal color in the beauty industry. [5]

This review investigates the taxonomy, science, and cultivation of cochineal insects, the chemical composition of cochineal color, different extraction methods, and its applications in cosmetics. Furthermore, it addresses the regulatory and ethical considerations encompassing it utilize, concluding with a talk of future trends and research directions in this field.

1. Historical significance of cochineal dye

The use of cochineal color can be followed back to the ancient civilizations of Central and South America, especially the Aztecs and Mayans, who profoundly prized it for its strongly red color. Cochineal color was used in regal pieces of clothing, religious ceremonies, and craftsmanships. With the entry of Spanish conquistadors in the 16th century, cochineal got to be a profitable trade, rivaling gold and silver in its economic importance. [6]

During the colonial period, cochineal color got to be a noteworthy trade thing for Spain, as European request for high-quality red colors developed. It got to be a noticeable material for coloring textiles, counting textures used by the European first class and sovereignty. The request for cochineal too extended to other applications, counting food and beauty care products, stamping its worldwide reach. [7]

The historical importance of cochineal color is underscored by its long-standing use and its part as one of the most important natural colors before the coming of synthetic colors in the 19th century. In spite of the fact that its use disappeared with the presentation of synthetic colorants, cochineal has made a comeback in the present-day period due to its natural origin and customer request for sustainable items. [8]

2. Modern resurgence in the cosmetic industry

In recent years, there has been a outstanding resurgence of cochineal color in the cosmetic industry, driven by a move toward natural fixings and eco-conscious consumerism. The cosmetic industry has progressively looked for options to synthetic colors, numerous of which are petroleum-based and connected to natural and wellbeing concerns. Cochineal color, determined from a renewable natural source, fits inside the "clean beauty" movement, which emphasizes the use of non-toxic, cruelty-free, and sustainable products. [9]

The resurgence of cochineal color is moreover connected to the developing request for straightforwardness in cosmetic definitions. Customers are more learned and observing around the ingredients in their items, with a inclination for characteristic colorants over synthetic choices. Cochineal color, labeled as carmine (CI 75470) in cosmetic definitions, is considered secure by regulatory organizations like the FDA and EFSA, which assist contributes to its popularity. [10]

Additionally, cochineal dye's steadiness and dynamic red tone make it a favored choice for different cosmetic

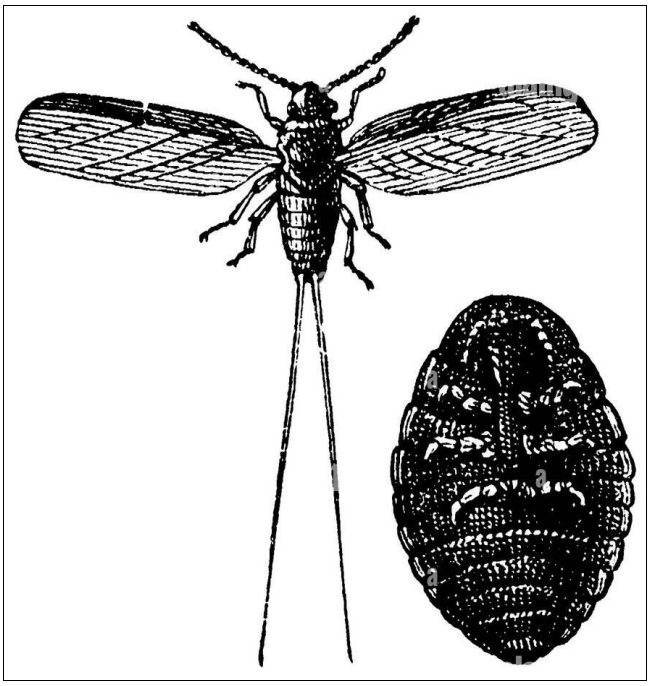
applications, counting lip items, blushes, eyeshadows, and nail polishes. Its compatibility with other normal fixings and its capacity to keep up color escalated beneath diverse natural conditions make it a flexible and profitable resource in defining high-quality, natural beauty care products. [11]

Taxonomy and biology of cochineal insects

Cochineal insects (*Dactylopius coccus*) are little, sap-sucking scale insects from the family Dactylopiidae. These insects are eminent for creating carminic acid, the essential compound capable for the dynamic red color known as cochineal, which has been utilized for centuries in different businesses, especially in beauty care products. Local to tropical and subtropical regions of the Americas, these insects are cultivated basically in Peru, Mexico, and the Canary Islands for commercial color production. [12]

1. Taxonomy of cochineal insects

Cochineal insects have a place to the order Hemiptera, family Dactylopiidae, and genus Dactylopius. Inside this genus, *Dactylopius coccus* is the most financially noteworthy species due to its capacity to create high yields of carminic acid.



(a) **(b)**

Fig 1: (a) Male & **(b)** Female *Dactylopius coccus*

The taxonomy of cochineal insects can be detailed as follows:

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Hexapoda
Class: Insecta
Infraclass: Neoptera
Subclass: Pterygota
Order: Hemiptera
Suborder: Sternorrhyncha
Superfamily: Coccoidea
Family: Dactylopiidae
Genus: Dactylopius
Species: *Dactylopius coccus* [13]

The cochineal insect is a sessile parasite, meaning that it spends most of its life connected to host plants, particularly species of the cactus genus Opuntia, commonly known as thorny pear. Other species inside the Dactylopius genus can create carminic acid, but D. coccus is favored for commercial purposes due to its higher color yield. [14]

2. Biology of cochineal insects

Cochineal insects are little (around 3-5 mm in length) and show sexual dimorphism, with females being bigger and capable for carminic acid generation, whereas males are littler and have wings. Female cochineal insects are the essential source of carminic acid, and it is their bodies that are collected and prepared to get the color.

Feeding and life cycle

Cochineal insects nourish on the sap of Opuntia cacti, utilizing their specialized mouthparts to extricate supplements. The life cycle of the cochineal insect incorporates a few stages: egg, nymph (to begin with, second, and third instar), and adult. Females stay sessile all through their grown-up life, nourishing on the cactus sap, whereas males create wings and are more portable but have a shorter life expectancy. The propagation prepare is fast, and the insects can create a few generations per year beneath perfect conditions. [15]

Carminic acid production

Carminic acid is created by female cochineal insects as a defense component against predators. The concentration of carminic acid in female insects can extend from 17% to 24% of their body weight, making them an effective source of the color. This acid is put away in the hemolymph and gives security from other insects and creatures, making it a naturally occurring compound with critical esteem in different industries. [16]

3. Farming Practices for Cochineal Insects

The development of cochineal insects is a specialized process that has been practiced for centuries, especially in the Andean districts of Peru and Mexico. The cultivating of cochineal includes a few steps, counting planning the host cactus, presenting the insects, and managing the collecting process.

Host cactus preparation

Cochineal insects are cultivated on species of the Opuntia cactus, which serves as their host. These cacti are cultivated in areas beneath parched conditions, which are ideal for both plant and insect development. The Opuntia cactus is drought-resistant and requires negligible water, making it a feasible crop in locales with constrained rainfall. Farmers plan the cactus by evacuating spines and guaranteeing a healthy growth environment.

Insect introduction and monitoring

Female cochineal insects are presented to the cactus pads, where they join and start nourishing. The insects are checked closely to guarantee ideal development conditions, and farmers take measures to control predators, such as ants, that can harm the insects. Depending on natural conditions, cochineal insects can be collected numerous times a year. [17]

Harvesting and processing

After a few months, when the insects reach development and contain adequate carminic acid, they are collected. The collecting process includes expelling the insects from the cactus, ordinarily by hand or utilizing mechanical brushes. [18]

4. Geographical distribution and economic importance

Cochineal insects are basically cultivated in locales with appropriate climates, such as Peru, Mexico, and the Canary Islands. These regions give the perfect developing conditions for the Opuntia cactus, which serves as the host plant for the cochineal insects. Peru is as of now the biggest worldwide maker, accounting for around 80% of the world's supply of cochineal color. The country's favorable climate and broad cactus manors permit for large-scale production, making cochineal a financially noteworthy product. Small-scale agriculturists in Peru depend on cochineal farming as a source of wage, contributing to the nation's trade economy.

Mexico, especially the Oaxaca locale, has a long history of cochineal development, with conventional methods passed down through eras. Whereas Mexico's production levels are smaller than Peru's, it remains a key player in the worldwide cochineal showcase due to its verifiable importance and talented cultivating methods. Additionally, the Canary Islands, particularly Lanzarote, have been developing cochineal for centuries, in spite of the fact that production has lessened in later years. [19]

Globally, cochineal color is esteemed for it utilize as a characteristic colorant in different businesses, counting beauty care products, nourishment, and textiles. As customer inclinations move toward natural and feasible ingredients, the request for cochineal has developed. This expanded request has raised the financial significance of cochineal production, as it is seen as a renewable and ecologically inviting elective to synthetic colors. Cochineal's worldwide market esteem proceeds to rise, especially in reaction to the clean beauty and natural item trends. [20]

Chemical composition of cochineal dye

Cochineal dye, inferred from the dried bodies of female *Dactylopius coccus* insects, owes its dynamic red color to carminic acid, the essential chemical constituent capable for its coloring properties. Along with carminic acid, the dye contains other compounds such as proteins, lipids, and sugars, which contribute to the in general steadiness and characteristics of the color. The concentration of carminic acid in cochineal can shift based on variables such as the insect's diet, natural conditions, and the collecting strategies utilized. Cochineal dye is profoundly esteemed in the beauty care products, nourishment, and textile businesses for its natural origin, solid coloring capacity, and steadiness against light and heat. [21]

1. Carminic acid: The primary pigment

Carminic acid, a glucosylated hydroxyanthraquinone, is the fundamental color found in cochineal insects and constitutes between 17% and 24% of their dry body weight. Chemically, it is a red crystalline substance with the molecular formula $C_{22}H_{20}O_{13}$. This anthraquinone subordinate is what gives the shinning red color to cochineal dye, making it exceedingly looked for after for utilize in different industries.

Carminic acid is actually delivered by female cochineal insects as a defense component to prevent predators. Its chemical structure contains carboxyl and hydroxyl groups, permitting it to shape steady complexes with metal ions, which improves its steadiness and coloring properties. In beauty care products, carminic acid is utilized beneath the name carmine (CI 75470), where it gives a profound red tone that is safe to light and temperature varieties, making it a solid color in different formulations. [22]

2. Other constituents of cochineal dye

In addition to carminic acid, which is the essential coloring agent in cochineal dye, there are a few other minor components display that contribute to its in general properties. These components, in spite of the fact that less concentrated, can impact the dye's color, solidness, and execution in cosmetic formulations. Flavokermesic acid is one such anthraquinone derivative found in littler amounts. It has a yellowish tone and can change the in general shade of the dye when combined with carminic acid. Its molecular structure resembles carminic acid but needs the glucose moiety, making it less water-soluble. In spite of the fact that flavokermesic acid is not as broadly considered as carminic acid, it serves as a secondary pigment, altering the red tone of cochineal dyes with a unpretentious yellow tone.

Kermesic acid, another anthraquinone pigment show in cochineal insects, contributes to the dye's color range. Basically comparable to carminic acid but more lipophilic due to the nonappearance of a sugar component, it breaks down superior in oil-based formulations such as creams and lipsticks. Kermesic acid develops the red color in cochineal dye, improving its concentrated in cosmetic items where a wealthier tone is desired.

Additionally, cochineal color contains follow amounts of proteins and lipids from the insect's body. Whereas these do not specifically influence color, they can impact the stability and texture of the color in certain formulations. Proteins can influence emulsification properties, whereas lipids can affect the solubility of the color in oil-based items and improve skin absorption.

Mineral salts, counting calcium and magnesium, are too present in little amounts. These salts can influence the dye's solubility and attachment to surfaces, such as skin or textures, and may contribute to its stability in different formulations. The presence of mineral salts can too impact the dye's pH sensitivity, influencing its color stability beneath diverse natural conditions.

Whereas carminic acid remains the prevailing component of cochineal dye, minor compounds such as flavokermesic acid, kermesic acid, proteins, lipids, and mineral salts play vital parts in altering the dye's color, stability, and application potential. Understanding these components is key to optimizing cochineal color for use in a wide range of cosmetic formulations. [23, 24]

Extraction methods of cochineal dye

There are many ways to extract carmine dye to obtain colors suitable for cosmetic and other uses. Each extraction process is designed to maximize the effectiveness and quality of carminic acid while minimizing impurities. The choice of extraction method can affect the properties of the final dye, including color, solubility, and stability. Some of the cochineal dye extraction methods used are:

1. Traditional methods

The Traditional extraction method is by drying the cochineal, which can be done by sunlight or drying. After drying, the insects are ground into powder. The powder is then mixed with water or other solvents such as ethanol or methanol to facilitate the extraction of carminic acid. The mixture is heated and stirred to promote the release of colour. This method is quite simple and has been used for centuries, but different colours and quality levels can be produced. [25]

2. Modern techniques

In Modern techniques, the use of organic solvents has become more common. Ethanol, methanol, and acetone are commonly used in the extraction process. This solvent effectively dissolves the carminic acid and other soluble components in cochineal. The process usually involves soaking dried insects in a solvent for a certain period of time and then filtering the liquid extract to separate the residue. This method increases the purity and concentration of carminic acid, resulting in more vibrant dyes suitable for cosmetic formulations.

2.1 Supercritical fluid Extraction

By Using supercritical fluid. In this method, carbon dioxide is pressurized and heated until it can replace gas and liquid. This avoids the use of organic solvents while ensuring good pigment dissolution. Advantages of SFE include the production of high purity material and reduced environmental impact compared to traditional solvent methods. The use of supercritical CO2 can extract certain compounds such as carminic acid while leaving unwanted compounds behind. [26]

2.2 Ultrasound-assisted extraction:

Ultrasound-assisted extraction (UAE) is another method that has become popular in recent years. This machine uses ultrasonic waves to create cavitation bubbles in the solvent, thereby increasing mass transfer and improving extraction efficiency. The application of ultrasound can reduce extraction time and increase the yield of carminic acid. UAE can be combined with other extraction methods such as solvent extraction to enhance the process. This method improves solvent diffusion into the plant material and improves the extraction of carminic acid.

2.3 Microwave assisted extraction

Microwave Assisted Extraction (MAE) has many advantages over traditional methods, including shorter process times, reduced solvent consumption and improved colour yield. The technology is particularly attractive for large-scale applications where performance and cost-effectiveness are important.

As demand for natural pigments continues to grow in the cosmetics and other industries, optimizing the extraction method for carmine dyes is important to ensure stability and efficiency. Continuous research and innovation in technology will help improve the quality of carmine dyes, while reducing environmental impact and increasing profitability for manufacturers. [27]

Applications of cochineal in cosmetics

Cochineal dyes are obtained from the insect *Dactylopius coccus* and are widely used in the cosmetics industry due to their natural color, bright red, carminic acid. This dye is valued for its strong color, stability and origin, which makes it useful in many cosmetics. One of its main uses is in lipsticks and lip balms, where it provides a rich red hue and excellent coverage. Carmine (CI 75470) is a purified form of carmine dye that provides long-lasting color, is light and heat resistant and is ideal for lip products. Its natural origin also makes it popular in organic and natural cosmetics. [28]

Carmine dye is also often found in powder products such as blush and eye shadow, where it creates a variety of shades of red and pink. It mixes easily with other pigments and finishes to create a smooth, matte or satin finish, depending on the product. The stability of carmine dye ensures that the color remains strong and does not fade quickly, making it reliable for long-term coloring. [29]

Carmine dye is also used to create red color in nail polishes, especially in models with natural ingredients and no chemicals. It is stable in most solvents used in nail polish, making it an ideal colorant for environmentally friendly organic nail polish brands. The dyes are used in tinted moisturizers or balms that require a reddish-brown color. The natural properties of carmine dye make it suitable for clean beauty, appealing to customers looking for insect or plant ingredients. [30]

The increasing demand for natural, sustainable and eco-friendly beauty products has further increased the popularity of carmine dye. It is particularly popular with brands that focus on clean, green and organic designs, offering an alternative to synthetic dyes. However, ethical considerations can be problematic, especially for consumers who prefer vegan or cruelty-free products. Although carmine dye is a natural colour, the fact that it is derived from insects can be confusing to some consumers. Therefore, transparency in sourcing and labelling is important for brands that use cochineal dyes to maintain consumer trust. business case. As the beauty trend continues, carmine dyes will continue to be important products in cosmetics, especially in high-end or niche markets that prefer products with natural ingredients.

Regulatory and Ethical Considerations

The use of cochineal dyes in cosmetics is based on many rules and ethics that companies must follow in order to maintain consumer trust. Given that carmine dye is derived from insects, its safety and ethics play an important role in its acceptance in different markets and among different consumers.

From a regulatory perspective, cochineal dye (carmine) is considered safe for cosmetic use and has been approved by many regulatory agencies worldwide. In the United States, the Food and Drug Administration (FDA) regulates the use of carmine dye in the Color Additive Amendments of 1960, which lists it as a color additive approved for use in foods, drugs, and cosmetics (CI 75470). However, the FDA has stated that all products containing carmine must be clearly labeled for consumers, especially since allergic reactions may occur in a small portion of the population. Similarly, in the European Union, carmine is approved for use in cosmetics but must comply with the labeling requirements set out in the European Commission Cosmetics Regulation (EC No 1223/2009). This makes this clear, especially for customers with allergies or dietary restrictions that preclude the use of animal products. [31]

Ethically, the use of carmine dye has raised concerns among some consumer groups, particularly vegetarians and advocates of non-toxic products. Since carmine dye is derived from insects, its use in cosmetics is incompatible with the content of animal-free foods. In response, many

cosmetic brands have turned to plant-based or synthetic ingredients to meet the needs of vegan consumers. However, given its non-synthetic origin and biodegradable nature, cochineal remains a popular choice for brands emphasizing natural or organic standards.

Other ethical considerations include the processing and sourcing of cochineal. Cultural practices have become increasingly important to both consumers and companies to ensure insects are cut in a way that minimizes damage and environmental impact. Sustainable practices, such as diversifying livestock and using environmentally friendly farming methods, help brands achieve their sustainability goals and ensure people use ethically sourced products. [32]

Transparency in labeling is essential for addressing both regulatory and ethical concerns. Customers are progressively looking for clarity around the origins and composition of the ingredients in their beauty items. Transparent labeling not only aids individuals with specific allergies in avoiding products that may provoke reactions, but it also empowers ethically minded consumers to make informed choices. For companies that use cochineal dye, it's crucial to clearly indicate whether their products align with vegan, cruelty-free, or sustainable criteria to foster and maintain consumer trust. [33]

While cochineal dye is a safe and commonly used ingredient in cosmetics, its application comes with regulatory and ethical responsibilities. Adhering to international regulations and ethical sourcing practices, along with clear and transparent labeling, will be crucial for manufacturers aiming to integrate cochineal dye into their cosmetic offerings in a manner that complies with both industry standards and the evolving expectations of consumers.

Future trends and research directions

The future of cochineal dye in cosmetics will emphasize the need to balance its natural allure with the rising expectations for sustainability, ethical practices, and innovation. As the clean beauty movement gains momentum, cochineal continues to be favored; however, the increasing prevalence of veganism and cruelty-free products may necessitate the exploration of alternatives. Research is expected to focus on plant-based or biotechnological substitutes that can mimic cochineal's coloring properties without using insects.

Adopting sustainable extraction methods, like enzyme-assisted or green solvent technologies, will be crucial in minimizing the environmental impact of conventional processes. There will also be efforts to enhance the functionality of cochineal dye, such as improving its solubility and stability through nanotechnology. Furthermore, forthcoming regulations are likely to call for increased transparency and consumer protection, especially concerning allergens and ethical issues, which will influence the ongoing application of cochineal in cosmetics. [34, 35, 36]

Conclusion

In Conclusion, cochineal insects are essential to the cosmetic industry, serving as a natural source of vibrant red dye through the extraction of carminic acid. With a rich history and distinctive properties, cochineal dye is widely used in cosmetic products, such as lipsticks, blushes, and nail polishes. However, its use raises significant regulatory and ethical issues, particularly regarding transparency, allergen awareness, and its fit within vegan and cruelty-free markets.

As consumer preferences move toward clean, sustainable, and ethically sourced ingredients, the future of cochineal dye will hinge on the industry's capacity for innovation and adaptability. Advances in alternative sources, sustainable extraction techniques, and improved functionalities of cochineal dye will be vital for ensuring its continued significance in the cosmetic sector. By tackling these challenges and adapting to changing trends, the cosmetic industry can maintain its use of cochineal while fulfilling the increasing demand for responsible and ethical beauty products.

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Conflict of Interest

All the authors declare that they have no conflict of interest.

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