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Sustainable Quality Management Systems in Cosmetics: Integrating Green Chemistry and Circular Manufacturing.

SOWMYA

Department of Pharmaceutical Quality Assurance, SRM College of Pharmacy, SRMIST, Kattankulathur, Chennai, Tamil Nadu, India

+91-8248143335

Sowmyak0306@gmail.com

Dr. KELLA ALEKHYA S*

Assistant professor, Department of Pharmaceutical Quality Assurance, SRM College of Pharmacy, SRMIST, Kattankulathur, Chennai, Tamil Nadu, India

+91-7397312159

kellaals@srmist.edu.in

Dr. MANIMARAN

Professor and Head, Department of Pharmaceutical Quality Assurance, SRM College of Pharmacy, SRMIST Kattankulathur, Chennai, Tamil Nadu, India

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ABSTRACT

The entire cosmetic industry undergoes a transformation toward sustainability, with consumers becoming increasingly aware, the market acquiring heavier regulations, and increasing global concerns over the environment. This paper treats Sustainable Quality Management Systems in the cosmetic sector, especially on the synergic interaction between green chemistry and circular manufacturing. Existing QMS models often do not take into account long-term ecological impacts. Hence, there is a need for quality systems precious for product safety and also that look into ethical sourcing and environmental impacts. Such consideration on international regulatory compliance systems with utmost transparency is illustrated through ISO 22716 and the Indian Drugs and Cosmetics Act in the sustainable product development method. Aspects of green chemistry ranging from the prevention of waste, atom economy, and less hazardous chemical syntheses to using renewable feed stocks are evaluated in relation to raw material selection, product formulation, and risk assessment. On the other hand, circular economy strategies put to evaluation are reuse, recycle, and closed-loop supply chain, with case studies provided in reference to prominent players like L'Oreal. The findings point out that cosmetic manufacturers need to implement holistic quality systems with sustainability linked to them so that it can form a basis for competitive advantage and long-term ecological stewardship.

INTRODUCTION

BACKGROUND OF THE COSMETIC INDUSTRY AND GLOBAL MARKET TRENDS:

In the globalized and interconnected economy of today, consumers are surrounded by cosmetic and personal care products from around the world. The country of origin (COO) has thus emerged as a strong driver of consumer perceptions of a product's quality, safety, and credibility. Consumers tend to tag certain nations with certain values, cultural norms, and degree of manufacturing superiority. These pairings affect expectations and, in turn, determine purchasing choice. COO not only refers to a product's source geographically but also acts as an implicit guarantee of trust, particularly when buyers are not familiar with a brand [1].

Studies indicate the effect of COO differs by region and product categories. For example, in East Asia, cosmetics that are produced in countries like France and South Korea are commonly seen as more stylish and desirable. This is related to social values such as having a cultured public image, gaining social status, and striving towards cosmopolitan, globalized lifestyles. In such cultural environments, brand reputation and country of origin considerably boost the confidence of consumers, exemplifying the way global image and cultural identity influence the contours of the global cosmetics industry [1].

At the same time, India's cosmetics industry has achieved significant growth in the last ten years. Variety and availability of beauty and personal care products have grown considerably with domestic companies making concerted efforts to achieve international quality. Indian natural and herbal cosmetics, in fact, have attracted a global market with several of them being marketed under well-known global brands [2].

This growth, projected at almost 20% per year, is driven by two key factors: the increasing demand for affordable, locally produced products and higher incomes for Indian consumers. Furthermore, universal access to satellite television and the web has introduced the typical Indian shopper to international beauty trends and advertising, creating a greater interest in cosmetics. The concurrent growth of India's fashion and media sectors has further fuelled concern for outward appearance, solidifying the increasing need for quality cosmetic products [2].

IMPORTANCE OF PRODUCT QUALITY, SAFETY, AND CONSUMER TRUST

The beauty care industry is increasingly being targeted for using ingredients that are potentially harmful to health. Although most products are safe, a significant number still have ingredients associated with concerns such as hormonal disruption, carcinogenicity, and allergies. Regulatory agencies differ greatly in their requirements; the European Union, for instance, prohibits more than 1,300 cosmetic chemicals while the United States only limits a small percentage of that total. This disparity in worldwide regulations confuses consumers and presents the need for standardized, clear quality control systems that are committed to consumer health [3].

Today's consumers are better informed than ever. Through the help of mobile apps and web-based tools, consumers are able to readily view the ingredients of products, their safety profiles, and consumer feedback. This has led to the creation of a highly engaged class of consumers who actively explore what they put on their skin. These "smart consumers" value safety and transparency above reputation brands, so companies are turning to cleaner formulations and ingredient transparency as part of their quality and ethical duty [4].

To today's consumers, product safety assurance is the key to the decision-making process. Third-party safety certifications and ingredient scores are now more important than ever compared with good branding alone. Clean, green, or toxin-free products are in demand, particularly when backed up by quantifiable facts. This increased demand for safety information signals a change in product quality perception that puts more emphasis on openness, responsibility, and demonstrable safety as opposed to marketing-oriented attractiveness [5].

Economic values are becoming more in tune with health, ethics, and environmental sustainability. Studies indicate that persons who prioritize personal achievement, health, and image are particularly likely to buy products that contain no harmful chemicals. Product safety for some is not only avoiding undesirable health consequences—it also signifies what they think and how they define themselves. Cosmetic companies, therefore, need to think not only about functional performance but also about how their approach to safety resonates with their audience's values.

The concept of quality in cosmetics has stretched a long way. Today, it includes not only product performance, but also consumer confidence, emotional reassurance, and social signaling. Brands that are seen as safe and ethically made have higher emotional and brand value to consumers. Companies that do not match changing safety expectations, however, risk losing trust—and ultimately, sales—despite performing well. To be competitive and reliable, cosmetics companies have to adopt strict quality control measures that reflect on-going dedication to customers' welfare [6].

LIMITATIONS OF TRADITIONAL QMS IN ADDRESSING SUSTAINABILITY

Most regional cosmetic producers have great difficulty in embracing sustainability because of meager resources and insufficient life cycle effects knowledge. Therefore, these firms usually persist in running their affairs in conventional, linear business models focusing on short-term profit maximization rather than long-term environmental or social responsibility. Where some try to tackle sustainability, their solutions are generally ad hoc and reactive and not part of an integral strategic quality or business model. For small and medium-sized enterprises (SMEs) specifically, generating profits usually overwhelms more general aims such as ethical sourcing, waste minimization, or community benefit. By doing so, they tend to ignore the extended environmental and societal effects of their production processes. Even more challenging is the implementation of sustainability for cosmetic firms operating in developing countries. Such nations often face poor access to necessary resources, high social inequalities, and underdeveloped regulatory systems, all of which present obstacles to the routine and effective implementation of sustainable practices [7][8].

One of the main barriers to adopting sustainability is the lack of enough and reliable data on environmental raw materials. In addition, the lack of clear guidelines defining the sustainability responsibilities of cosmetic firms hampers their movement toward more sustainable operations. While there has been some improvement in sustainable consumption, there are still lots of room for improvement as well as challenges. Though corporations have evolved in Corporate Social Responsibility (CSR), their compliance with Design for Sustainability (DFS) practices remains in infancy [8].

EMERGENCE OF SUSTAINABILITY, GREEN CHEMISTRY, AND CIRCULAR ECONOMY CONCEPTS

The drive for green chemistry and sustainability in the cosmetic industry is a result of increasing external demands, such as regulatory agencies, government agencies, and consumer demand for human health and environmental issues. Green chemistry, with its roots in the early 1990s, has quickly become an integral part of the scientific world, developing from its historical place in synthetic organic conversions into what it is today: all aspects of chemistry, chemical engineering, and manufacturing sciences [9].

Public concern over dangerous chemicals in cosmetics, as well as ethical factors, has strongly driven the expansion of the market for organic cosmetics. This section exhibited significant growth, with organic cosmetic revenues worldwide amounting to an estimated USD 13.33 billion in 2018. In addition, natural beauty and skincare products, worth around $33 billion in 2015 and accounting for 13% of the international beauty market, were estimated to reach $50 billion by 2019.Numerically, historically, up to the 1980s, pollution control was the predominant concern of the chemical industry as well as regulatory agencies. But a turning point came with the signing into law of the Pollution Prevention Act in 1990, which promoted ending pollution via source reduction instead of treatment and disposal. The shift in policy brought about the formalization of green chemistry as an established scientific field in the 1990s as a means of providing a methodology for transforming chemical products and processes fundamentally to present fewer risks to human health and the environment [10].

As a result, green chemistry has become a major factor for cutting-edge industrial players who uphold environmental stewardship. Top firms have proactively incorporated green chemistry concepts into every aspect of a product's lifecycle, from original design through consumer usage, a dedication that has been ongoing for over a decade [11].

REGULATORY FRAMEWORK AND QUALITY STANDARDS

OVERVIEW OF MAJOR COSMETIC REGULATIONS:

1. **ISO 22716 (GMP for Cosmetics)**

   ISO 22716 provides internationally agreed standards of Good Manufacturing Practices for the use in the cosmetic industry. It provides systematic guidelines for manufacture, quality control, storage, and distribution to ensure that cosmetic products are manufactured and handled uniformly according to specified quality standards and regulatory standards. Such standards are based on scientific principles and risk-management approaches aimed at ensuring product safety and consistency. Basic Components of ISO 22716:

   1. Establishment of an official quality management system with defined roles in the organization.
   2. The proper equipment and production facility design, operation, and maintenance.

3. Robust product development and material handling procedures.
4. Dispute resolution procedures, consumer complaint handling, and conducting product recalls.
5. Focus on ongoing process improvement and refinement [12].

Organizational Accountability and Quality Management System

One of the most significant GMP principles according to ISO 22716 is the establishment of an educated staff capable of assuring the product quality and not causing any harm to the consumers. Production staff should be trained and their duties should be allocated accordingly. Proper internal and external communication systems should also be put in place to ensure coordination, accountability, and active participation at all levels of the organization [12].

Premises and Plant Requirements

The physical configuration of the manufacturing plants, the areas of storage, and the departments of quality control needs to be thoughtfully designed and coordinated with the operational requirements. Segregation of the manufacturing and storage spaces is necessary for restricting the potential risks of contamination and mixing of products. Ongoing cleaning, disinfection, and calibration of equipment are necessary for ensuring the operational efficacy of the infrastructure and equipment. The quality assurance (QA) department has a key function in monitoring changes and maintaining continuous regulatory compliance [12].

Managing Deviations, Complaints, and Product Recalls

Organizations must develop effective processes for identifying, examining, and correcting any variations that may occur along the supply chain. These may be because of raw material issues, transportation defects, or issues after distribution. There must be processes in place for customers to report complaints, which must be carefully examined, followed by appropriate corrective actions. If a product defect poses a health risk, immediate recall processes must be activated, with due notice to regulatory bodies and affected parties [12].

Advantages of ISO 22716:

1. Blends traditional Good Manufacturing Practice (GMP) regulations for product and process quality with higher quality management requirements, e.g., in ISO 9001.
2. Facilitates straightforward deployment to various sizes and complex organizations.
3. Offers a globally accepted standard for ensuring quality and compliance to safety standards across the entire supply chain for cosmetic products.
4. Offers consistent management of risks throughout the supply chain, with ongoing enhancement of quality and safety [12].

COSMETICS REGULATIONS IN INDIA:

In India, cosmetics, including herbal cosmetics, are regulated under the Drugs and Cosmetics Act of 1940 and the Drugs and Cosmetics Rules of 1945. These acts make provisions for various aspects like the manufacturing process, labeling, and ingredients used in cosmetic products are allowed. Herbal cosmetics are also covered under these sets of rules, and additional provisions are made by the Indian Pharmacopoeia Commission, especially under the Ayurvedic, Siddha, and Unani (ASU) systems of medicine. The Central Drugs Standard Control Organization (CDSCO) is the central governing body that ensures the quality, safety, and efficacy of both conventional and herbal cosmetic products in the country [13].

Key aspects of Indian cosmetics:

Product Safety

Cosmetic products available in the Indian market must be safe for use on human beings and also meet the specifications laid down in the Drugs and Cosmetics Act of 1940, and the Drugs and Cosmetics Rules of 1945. It is the responsibility of the manufacturers to render the products safe and of the desired quality. Moreover, Cosmetic Rules of 2020, including the latest regulatory amendments, have been framed to further regulate and control the manufacturing, production, importation, and advertising of cosmetic products all over the country.

Licensing

In India, the cosmetic businesses must procure the manufacturing license from the concerned State Licensing Authority prior to production. Additionally, the manufacturing facilities must also fulfill all the infrastructural and operational norms laid in Schedule M-II of the Drugs and Cosmetics Rules, 1945, with proper hygiene, equipment, and staff precautions to manufacture safe cosmetics.

Labeling

Indian cosmetics that are on the market must adhere to the labeling requirements outlined in the 1945 Drugs and Cosmetics Rules. Labels must be followed by all the details of the product, including product name, manufacturer's name and address, manufacture license number, batch number, date of manufacture, expiry date, and complete ingredient list. This is to provide transparency and allow consumers to make highly informed choices while facilitating traceability of the product as well as compliance with the regulations.

Ingredient Restrictions

Drugs and Cosmetics Rules, 1945 have detailed provisions for use of ingredients employed in the production of cosmetics that are allowed and banned. Appendix A has the standards to which the cosmetic products must adhere, and Appendix B has the list of ingredients that cannot be used in cosmetics. The rules ensure the health of the consumer by banning harmful or toxic ingredients that are used in cosmetics that are for sale in India.

Import and Registration

Legally importing cosmetics to India requires importers to obtain a Registration Certificate from the Central Drugs Standard Control Organization (CDSCO). Registration requires submitting a list of documents that are required, such as product information, safety and efficacy data, and information about the manufacturing facility. Requirements are established to ensure that imported cosmetic products meet Indian regulatory standards for quality, safety, and conformity [13].

GREEN CHEMISTRY PRINCIPLES IN COSMETIC QUALITY SYSTEM

The United States Environmental Protection Agency (EPA) defines green chemistry as the design of chemical processes and products that minimize or completely do away with the usage and production of hazardous materials.. The overall goal is to produce chemicals that degrade to harmless byproducts and therefore do not linger in the environment. This is also augmented through the employment of effective synthetic pathways, safer and less harmful reagents, improved energy efficiency, and replacement of toxic organic solvents with more harmless alternatives such as water. Whereas their use at the laboratory scale maintains environmental safety, usage on an industrial scale can translate into enormous economic gains, the ability to save millions in operating costs [15].

Green chemistry is an interdisciplinary approach that integrates chemical innovation with social and environmental stewardship. Unlike being a conventional scientific discipline, it operates across a variety of disciplines to ensure the development of sustainable, non-toxic chemical processes. As a relatively new area of study, it seeks to balance the ethical utilization of natural resources, economic growth, and the preservation of ecological systems to ensure long-term sustainability. [15].

PRINCIPLES OF GREEN CHEMISTRY:

The green chemistry concept was established by John Warner and Paul Anastas in 1998 when they proposed twelve guiding principles. The principles are aimed at avoiding or minimizing the use of dangerous substances in chemical transformations, and the general aim is avoidance of the use of toxic solvents and the creation of waste at the source [14].

The twelve green chemistry principles encourage the sustainable production and elimination or minimization of harmful substances in the synthesis, production, and use of chemical products. In this way, the use of materials harmful to the environment and human health is significantly reduced. In practice, it is always difficult to implement all twelve principles simultaneously in one chemical process. The use of as many of the principles as possible at different stages of the synthesis is attempted to make the process more sustainable and safer in general [15].

Table 1: Principles of green chemistry

SL.NO	PRINCIPLES	DESCRIPTION
1.	Prevention	The concept of waste prevention is to avoid producing the waste initially rather than treating it once it has been produced. Throughout the world, massive amounts of waste are generated every year through household, industrial, and farming activities. To minimize the health and environmental risks the waste is exposing, it must be collected, warehoused, and treated by appropriate recycling or waste disposal methods. New recycling technologies now enable the waste materials to become valuable, high-quality products [14].
2.	Atom Economy	Atom economy or atom efficiency is placing the largest percent of the starting material atoms in the end product. It would be ideal if all the starting material atoms were placed in the end product in chemical reaction with minimal waste. This is not possible practically. Therefore, chemical processes must be designed to keep by-product formation to a minimum, reduce the number of steps in a reaction, and render it ecologically benign [14].
3.	Less chemical synthesis	Wherever practicable, synthetic routes must be designed to use and produce material which is non-toxic or of very low hazard to human health and the environment [15].
4.	Designing safer chemicals	The idea of safer chemical design is to design chemicals that perform their duties well with a minimal negative impact on the environment and human health. For instance, scientists such as Epp et al and others developed an herbicide known as Rinskor, which is quite efficient in weed control at much lower dosage levels (5–50 g/hectare). Lower dosage helps in minimizing pesticide residues in the ecosystem as well as in crops [14].
5.	Safer solvents and auxiliaries	Safer Solvents and Auxiliaries principle encourages minimizing auxiliary chemicals used in chemical processes, such as solvents and separation agents. Where use is unavoidable, chemicals consumed must be non-toxic and environmentally friendly. Under green chemistry principles, selection of alternative solvents should consider factors such as worker safety, process safety, compatibility with the environment, and overall sustainability. The solvents should be physically and chemically stable, low-volatile, and simple to use and handle [15].
6.	Design for energy efficiency	Energy demands of the synthetic processes must be determined along with their environmental and economic costs and must be saved. Operations must be carried out at ambient temperature and pressure, if feasible. The 1973 oil crisis led to the design of numerous processes in which energy savings are achieved under the aim of making the best use of every kJ of energy in the manufacturing process. Following the above Principle of Energy Efficiency, whose other designation is referred to as Design for Energy Efficiency, as a minimum requirement, reduces the consumption of energy [15].
7.	Use of renewable feed stocks	Renewable raw materials are based on the concept of promoting sustainability by incorporating naturally renewable materials into chemical processes. Cellulose, lignin, lactic acid, and chitin—usually plant or water-based—are common examples. Utilizing such renewable raw materials reduces environmental degradation and promotes long-term resource preservation. For example, Nature works makes environmentally friendly bottles from corn-based raw materials, thereby providing a substitute for conventional petroleum-based plastics [14].
8.	Reduce derivatives	Unnecessary derivatization steps must be minimized or eliminated as much as possible because they add to the requirement of more reagents and the generation of waste [10].
9.	Catalyst	Catalysts are reagents that accelerate chemical reactions without being consumed by them or altered permanently in the process—a process referred to as catalysis. By enabling reactions to happen more efficiently and under less severe conditions, catalysts reduce the need for energy and waste. Aside from promoting green practice, the use of catalysts also brings economic benefit in the form of greater reaction yields and lower production costs [14].
10.	Design degradation	Chemical products should be developed in a way that they break down into non-toxic materials after they have served their intended use, thus avoiding long-term environmental accumulation. Design for degradation highlights the importance of developing materials that break down naturally into non-toxic by-products after they have served their intended use. Technological parameters may have to be altered at the manufacturing level, as well as alter auxiliary materials used at various production stages. The end aim is to avoid the creation of toxic residues and to maximize waste recovery through optimal recycling processes [15].

11.	Real time analysis of pollution prevention	The Real-Time Analysis for Pollution Prevention policy aims at creating analysis methods that allow for ongoing monitoring of chemical production processes. By allowing for real-time observation at every stage of the process, this method allows for the detection and prevention of potential defects before the creation of harmful products. In addition to reducing environmental and health threats, such preventive monitoring also enhances process efficiency by correcting defects and preventing the emission of harmful by-products [15].
12.	Inherently Safer Chemistry for Accident Prevention	Twelfth Green Chemistry Principle, Inherently Safer Chemistry for Accident Prevention, focuses on minimizing the use of dangerous chemicals in chemical processes. The goal is to minimize the likelihood of accidents, such as chemical spills, explosions, or toxic exposures, by formulating processes on the basis of safer materials and conditions from the outset [15].

GREEN CHEMISTRY IN RAW MATERIAL SELECTION AND PRODUCT FORMULATION:

Raw materials:

Sourcing ingredients and raw materials effectively is an important phase in creating cosmetics and personal care products. Product formulators need to incorporate available environmental, ecosystem, and human health information to enhance sustainability in their product lines.

Ingredient sourcing information taken into account include feedstock source (plant, mineral, petroleum, etc.), country of origin, and available sustainability certifications, including certified organic and Roundtable on Sustainable Palm Oil (RSPO).

To further discourage the use of poorly performing ingredients, a numerical penalty system is employed to deduct from the score. 0.1 Deduction is applied for each individual metric that is scored 1 (lowest possible starting scores).

Green chemistry principle 7 – as expressed in the ENV sourcing score – is that "a raw material or feedstock should be renewable rather than depleting whenever technically and economically feasible [16].

Product formulations:

Cosmetic formulators today have more available options of environmentally responsible natural and synthetic ingredients. Nevertheless, to choose the best ones to maximize sustainability while minimizing compromise to product performance continues to need systematic direction.

To underpin this, the Green Score system has been established. It evaluates ingredients and formulations according to key green chemistry principles, with a view to determining three main categories: human health, ecosystem effect, and environmental sustainability.

At the formulation level, a product's Green Score is calculated by averaging its individual ingredient scores, weighted by their proportion in the formula—water content excluded.

This scoring method is particularly useful for reformulation. It identifies lower-rated sustainability ingredients and aids the creation of better formulations with better overall environmental performance [16].

Table 2: Green Products used in cosmetic formulation

MATERIALS	FUNCTION	EXAMPLE
Emollients	Forms a barrier on the skin that prevents dryness, encouraging softness and smoothness.	Coconut Oil Shea Butter
Emulsifier	Assists in keeping the stability of oil and water mixtures, creating a smooth and even texture across the formulation.	Beeswax Stearic acid
Surfactants	Lowers surface tension to aid in lifting away dirt, oils, and impurities for effective cleansing.	Alkyl polyglucosides Soap nut extract
Fragrance compounds	Provides a scent to cosmetic products, which boosts their attractiveness and sensory experience overall.	Geraniol Floral oils
Polymers	Improves product thickening, consistency, and stability as a thickener, film-former, or stabilizer.	Starch Chitosan
Anti-oxidants	Helps prevent early signs of aging by defending the skin against oxidative stress from free radicals.	Milk thistle Grape seed
Colorants	Natural pigments are added to cosmetic goods to provide both attractive and practical coloration.	Calendula Buriti oil
Moisturizing agents	Increases skin hydration, suppleness, and elasticity.	Aloe Vera Glycerin
Thickening agents	Improves formulation viscosity, resulting in stable and desired consistency.	Guar gum carrageenan
UV absorbents	Protects skin from premature aging and sun damage by absorbing harmful UV light.	Stilbenes ferulic acid
Skin brightening agents	Decrease melanin and dark spots, resulting in balanced skin tone and a beautiful appearance.	Kojic acid Liquorice extract
Anti inflammatory agents	Calms the skin by minimizing redness, irritation, and inflammation, making it suitable for sensitive or reactive skin types.	Turmeric green tea extract

REGULATIONS OF GREEN CHEMISTRY:

Insufficient definitions of natural and organic cosmetics hinder precise government regulation. While voluntary green labeling schemes like the Cosmos-Standard have bridged the gap, they are more regulated than the conventional cosmetic law. Products must initially adhere to general cosmetic regulations and then meet additional, stricter conditions to qualify for certification. Third-party audits enforce adherence through regular checks on product and process control, traceability, claims, storage, packaging, and documentation. Laboratory testing is also necessary to guarantee adherence to standards.

Each of these certifying systems also incorporates animal welfare standards, excluding animal testing and restricting the use of dead animal-derived materials. They all restrict some ingredients and processes, usually excluding GMOs as well as ionizing radiation processing. These restrictions are primarily for Green Chemistry principles of reducing human and environmental toxicity.

So far, though, only Cosmos-Standard specifically refers to Green Chemistry and provides pointers to look for to ensure compliance with some of its Twelve Principles. These include measuring atomic economy, requiring a minimum aquatic toxicity and biodegradability standard, and excluding Bio accumulative and non-biodegradable compounds. Cosmos-Standard acknowledges that continuing Green Chemistry research limits the potential to prescribe certain requirements for all principles [10].

Risk Assessment in green cosmetics:

Risk assessment is a critical process that utilizes scientific evidence to evaluate the potential health impacts resulting from human exposure to hazardous substances. This evaluation typically incorporates data from epidemiological studies, clinical research, toxicological analyses, and environmental monitoring. Given that both conventional and organic/natural cosmetic products may contain additives or unintended toxic impurities, the implementation of robust and comprehensive risk assessment frameworks is essential. Such models are necessary to ensure product safety, regardless of the origin or labeling of cosmetic ingredients [10].

APPLICATIONS OF GREEN CHEMISTRY IN COSMETICS:

1. Pharmaceutical quality control role in green chemistry

The drug industry considers quality control to be an essential element towards delivering excellence in products. Quality is defined as a product's capability to achieve customer specifications, be defect-free, and ultimately guarantee satisfaction by the consumer. The successful execution of three essential management procedures—quality planning, quality control, and quality improvement—is necessary to achieve such quality. As defined by the World Health Organization (WHO), quality control is a vital step in the manufacturing of pharmaceuticals. It entails actions like sampling, the establishment of product specifications, carrying out analytical tests, and monitoring both materials and environmental conditions in production areas. Quality control makes it possible for decisions on whether to approve or reject materials and finished products to be made. Quality control is incorporated into good manufacturing practice and is essential for providing pharmaceutical safety and efficacy. Yet, conventional quality control analytical methods are usually environmentally suspect since they typically employ organic solvents with harmful or carcinogenic content. To help solve the problems, green chemistry principles are being translated into more sustainable analytical methodologies. This environment-friendly approach reduces environmental impact while maintaining efficacy. A more environmentally friendly analytical process can be obtained by the following ways:

- Avoiding of toxic reagents,
- Evaporation or removal of the reagent
- Minimization or elimination of fumes, gas, liquid, and solid waste generated in the laboratory,
- Reducing labor (preferably through complete automation,
- Wherever there is potential, direct analysis of treatment-free samples (e.g., direct analysis by near-infrared technologies),
- Utilizing other less environmentally polluting sample treatment methods, and
- Alternative reagent and solvent exploration

SUSTAINABLE WASTE MANAGEMENT IN GREEN CHEMISTRY

The largest issue in today's society is environmental conservation and protection. Due to this, the Globally Harmonized System (GHS) of classification and labeling of chemicals came into being. This method integrates chemical hazard classification and communication, providing precise information for each substance. All these industries that deal with handling or producing hazardous chemicals are mandated to adopt these safety precautions. While the industrial sector is known to produce enormous amounts of hazardous waste, schools are also largely responsible for this. Schools thus play an important role in ensuring safe waste disposal.

In the past few years, green chemistry application has progressed considerably, especially in the academic setting, where laboratory application has yielded encouraging outcomes. Green chemistry principles—like waste reduction, elimination of use of toxins, and safer process chemistry design—have found expression in noteworthy changes in laboratory processes. Some of these changes are the utilization of safer reagents instead of extremely hazardous ones and, as a result, the elimination of toxic waste creation. Furthermore, educational measures, like new laboratory procedures and waste disposal, not only lowered operational costs but also ensured greater human and environmental health advantages.

GREEN CHEMISTRY ROLE IN COSMETIC INDUSTRY

The cosmetics sector is growing fast, and with this growth comes greater use of natural resources and the demand for sustainable methods. To meet this demand, the industry is moving more toward green cosmetics, which focus on environmental, economic, and social sustainability. Organic and natural ingredients are now preferred over synthetic equivalents as people become more environmentally conscious and social media awareness continues to grow. Green cosmetic products work to reduce environmental footprint by employing biodegradable packaging, minimizing synthetic content, and using recyclable materials. Sustainable packaging materials such as glass, plant-based plastics, and biopolymers are given preference. Emollients (e.g., jojoba oil, almond oil), emulsifiers (glycerin, lecithin), surfactants (decyl glucoside), essential oils, antioxidants (rosemary extract, vitamin E), UV protectors (ZnO, shea butter), and skin-strengthening ingredients. These ingredients not only enhance product performance but also meet green chemistry principles by minimizing toxicity and waste.

To guarantee the credibility and safety of natural products, various global certifications and standards have been put in place. The COSMOS standard is recognized globally, providing transparency for consumers on raw materials and production processes. Certifications like ECOCERT, COSMEBIO, NATRUE, ICEA ECO BIO, and BDIH are well-known in Europe and have stringent standards for organic products. The EU Ecolabel takes into account the environmental performance throughout the lifecycle of a product. In the United States, COPA requires that 70% of the ingredients must be organic, while the Natural Products Association (NPA) encourages biodegradable and sustainable ingredients. Ethical certifications like VEGANOK guarantee cruelty-free and vegan compliance. Furthermore, the ISO 16128 standard establishes clear guidelines for the definition and certification of natural and organic cosmetic ingredients, with the goal of standardizing global procedures and increasing consumer confidence in sustainable cosmetic manufacture [14].

CIRCULAR MANUFACTURING IN COSMETICS:

As the European Commission (EC) defines it, a circular economy is one that "preserves the value of products, materials and resources for as long as possible by recycling them into the production cycle at the end of use, while reducing waste generation to a minimum." The action plan by the EC thus points to an immediate need for sustainable products that are re-usable, long-lived, and repairable—something the cosmetics industry now has to face. To facilitate this shift, the Commission established the 4R approach—reduce (R1), reuse (R2), recycle (R3), and recover (R4)—with the dual objectives of safeguarding both human health and the environment while driving the transition towards a circular economy (EC, 2008).

Circular-economy thinking is a strong path to sustainability for cosmetic makers in product design and packaging. A recent survey of low-carbon and circular-economy literature indicates that production is the second-most-researched sector, highlighting the increasing level of interest among scientists in raw chemical production—a core activity for cosmetics. However, in spite of this increased focus, there are still lacunae in our knowledge of how circular principles are truly being put into practice within the development of sustainable cosmetics formulas and packaging. While various scholars have already addressed these concerns, few have taken an entrepreneurial approach to discussing how cosmetics companies can navigate the practical transition towards circularity.

In the same vein, although numerous studies promote circular-economy practices as a solution for enhancing sustainability performance, the relationship between circularity and total sustainability remains being charted. Certain is that the two are very much interdependent, and promoting circular practices in the cosmetics industry holds major promise for obtaining long-term environmental and economic rewards [17].

KEY PRACTICES OF CIRCULAR MANUFACTURING IN COSMETICS:

R strategies of packaging:

Packaging design should take into account product characteristics, sterilization (where necessary), sealing, labeling, secondary packaging, storage, transit, regulatory requirements, and final use. Environmental considerations are being given higher priority, but merely possessing an environmentally friendly product is not sufficient. There must be wider adjustments in supply systems. New models such as Product-Service Systems (PSS) deliver holistic solutions—such as the detergent companies selling refills directly into customers' containers to minimize packaging waste. The R-strategies (such as Reduce, Reuse, Recycle) inform sustainable packaging. Although others, such as Refurbishment, are not as widely spoken about, they're applicable—particularly reuse, where packaging is refurbished by suppliers or reused by the consumer to reduce waste [20].

1. Reuse

Though transition to sustainable materials is prevalent, reusability-based strategies are not frequent. Reusability-based packaging consists of several cycles of use or refilling, usually with the support of auxiliary tools. When reuse is no longer possible, this packaging ends up as waste. Well-executed returnable packaging can remarkably lower the environmental footprint as well as enable circular flows of materials. In addition to conserving raw materials, water and transport emissions can also be reduced. Gatt & Refalo discovered that reusability can perform better environmentally than dematerialization, even if the reusable material is not recyclable. Yet, putting reuse and recyclability together does not always provide additional benefits and sometimes actually adds to environmental load.

Despite its advantages, reuse is not always the best strategy. For instance, cosmetic packaging with replaceable aluminium trays proved less sustainable than simpler reusable design. Also, reusable packaging tends to be heavier, increasing resource use and emissions if improperly discarded.

Success is not only a function of environmental performance but also of consumer acceptance. Previous failures are attributed to inconvenience and lack of motivation. Designs that build emotional connection, aesthetic value, and value clarity can enhance retention and reuse.

Refillable systems design involves overcoming durability, safety, user simplicity, hygiene, and consumer transparency. Refills need to be simple and safe, without dangers such as contamination or abuse. Choice of materials, ease of cleaning, and complete product extraction are critical considerations. For instance, easy-to-clean surfaces are helpful, and opaque packaging can enhance perceived value if the content is not completely extractable.

Lastly, microbial safety is essential—refill designs must minimize exposure and enable controlled dispensing. Sealed pouches with built-in nozzles are some of the features that can provide a hygienic and user-friendly solution [20].

2. Recycling

Recycling disposable items can have large environmental payoffs—reducing landfill waste, preserving energy, and saving more than 90% of resources by reusing materials. Recycling is not always the most convenient end-of-life (EoL) option, though. Contamination and lack of economies of scale are the typical holdups, and they make recycling more of a Plan B than a Plan A. Rates of recycling are still low. For instance, much plastic waste is still not recycled, commonly because it is inconvenient for consumers or its disposal process is not clearly defined. Consumers are less likely to comply if recycling is not convenient or straightforward. For better recycling results, packaging structure should be simple. With fewer materials being used and parts that are straightforward to separate, the prospect of better recycling is facilitated. Easy-to-follow instructions that are also clear can assist consumers in the disposal process. Moreover, the chosen materials have to fit into available technologies for recycling so that there is technical feasibility [20].

CLOSED-LOOP SUPPLY CHAIN MODELS IN COSMETICS

Closed-loop supply chains are at the heart of sustainability, with economic and environmental objectives being aligned through the circular economy model. Rather than adopt the conventional linear "flow economy" paradigm where materials turn into waste upon usage, closed-loop systems reuse, recycle, and repurpose materials throughout the supply chain. This change is facilitated by sustainable supply chain networks (SSCNs), which allow cooperation among firms—across industries—to complete process chains and mitigate adverse effects such as energy use, packaging waste, and emissions. Waste is no longer considered in this system as a disposal issue but as a resource that can create more value. By recycling waste as an input for another process, firms can add profitability and efficiency to their use of resources. Waste minimization is a key part of the strategy. It starts at the manufacturing level with means to prevent, reduce, reuse, and recycle. Environmental purchasing is also involved, whereby companies use materials that are recyclable, involve suppliers in ecologically designing, and strive for minimal packaging. Remanufacturing and recycling are the major components in limiting raw material demand, energy consumption, and waste hazards. When combined with careful planning, these policies turn "valueless wastes" into valuable resources, enabling businesses to shift toward a circular economy while complying with the environmental standards and enhancing long-term competitiveness [19].

CASE STUDY OF LOREAL PARIS COMPANY IN CIRCULAR MANUFACTURING:

L'Oreal shows a high level of commitment to circular production through sustainable processes integrated into each phase of its product life cycle. During the designing stage, the company aims to minimize environmental footprint through principles of eco-design. This involves creating lighter packaging to reduce waste and landfill disposal.

Throughout the sourcing process, L'Oréal gives preference to sustainable raw materials, especially those that come from plants, in favor of biodiversity conservation and green chemistry principles. The company conducts life cycle assessments (LCA) to analyze the environmental performance of its products, tracking parameters like eco-toxicity, biodegradability, and bioaccumulation. Materials from recycling are also extensively utilized in production, reflecting the brand's emphasis on circularity. Throughout the production process, all manufacturing sites adopt water management systems such as "Water scan" to monitor and cut down on water consumption. Heat recovery systems make it possible for the recycling of energy via evaporation processes of water. The "Carbon Balanced" initiative by the company has also helped avoid substantial CO_2 emissions, reflecting its commitment to climate-friendly production.

L'Oréal has also implemented certain rules in the packaging process to avoid hazardous materials such as PVC and protect consumers. It has substituted conventional materials with recycled PET that is food-grade and fiber-based material, which decreases cosmetic packaging's environmental impact.

During the distribution phase, the company achieves a 60% waste reduction and a 20% reduction in CO_2 emissions from product transportation. The achievements demonstrate the adoption of sustainability in logistics and supply chain practices.For the consumer-use stage, L'Oréal makes investments in workers' well-being and social support initiatives, which indirectly lead to operational efficiency. The company also promotes community-based initiatives, such as inclusive employment and ethical retailing.

During the post-consumer stage, L'Oréal encourages the collection, recycling, and recovery of packaging and product material waste. Non-recyclables are sent to energy recovery procedures. The company is certified with several standards such as ISO 9001, ISO 14001, ISO 50001, and OHSAS 18001, reflecting strong and open-minded dedication to sustainability.

L'Oréal releases extensive annual sustainability reports, with hundreds of pages consumed by non-financial disclosures, and with a focus on circular economy approaches. "Water consumption," "energy efficiency," "recycling," and "reuse" are used repeatedly, echoing the brand's holistic approach to circular production in the world of cosmetics [18].

CONSLUSION

Green Cosmetics industry, in its evolution, had come to integrate sustainability in its quality management system. And with consumers sourcing safer, more ethical, and environmentally friendly products, manufacturers are left with no option but to move beyond the typical quality assurance system. This paper illustrates how the implementation of green chemistry and circular manufacturing within QMS frameworks can optimize environmental performance and build consumer trust.

It is an excellent way to minimize waste and reduce toxicity at the very start of product creation. Wanting to use more green chemistry in manufacturing products that are circular, sustainable, and overall better, manufacturers need to consider resource efficiency and waste reduction through the entire product lifecycle - sustainability can only extend so far if waste is built into the product from the start. Regulatory adherence to ISO 22716 and national regulations, such as the Drugs and Cosmetics Act of India, provides a base layer of consistency and safety, but true sustainability requires that companies practice design-for-quality, lifecycle-based evaluations, and continuous improvements, such as Corrective and Preventive Actions (CAPA).

This case of L'Oréal shows how multinationals can organize sustainable QMS in sourcing, production, packaging, or post-consumer phases. Cosmetic companies can lay the foundation for responsible manufacture by developing sustainable project guidelines that can be aligned with circularity principles and green innovation. It will then be in the hands of the cosmetic industry to accept the systemic change, invest in sustainable technologies, and start working on projects collaboratively along the supply chain. In summary, while sustainable quality management is a matter of regulatory compliance and ethics, becoming the way forward would lift it as a sustainability need for resilient and professional standing and long-term growth of the cosmetic industry.

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