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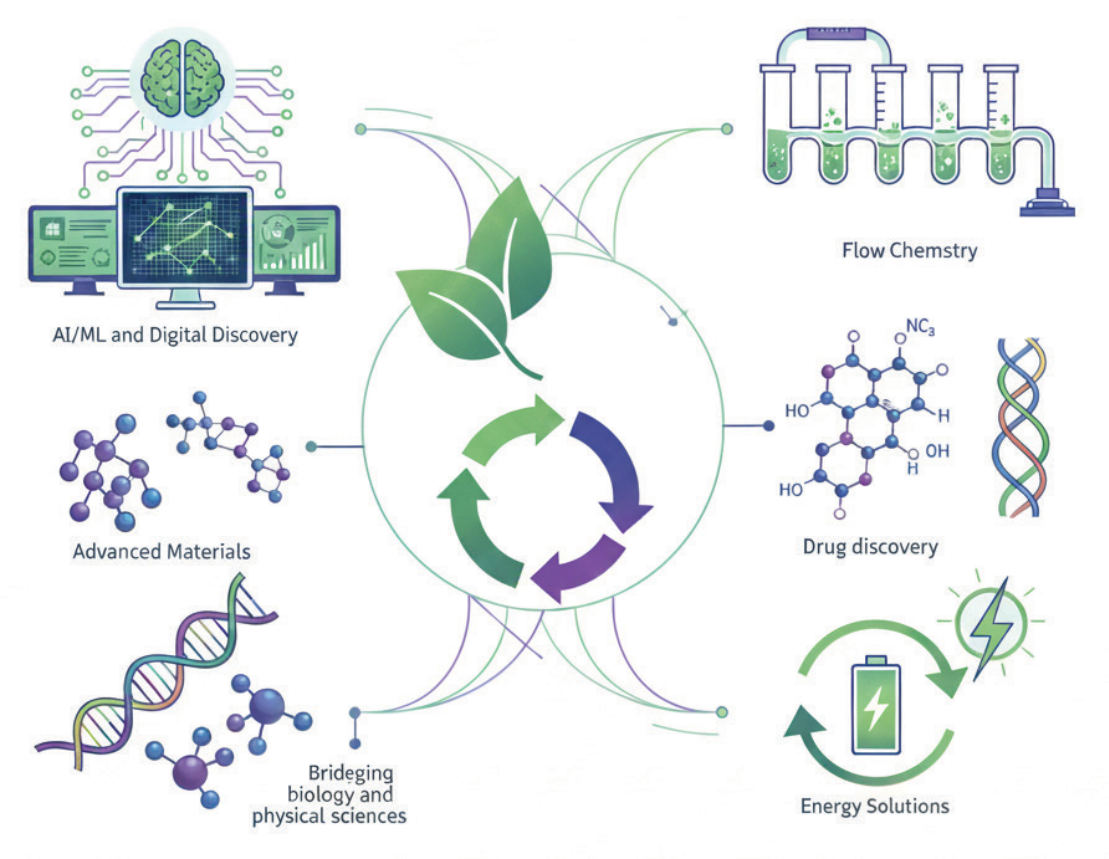

The Tri Annual Publication of the Institute of Chemistry Ceylon

Chemistry in Sri Lanka ISSN 1012 - 8999

The Tri-Annual Publication of the Institute of Chemistry Ceylon

Founded in 1971, Incorporated by Act of Parliament No. 15 of 1972

Successor to the Chemical Society of Ceylon, founded on 25th January 1941

Vol. 42 No. 3 **September 2025**

Theme for the year -

Journey towards economic sustainability in Sri Lanka - Role of Chemists

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Outline of our Institute

The Institute of Chemistry Ceylon is a professional body and a learned society founded in 1971 and incorporated by act of Parliament No. 15 of 1972. It is the successor to the Chemical Society of Ceylon which was founded in 1941. Over 50 years of existence in Sri Lanka makes it the oldest scientific body in the country.

The Institute has been established for the general advancement of the science and practice of Chemistry and for the enhancement of the status of the profession of Chemistry in Sri Lanka. The Institute represents all branches of the profession and its membership is accepted by the government of Sri Lanka (by establishment circular 234 of 9-3-77) for purposes of recruitment and promotion of chemists.

Corporate Membership
Full membership is referred to as corporate membership and consists of two grades: Fellow (F.I.Chem.C.) and Member (M.I.Chem.C.)

Application for non-corporate membership is entertained for four grades: Associate (former Graduate) (A.I.Chem.C.), Licenciate (L.I.Chem.C.), Technician (Tech.I.Chem.C.) and Affiliate Member.

Revision of Membership Regulation
All Special Degree Chemists can now apply directly to obtain Associate (Graduate) Membership. Three year B. Sc. Graduates (with an acceptable standard of Chemistry) can
(i) directly become Licentiate
(ii) obtain corporate membership in a lesser number of years.

Tech.I.Chem.C.
Those who have passed the DLTC examination or LTCC examination or have obtained equivalent qualification and are engaged in the practice of Chemistry (or chemical sciences) acceptable to the Council are entitled to the designation Tech.I.Chem.C.
Members/Fellows with Membership for Life are entitled to the designation of Chartered Chemist (C.Chem.) on establishment of a high level of competence and professionalism in the practice of chemistry and showing their commitment to maintain their expertise.

All corporate members (Members / Fellows) are entitled to vote and become Council/ Committee members whether Chartered Chemists or not.

Membership Applications
Any application for admission to the appropriate class of membership or for transfer should be made on the prescribed form available from the Institute Office.

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Fees should be payed on 1st of July every year and will be in respect of the year commencing from 1st July to 30th June

Fellow	Rs. 2000
Member	Rs. 2000
Associate	Rs. 1500
Licenciate	Rs. 1200
Technician	Rs. 750
Affiliate	Rs. 1200
Membership for Life	Rs. 15000

Entrance Fee

All the grades	Rs. 1000
Processing Fees*	Rs. 500
Processing Fee for Chartered Chemist designation	Rs. 5000
Institutional Members	Rs. 2500

*per application for admission/transfer to any grade

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Cover Page

Cover page shows a illustration of the latest chemistry trends focus heavily on sustainability (Green Chemistry, circular economy), digital transformation (AI/ML for discovery), and advanced materials (nanotech, biomaterials), with major developments in automating synthesis (flow chemistry), drug discovery (ADCs, nucleic acids), and energy solutions (battery recycling, catalysis), bridging biology and physical sciences for new applications. These trends aim to solve global challenges like climate change, resource scarcity, and healthcare needs, making the chemical industry more efficient, sustainable, and innovative through digital tools and interdisciplinary collaboration.

Message from the President

It is an honour for me to be bestowed with the prestige of serving as the President of the Institute of Chemistry Ceylon for 2025/2026.

Institute of Chemistry contributes towards the advancement of Chemical Sciences and it is the largest producer of qualified chemists in Sri Lanka. Considering the vision and mission of the Institute of Chemistry Ceylon and the prevailing economic crisis in the country, the theme "Journey towards economic sustainability in Sri Lanka - Role of Chemists" was selected for 2025/2026 with the vision of promoting chemistry based innovations and product development for local and foreign market using natural resources in the country, which are not currently being effectively used. In order to achieve this task, bridging the gap between academia and industry is essential. Institute of Chemistry will take the leadership in bridging this gap and open up avenues for chemistry-based journeys towards economic sustainability in Sri Lanka.

My primary goal is to ensure maintenance of high standards of all the educational programs offered by the Institute of Chemistry in order to achieve the mission of the College of Chemical Sciences. To achieve this goal, necessary activities will be implemented. Modern facilities for teaching, learning and skill development activities will be available with the commencement of academic programs at Malabe campus in November / December -2025. A project will be initiated to establish a well-equipped Instrument center to facilitate research work of undergraduate and postgraduate students and academic staff of Institute of Chemistry. Necessary steps will be implemented to obtain the approval for the Institutional review and for the program reviews of the BSc (Hons) in Chemical Science, proposed MLS degree program and Master of Science degree program in Analytical Chemistry and Quality Assurance. Necessary steps will be initiated to introduce a new degree program.

In addition to the academic and professional commitments, institute provides services to the community through dissemination of knowledge and skills in chemical science. Aligning with this task, relevant programs in chemistry for secondary level chemistry teachers, professional development programs for chemists and awareness programs on chemistry related issues for the general public will be conducted.

With the support of the council and the membership, I am confident that I will be able to achieve all the above goals towards uplifting of the status of the Institute of Chemistry.

Prof. H M K K Pathirana

BSc (University of Sri Lanka, Vidyodaya Campus), PhD (University of Aston in Birmingham, U.K.), C.Chem., F.I.Chem.C.

President, Institute of Chemistry Ceylon

Emeritus Professor, Department of Chemistry, University of Ruhuna

Induction of the 88th President and Annual Dinner of the Institute of Chemistry Ceylon - 2025

Chief Guest's Address

Value addition to local mineral resources

Professor Emeritus O. A. Ileperuma
Department of Chemistry, University of Peradeniya

It is both an honour and a privilege to be invited as the Chief Guest for the inauguration of Prof. Hema Pathirana, as the new President of the Institute of Chemistry. I wish to share some thoughts on the use of natural resources, particularly mineral resources from decades of my experience for the economic development of Sri Lanka.

Sri Lanka has an abundance of high quality mineral deposits which have not been effectively utilised for the economic development of the country. While some have not been exploited to their full potential, others are sold at a pittance to overseas buyers. Our industrial policies have never entailed using mineral resources for economic development.

Exploitation of mineral resources without the concomitant development of a chemical industry is meaningless; neither is possible without the other. At the present time we do not have a single chemical industry in Sri Lanka going by the true definition of "chemical industry". When the Paranthan chemical factory was functioning, we manufactured caustic soda for the soap industry and even manufactured hydrochloric acid and chlorine for a brief period. Similarly, this factory had the capacity to produce hydrochloric acid and also bleaching powder used for the chlorination of our water supplies. These can be conveniently manufactured in Sri Lanka if we plan an integrated chemical industry. Commissioning a sulphuric acid plant can supply the requirement for a superphosphate plant to manufacture phosphate fertiliser from Eppawela apatite. In addition, such a plant could provide the acid required to fill the lead acid batteries used in vehicles which we import at the present time. Sulphuric acid is one of the cheapest acids since the raw material sulphur removed from petroleum at refineries is available at a very cheap price. Some examples of mineral resource utilization are given below.

1. Eppawela phosphate deposit to produce superphosphate fertiliser.

If we produce sulphuric acid, then it is possible to produce single superphosphate from apatite which can then be used to supply all our phosphate fertiliser requirements. Lanka Phosphate Ltd. produced 20 tons of single superphosphate (SSP) using a second hand steel container and a wooden paddle by mixing the mined ore from Eppawela with sulphuric acid. These were tested in all agricultural regions of the country. The SSP produced was found to be better even compared to the imported triple superphosphate (TSP) because the SSP contained sulphur in addition to phosphate and sulphur is an essential nutrient to plants. What is attractive is that the whole cost can be recovered in about 3 years while providing phosphate fertiliser at half the current selling price.

2. Value addition to mineral sands

Another mineral based industry that could be developed is the mineral sands industry. At the moment we export mineral sands such as rutile and ilmenite at cheap prices to overseas companies. These can be converted to pigment grade titanium dioxide by digesting these minerals with sulphuric acid. There is a novel and a more economical process using autoclaving the mineral with sulphuric acid at a low temperature.

3. Monazite and rare earths

We have an abundance of a deposit of monazite containing thorium and rare earths at Beruwela. Thorium found in monazite can be used in the production of nuclear fuels. At one time we had a small processing plant at Katukurunda for processing monazite and the rare earth phosphates of lanthanum, cerium and yttrium found in this type of sand. There is a great demand for rare earths since these metals are used

as magnets and as sensors in the electronics industry. Beneficiation and separation of the rare earths can have a positive economic impact considering the current demand. In the actual process monazite is treated with concentrated sulphuric acid at about 230 °C and the rare earth sulphates so formed are separated by a complex process of precipitation, solvent extraction and chromatography.

Another mineral which needs attention is thorianite, an extremely pure form of thorium oxide which was exported from Sri Lanka during early 1900's from mines at Nelluwa in the Galle district. Marie Curie's fundamental work on radioactivity was based on thorianite from Ceylon. Some other discoveries using our thorianite are; the radioactive decay law, discovery of polonium and radon. The Sri Lankan origin of thorianite is clearly mentioned in her published research papers. If thorianite can be mined, then its export will give dividends particularly because thorium based nuclear fuels are now studied as an alternative to uranium fuels.

4. Quartz

High quality quartz is found from many locations in the country and these are currently exported in the raw form without any value addition. It is the raw material used in producing silicon used for the huge semiconductor industry. Silicon production from quartz in Sri Lanka is not economical since it is technologically very complex and the electricity requirements are very high. However, there are many other smaller industries which can be started with quartz as the raw material such as water glass (sodium silicate), quartz lenses and other quartz glass items which involve simple melting and reforming of quartz.

5. Graphite based industries

There are a number of other minerals where value addition can be carried out in Sri Lanka. The best quality graphite in the world has always come from Sri Lanka and only about 5% of the total graphite mined is used in Sri Lanka. Also, the Ceylon Ceramics Corporation at one time had a small crucible factory where graphite was used to make crucibles for the foundry industry. This industry too died as a result of the post 1977 economic liberalisation policy. All graphite we mine now is exported and we buy the finished products of graphite such as carbon brushes for motors and electrodes for dry batteries from abroad at exorbitant prices. Sri Lanka can do well by starting a graphite based industry to manufacture carbon brushes, electrodes for torch batteries and graphite greases. Several methods are available for the exfoliation of graphene from graphite. Graphene and graphene oxide are two recent products with commercial applications.

6. Iron industry

There was a well-developed iron industry in Sri Lanka before the British Colonial times. Archaeological evidence points out to a well organised steel industry dating as far back as 1200 A.D. long before Europe's first bellow driven iron manufacturing plants came into operation. There is evidence for a large steel manufacturing facility in the southern slopes of the Samanalawewa area where wind tunnels were used to create the high temperatures required for the iron making process. A British archaeologist working in the Samanalawewa area actually produced iron by reconstructing such wind tunnels using iron ore available here. Recently a good quality magnetite ore has been discovered off Buttala by geologists of the University of Peradeniya. This ore contains about 60 –70% iron in quite a pure form and found at the surface and far superior in quality to already recorded iron ore deposits found elsewhere in the country. Even if we export this ore without value addition, we can earn valuable foreign exchange.

The possibility of starting an iron industry using the magnetite ore along with limestone should be explored.

7. Limestones and precipitated calcium carbonate

The drug industry uses magnesium carbonate and calcium carbonate as bulking components of drugs. Our dolomite can be exploited for this purpose. Toothpaste manufacture also involves calcium carbonate and we import nearly 100,000 tons of precipitated calcium carbonate per year and it is a crime to spend so much for importing calcium carbonate because we have ample deposits of calcium carbonate. We have a calcite deposit at Balangoda which is pure calcium carbonate. Precipitated calcium carbonate required by many

industries can be made starting with this deposit of calcite.

8. Other mineral resources

One interesting mineral deposit is the iron pyrites ore at Panirendawa in the Seruvila area. This is the only sulphur containing mineral found in Sri Lanka and the only one with copper. This is a neglected resource, and these pyrite ores usually also have gold in its composition. Gold plating of pinnacles of stupas is where gold has been used from Sri Lanka. In addition, gold nuggets are found at Balangoda in the Walave river and its tributaries.

There is also an often neglected mineral at Ussangoda area at Hambantota. Here we can find greenish rocks of serpentinite containing nickel and even the red soil is rich in nickel. A simple process to extract nickel using sulphuric acid can produce nickel sulphate which can be directly used in nickel plating: For example nickel plating of pesticide tanks already carried out in Sri Lanka uses imported nickel sulphate.

I wish all the best to the newly inducted President Professor Emeritus Hema Pathirana and to the Institute of Chemistry to achieve all its targets.

Prof. O. A. Ileperuma *was a Senior Professor in the Department of Chemistry of University of Peradeniya and retired in 2014. His distinguished career in academia was also enriched with numerous contributions to the university administration by serving as the Head of the Department of Chemistry, Dean of the Faculty of Science and a Council member of University of Peradeniya. His active involvement in various national services is also remarkable. Considering his outstanding contributions as an academic he was appointed as an Emeritus Professor by the University of Peradeniya. He is an Inorganic Chemist having over 70 publications in International journals. Currently he is serving the University of Peradeniya as a member of the council and serves as a resource person for its development activities.*

CHEMISTRY IN SRI LANKA

Chemistry in Sri Lanka is a tri-annual publication of the Institute of Chemistry Ceylon and is published in January, May and September of each year. It is circulated among the members of the Institute of Chemistry and students of the Graduateship/DLTC course and libraries. The publication has a wide circulation and more than 500 copies are published. Award winning lectures, abstracts of communications to be presented at the annual sessions, review papers, activities of the institute, membership news are some of the items included in the magazine.

The editor invites from the membership the following items for publication in the next issue of the Chemistry in Sri Lanka which is due to be released in January 2026.

- *Personal news of the members*
- *Brief articles of topical interests*
- *Forthcoming conferences, seminars and workshops*
- *Latest text books and monographs of interest to chemists*

All publications will be subjected to approval of the 'Editorial and Publicity Committee' and the Council of the Institute of Chemistry Ceylon.

Further, prospective career opportunities for chemists, could be advertised in Chemistry in Sri Lanka at a nominal payment. The editor in charge welcomes suggestions from the members for improvement of the publication.

Induction of the 88th President and Annual Dinner of the Institute of Chemistry Ceylon - 2025

Head Table at the Induction Ceremony

Welcome address by Prof. Janitha A Liyanage

Prof. Hema Pathirana being inducted as the 88th President of the IChemC

Prof. Hema Pathirana addressing the gathering

Chief Guest, Prof. Emeritus O. A. Illeperuma

Guest of Honor, Prof. Kapila Seneviratne

participants

Cultural programme

54th Annual Sessions and 84th Anniversary Celebrations 2025

Inauguration Ceremony

Head Table at the Inauguration Ceremony

Welcome Speech and Presidential Address by Prof. Janitha A Liyanage

Chief Guest, Prof. Uday Maitra

Guest of Honor, Prof. Saptarshi Mukherjee

Distinguished Service Award - Prof. Sudantha Liyanage

Yeoman Service Award - Prof. Ramanee Wijesekera

Winners of the Inter School Chemistry Quiz

Winners of the Sri Lanka National Chemistry Olympiad

Guest Articles

Safe Cosmetic Practices: Beauty without Harm

Dr. Indira Kahawita

Consultant Dermatologist, National Hospital of Sri Lanka

Introduction

Cosmetics have become an integral part of personal grooming and self-expression in today's world. From skin care to makeup and hair products, these items play a significant role in enhancing appearance and boosting self-esteem. However, the widespread and often unregulated use of cosmetics can lead to unexpected health risks if not used responsibly. This article explores the fundamentals of cosmetic use, potential hazards, and how to adopt safe practices for long-term well-being.

Understanding Cosmetics: Definitions and Applications

Cosmetics are defined as substance or preparation that are intended to be placed in contact with various external parts of the human body or with the teeth or the mucous membranes of the oral cavity with a view exclusively or mainly to cleaning, perfuming, changing appearance correcting body odors, protecting or keeping them in good condition[1, 2].

Cosmetic products are designed for application to one or more external parts of the human body. These include the epidermis (such as the skin and the area around the eyes), the hair system, nails, lips, and external genital organs, as well as the teeth and mucous membranes of the oral cavity. The classification of a product as a cosmetic is primarily determined by its site of application and its intended cosmetic function, such as cleansing, beautifying or protecting these areas.

Cosmetic products encompass a wide range of preparations to enhance appearance, hygiene, and personal care. These include moisturizing preparations such as creams, lotions, gels, and oils; skin lightening and anti-aging products; and a variety of hair care items including tints, bleaches, shampoos, conditioners, and styling products. Other examples include bath and shower preparations, soaps, shaving products, baby and facial wipes, depilatories, deodorants, products for external intimate hygiene, and facial masks[2]. However, it is important to note that not all personal care or beauty-related products are classified as cosmetics. Items such as massage oils, essential oils used for aromatherapy, aesthetic devices, lubricants, insect repellents, sanitary pads, hand sanitizers, and medicated creams for skin conditions like eczema or acne are not considered cosmetics. Additionally, tools like toothbrushes, dental floss, fake eyelashes, nail stickers, and temporary tattoos, as well as any substances intended for ingestion, inhalation, injection, or implantation, fall outside the regulatory definition of a cosmetic product.

Proper Use of Cosmetics

When purchasing a cosmetic product, it is essential to evaluate several key details to ensure safety and suitability. These include the product's name, intended function, instructions for use, and a clear listing of ingredients; either main or complete, depending on the packaging size. Additionally, one should verify the country and address of manufacture, batch number, date of manufacture, expiry date or best-before date, and any relevant warnings or special precautions[3].

Safe cosmetic use also depends on proper handling before and after opening. Prior to use, reading the instructions carefully. Performing a patch test; especially for products like hair dyes is highly recommended. Once opened, products should be stored as instructed, kept tightly sealed, and discarded if expired, discolored, or if any change in smell is noticed. For added safety, cosmetics should always be kept out of reach of children.

Specific caution is advised in certain situations: for instance, alcohol-based products such as eau de cologne should not be used in infants under one year, baby powders should be avoided in the perineal area of female infants, and particular care should be taken

when selecting products during the preconception period and pregnancy, especially in the first trimester. Furthermore, the use of sunscreen is encouraged to prevent photo-induced skin darkening.

Benefits of Using Cosmetics

Cosmetics Improve the overall appearance of a person without making any permanent changes in the structure or the texture of the skin. Cosmetics may camouflage skin imperfections or conditions such as melasma or vitiligo, leading to improved self confidence in those affected. Another important function is to support skin and hair health through cleansing, moisturizing and protection. In many persons, especially the young, cosmetics help one to establish an identity or make a statement.

Risks and Adverse Effects of Cosmetics

Despite their benefits, cosmetics can cause significant harm, particularly when misused or when substandard products are used. Some common adverse effects include allergic reactions (especially from fragrances or preservatives), acne (Figure 1), changes in pigmentation (Figure 2), fungal infections, telangiectasia (Figure 3), stretch marks (Figure 4) and perioral dermatitis[4].

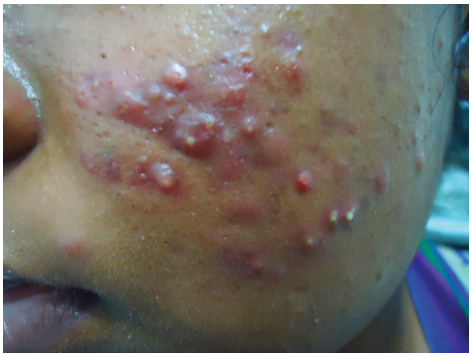

Figure 1: Cosmetic acne

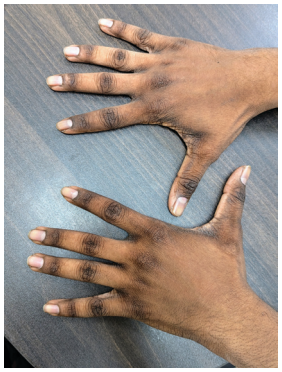

Figure 2: pigmentation of hands

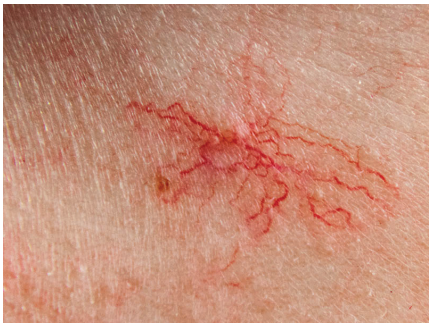

Figure 3: telangiectasia

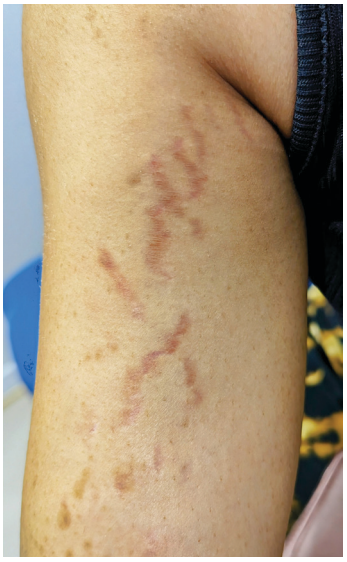

Figure 4: steroid induced striae

Hair dye allergy: Hair dye allergy is a relatively common adverse reaction that typically develops after repeated use, rather than upon the first exposure. Allergy can occur with various forms of permanent and semi-permanent hair coloring agents, including black henna and dye-based shampoos. The usual allergen is paraphenylenediamine, or PPD[5]. N-Isoprophyl-N-Phenyl- paraphenylenediamine (IPPD), which may be found in some rubber products, can act as a sensitizer for those with allergy to PPD[6]. Other potential allergens in hair dye include other aromatic amines, preservatives and fragrances[6]. Clinical manifestations often include itching, redness, eczematous rashes on the scalp, or facial swelling, usually emerging immediately or within two to three days after application. Management involves the use of topical or oral corticosteroids along with antihistamines to alleviate symptoms. Discontinuation of the offending product is mandatory. It has to be borne in mid that the allergy is due to the PPD, which is the usual ingredient in all permanent hair dye. Hence,

changing the brand of the dye is of no use. In some cases, safer alternatives free of PPD may be considered, but these products need frequent applications.

Common allergens in cosmetic products[7, 8]:

- Fragrance mixes I and II
- Balsam of Peru
- Methylchloroisothiazolinone / methyliso-thiazolinone (MCI/MI) (in leave on products)
- Lanolin alcohol

Awareness of these components is crucial for individuals with sensitive skin or a history of allergies.

The Hidden Dangers of Skin Whitening Creams

Skin whitening creams have gained widespread popularity due to aesthetic preferences and societal pressures. However, the ingredients used in many of these products can pose significant health hazards if not properly regulated or used under medical supervision.

A common active ingredient in whitening creams is hydroquinone, a depigmenting agent that inhibits melanin production. The accepted upper limit of hydroquinone (HQ) in prescription products is 4%. Its metabolites such as p-benzoquinone and glutathione conjugates formed in the liver and bone marrow, can cause DNA damage, genetic mutations, and disrupt cellular protective mechanisms, thereby increasing the risk of cancer. In the bone marrow, these metabolites may also contribute to serious conditions like aplastic anemia and acute myeloid leukemia, similar to effects observed in benzene toxicity. Nephrotoxicity, hepatic and renal adenomas and leukaemia has been reported in animal models following systemic absorption of HQ. Because of the concerns of these side effects in humans, US FDA and many other regulatory authorities have banned HQ in over-the-counter skin lightening products[9, 10]

Exogenous ochronosis, characterized by bluish-black pigment deposits on the skin, is a disfiguring condition linked to chronic hydroquinone use. Although there is currently no direct evidence linking topical hydroquinone use to cancer in humans, healthcare professionals should remain cautious of its possible systemic effects.

Additionally, these creams often contain topical corticosteroids, particularly high-potency steroids such as clobetasol, betamethasone and mometasone, which are inappropriate for facial use and can lead to long-term skin damage. Potent steroids in these creams may cause suppression of the hypothalamic-pituitary-adrenal (HPA) axis. Steroid dependency, where the skin becomes reliant on corticosteroids for normal appearance, is another concerning outcome. Other documented side effects include poor wound healing, thinning of the skin, stretch marks, permanently dilated capillaries (telangiectasia) increased risk of infections, and serious systemic consequences such as nephropathy. International League of Dermatological Societies issued a position statement in 2025 calling for global action on skin bleaching and the misuse of topical corticosteroids[11]

Heavy metals, including mercury and lead, are also frequently detected in these products, despite their known systemic toxicity. In the Sri Lankan context, laboratory testing for heavy metals in cosmetic products is carried out on a regular basis. The Consumer Affairs Authority recently published a list of 49 products containing mercury over the approved limit, which is 1 part per million. Some of these products are known to contain very high amounts of mercury and lead[12].

A study conducted in Iran assessed the presence of toxic metals such as lead, cadmium, and chromium in various lipstick brands from different countries[13]. Although the metal concentrations were within internationally accepted limits, significant variations were found between brands. Findings revealed that over 50% of the lipstick brands posed a potential health risk due to the presence of toxic metals. The authors emphasize the need for continuous monitoring of heavy metal content in cosmetics, especially considering the cumulative exposure from the use of multiple cosmetic products[13].

Systemic absorption of mercury may give rise to serious adverse effects. Nephropathy, both minimal change and membranous types have been reported[14-18]. Although penetration of the blood-brain barrier by inorganic mercury is poor, prolonged exposure can result in central nervous system (CNS) accumulation and neurotoxicity[19, 20]. Evaluation of the urine mercury concentration is supposed to be the best marker of mercury poisoning[19]. Other effects

reported in chronic use of mercury containing products include skin pigmentation and nail discolouration[21, 22]. Effects of methylmercury on the growing foetus have been well recorded. Neuropsychiatric symptoms and developmental delay have been reported[23-27].

Glutathione (GSH), a naturally occurring antioxidant, has gained popularity for its skin lightening effects, particularly through intravenous (IV) administration, despite limited scientific support. There is no clinical research supporting the safety or efficacy of long-term IV glutathione use for cosmetic purposes. Importantly, the lack of data on chronic use raises serious safety concerns[28]. One theoretical risk includes a shift from eumelanin to pheomelanin, potentially increasing the susceptibility to sun-induced skin cancers. The widespread and unregulated availability of injectable glutathione, especially from online sources further amplifies the danger of adverse effects and infusion-related complications.

Given these risks, the use of skin whitening creams especially those purchased without proper labeling or regulatory approval should be approached with extreme caution. Public awareness and stronger regulatory enforcement are essential to prevent the harmful consequences associated with these products.

Cosmetic Products and risk of cancer

There is growing concern and ongoing investigation into whether cosmetics contribute to risk of cancer. While definitive links are yet to be proven, studies have raised red flags about several types of cosmetics

Skin lightening products: there is a theoretical risk of skin cancer in long term usage of skin lightening products. Melanin, in particular eumelanin, absorbs UV radiation thus preventing the possible DNA damage due to UV rays. In addition, melanin has some antioxidant properties scavenging free radicals formed by UV radiation.

Thus, the reduced amount of melanin due to prolonged use of skin lightening products is likely to predispose individuals to skin cancer. So far, several case reports, most of them from Africa, of Squamous cell carcinoma occurring in persons using skin lightening products have been reported[29-32].

Hair dyes: Studies conducted in Finland, USA among both black and white individuals found evidence that prolonged use of hair dyes and hair straighteners may increase the risk of breast cancer[33]. Black individuals and prolonged users were at higher risk. A meta-analysis concluded that there is 18.8% increased risk of future breast cancer among hair dye users[34]

Talc-based powders: Several systematic reviews and meta-analyses confirm that there is increased risk of ovarian cancer associated with frequent perineal powder exposure.[35-37]. The use of talcum powder on the perineal region of females in strongly discouraged.

Antiperspirants: There is a popular belief that antiperspirants and deodorants pose a risk for breast cancer. Several meta-analyses of published literature failed to find a causative association between antiperspirants/ deodorants and breast cancer[38, 39].

In Sri Lanka, skin cancer incidence is on the rise. Although no direct association with cosmetic use has been established, the need for prospective studies on this subject is evident.

Conclusion

Cosmetics, when chosen and used wisely, can be valuable tools in enhancing personal appearance and self-esteem. However, the unregulated or indiscriminate use of certain products, especially whitening creams and hair dyes can lead to significant health complications. As consumers, awareness and caution are crucial. Always opt for safe, approved products, use them as directed, and consult healthcare professionals when in doubt. Beauty should never come at the cost of your health.

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Fuel Cells: A Quiet Revolution Powering a Sustainable Future

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Introduction: From Combustion to Conversion

Human progress has long been fuelled by combustion, but that very dependence has brought us to the edge of a planetary crisis. The continuous burning of fossil fuels has released immense quantities of carbon dioxide and other greenhouse gases, accelerating global warming. The Swedish chemist Svante Arrhenius[1] was among the first to describe this phenomenon in the late 19th century, yet it has taken over a century for the urgency of his insight to shape global energy policy. Today, as nations rally around net-zero commitments, the need for cleaner and more sustainable energy sources has never been greater.

Among the emerging technologies capable of answering this call, hydrogen fuel cells have emerged as one of the most promising. Hydrogen, long recognized as a crucial element in the transition to a sustainable energy future, offers the potential to provide abundant, clean, and secure energy.[2] When combined with fuel cell systems, hydrogen enables electricity generation without combustion, a process that emits only water vapor as its by-product. This elegant chemistry not only eliminates local pollutants such as nitrogen oxides and particulates but also provides exceptional energy efficiency, converting chemical energy directly into electrical energy at efficiencies reaching nearly eighty percent in certain systems.

Evolution and Principles of Fuel Cells

The journey of fuel cell technology began in 1838, when the German chemist Friedrich Schönbein first demonstrated the electrochemical reaction between hydrogen and oxygen. Several decades later, Sir Thomas Francis Bacon built upon this foundation to create the first practical hydrogen-oxygen fuel cell using nickel electrodes.[3] Although initially expensive and limited to laboratory research, Bacon's design established the principles that continue to guide fuel cell innovation today.

Modern research has since expanded fuel cell technology into several distinct types, each designed for specific operating conditions and applications. These include proton exchange membrane fuel cells, direct methanol fuel cells, alkaline fuel cells, phosphoric acid fuel cells, molten carbonate fuel cells, and solid oxide fuel cells, while more recent developments, such as microbial fuel cells, use biological catalysts to generate electricity from organic substrates. Of these, the proton exchange membrane fuel cell, often abbreviated PEMFC, has gained particular prominence due to its compact design, rapid start-up, and adaptability to mobile and stationary power uses.[4]

A PEM fuel cell works by converting hydrogen and oxygen into electricity through two complementary reactions: hydrogen oxidation at the anode and oxygen reduction at the cathode. Protons migrate through a polymer electrolyte membrane while electrons travel through an external circuit, creating a continuous flow of current.[5, 6] The overall reaction produces electricity, heat, and pure water, demonstrating the harmony between scientific ingenuity and environmental stewardship.

At the heart of the cell lies a sophisticated combination of materials. The electrodes are typically made from carbon-supported platinum catalysts blended with a proton-conducting polymer such as Nafion. The membrane allows protons to pass while keeping the gases separated, maintaining both chemical integrity and electrical isolation. Surrounding these components are gas diffusion layers made of porous carbon fibers treated with Teflon, which distribute the reactant gases, manage moisture, and collect current.[7, 8]

Despite decades of refinement, challenges remain. Only a fraction of the platinum catalyst surface area actively contributes to the reaction because of uneven ionomer distribution and restricted gas diffusion within the electrode. These microscopic inefficiencies, especially at the cathode where oxygen reduction is sluggish, reduce the overall cell efficiency.[7,9] Researchers are addressing these limitations through innovative

catalyst nanostructures, improved ionomer interfaces, and alternative materials that promise to lower cost and enhance durability.

Applications Across Sectors

Fuel cells are remarkable for their versatility, capable of powering everything from handheld devices to megawatt-scale power plants. Their applications can be broadly grouped into portable, stationary, and transportation domains, each with distinct technological and economic potential.

In the portable sector, fuel cells provide power for devices that traditionally rely on batteries, such as laptops, communication equipment, and small appliances. They are also used in outdoor and emergency power generation for activities like camping, disaster relief, and remote monitoring. These systems, which range from a few watts to several hundred watts, offer far higher energy density than rechargeable batteries and can operate for extended periods without recharging. While their commercial success is limited by cost and component lifespan, the growing demand for clean, mobile power continues to drive innovation in this area.

Stationary fuel cells represent the most mature and widespread application. Used for residential, commercial, and industrial power generation, they provide both stand-alone and grid-connected electricity. Their modular design, quiet operation, and ability to deliver combined heat and power make them ideal for decentralized energy systems. In particular, polymer electrolyte and direct methanol fuel cells have gained traction in telecommunications and emergency backup installations, replacing traditional diesel generators. Because they can operate under harsh conditions and require minimal maintenance, stationary fuel cells are now viewed as key enablers of distributed generation and microgrids, providing resilient power to communities and industries alike.

Perhaps the most transformative potential of fuel cells lies within the transportation sector. This industry accounts for a substantial share of global greenhouse gas emissions and decarbonizing it is central to achieving climate goals. Fuel cell electric vehicles, often referred to as FCEVs, offer a compelling alternative to internal combustion engines. They provide the range and refueling convenience of conventional cars while eliminating tailpipe emissions. Leading manufacturers such as Toyota, Hyundai, and Honda have introduced commercial models powered by hydrogen fuel cells, demonstrating that this technology is no longer confined to the laboratory. Beyond passenger vehicles, fuel cell systems are being developed for buses, trucks, trains, ships, and even aircraft, signaling a gradual but determined shift toward a cleaner transportation ecosystem.

Scientific and Engineering Challenges

Although fuel cells embody the ideals of sustainable chemistry, several scientific and engineering barriers still limit their widespread adoption. One of the most significant challenges is the dependence on platinum, a rare and costly metal, as the catalyst for both the hydrogen oxidation and oxygen reduction reactions.[4] Considerable global research effort is now devoted to developing platinum-alloy catalysts, core–shell nanostructures, and non-precious metal alternatives that maintain stability and activity while reducing cost.[10, 11]

Another critical issue concerns the longevity of the polymer membrane, which must withstand mechanical stress, high temperature, and chemical attack during continuous operation. Degradation of the membrane can lead to fuel crossover and reduced performance, so developing more resilient polymers remains a major research focus. Equally important is water and heat management: excess water can flood the electrode pores, while insufficient hydration increases electrical resistance. Innovative micro-porous layers, controlled humidity systems, and advanced flow-field designs are being engineered to manage these dynamics effectively.[12]

Finally, the success of fuel cells depends on a reliable hydrogen infrastructure. Sustainably producing hydrogen, ideally through electrolysis powered by renewable energy, remains a formidable logistical and economic challenge. Advances in storage materials, distribution networks, and safety protocols are vital to ensure that hydrogen can be delivered efficiently and safely at scale.[13]

The Future and Prospects of Fuel Cell Technology

The prospects for fuel cell technology are as dynamic as the field itself. Research is steadily moving toward systems that are not only efficient and durable but also economically competitive with conventional energy sources. The development of green hydrogen, produced through electrolysis powered by renewable energy, offers a pathway to close the carbon loop entirely. As renewable energy generation expands globally, coupling it with large-scale hydrogen production can ensure a continuous and flexible power supply that complements intermittent sources like solar and wind.

Advancements in materials science, particularly in the design of nanostructured catalysts and high-performance composite membranes, are expected to reduce costs while improving performance. Artificial intelligence and data-driven modeling now aid the design of optimized fuel cell components, accelerating discovery and commercialization. Furthermore, the integration of fuel cells into hybrid systems that combine batteries or supercapacitors is opening new frontiers in smart grid management, electric mobility, and off-grid electrification.

In the coming years, decentralized power systems supported by compact fuel cell units could become essential for energy access in remote areas and disaster recovery operations. As international collaboration strengthens and regulatory frameworks evolve, fuel cells are poised to transition from niche applications to a mainstream energy solution. Their quiet operation, clean by-products, and scalable design embody a technology perfectly aligned with the goals of sustainable development and circular energy systems.

Fuel cells demonstrate how chemistry and engineering together can redefine the way humanity generates and uses energy. From the pioneering experiments of the 19th century to the sophisticated systems of today, this technology has traveled a remarkable path. As materials improve, costs decline, and infrastructure expands, fuel cells will continue to transform sectors ranging from transportation to power generation. They represent not only a scientific achievement but a moral imperative, a cleaner, quieter, and more sustainable answer to the energy challenges of our age.

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Guest Articles

Electrospinning: A versatile approach of making innovative materials

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Electrospinning is a method extensively used for producing nanomaterials, particularly nanofibers. It is a technique where, a high voltage electric field is used to produce electrically charged jets from a polymer solution which then upon evaporation make nanofibers of the polymer. Electrospinning is a technique of fabricating man-made fibers using electrostatic forces. Polymers that are commonly used for electrospinning include polyvinylidene fluoride polysulfone, polyacrylonitrile (PAN), polyvinyl alcohol, cellulose acetate, and polyurethane.

This technique, known earlier as "electrostatic spinning," was discovered long ago. J.F. Cooley and W.D. Morton initially patented electrospinning in 1902 and gave details of the apparatus for electrically dispersing fluids. Generally, any electrospinning apparatus consists of three major components namely, a high voltage supply, a spinneret (metallic needle) and a collector (Figure 1). Usually, the polymer solutions are fed using a syringe pump, which is connected to the high voltage power supply, at a controlled rate. The highly charged polymer suspension in the syringe needle, directs fibers towards the oppositely charged collector, which can be a flat surface or a rotating drum, to collect the fibers. In conventional spinning techniques, the fiber is subjected to a group of forces such as tensile, gravitational, aerodynamic, rheological, and inertial, whereas in electrospinning, the spinning of fibers is achieved primarily by the tensile forces created in the axial direction of the flow of the polymer by the induced charges in the presence of an electric field.

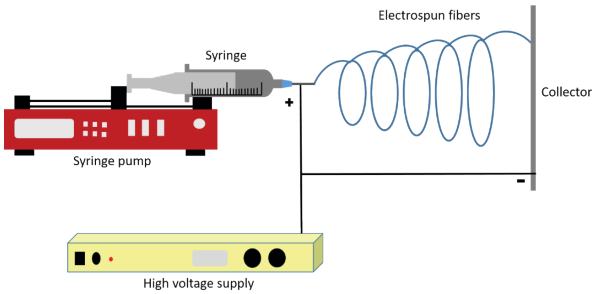

Figure 1. Schematic diagram of electrospinning apparatus

Further, by modifying simple electrospinning, a further step has moved forward to make coaxial electrospinning, in which by introducing multiple feed solutions to simultaneously electrospin two or more polymer solutions from coaxial capillaries. The spinnerets are sharing an axis, allowing for the injection of one solution into the other at the needle tip with the core fluid getting drawn within the outer one to produce continuous coated or hollow nanofibers. Moreover, coaxial spinning is highly effective in encapsulating

active materials in core-shell structures.

Typically, the produced nanomaterials are in fiber form in conventional electrospinning and core-shell structured fibers in coaxial electrospinning., which results in fiber mats or thin sheets. Usually the nanofibers are having very small diameters (<100 nm) are obtained by this technique. However, this simple basic 2-D mat form of electrospinning product has now advanced into making more complex structures with different shapes and even 3-D dimensions. Therefore, the applications of electrospinning vary from making water filtration membranes, advance textiles such as wearable electronics, energy devices such as battery/ supercapacitor electrodes and sensors, to biomedical applications such as wound dressings, drug delivery, tissue implants, biological scaffolds and also as a nanoencapsulation method to deliver drugs, cosmetics, fertilizers, etc.

The versatility of electrospinning method lies in the fact that ability to modify the polymer solutions with the materials as required by the application and also the potential of fibers to be modified in terms of constituents in order to improve target properties like mechanical properties, which are crucial in practical applications of using such materials. For example, an electrospun wound dressing can be prepared by adding antimicrobial agents to the neat polymer solution and also by including clay-like material to improve its tensile strength and hardness. In membrane technologies, elecrospun nanofiborus membranes (ENM) remains to be very attractive due to their high porosity ranging from nanometers to several micro meters, interconnected open pore structure, high permeability and high surface area per unit volume. Therefore, ENMs are considered as the most versatile, simple and efficient mode of membrane technology today.

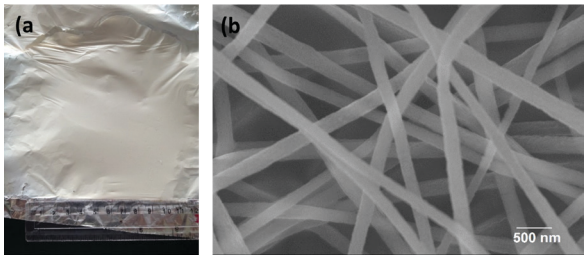

Figure 2. (a) electrospun polyacrylonitrile nanofiber mat (b) SEM image of PAN nanofibers

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Tetrapyrroles: Central molecules in life

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Introduction

Life on Earth would be unimaginable without tetrapyrroles. These structurally diverse and functionally rich molecules support numerous physiological processes, forming a crucial bridge between chemistry and biology. Their structural flexibility and functional variety have enabled life to adapt and flourish in diverse environments, ranging from sunlit forests to deep sea vents.

Well-known tetrapyrroles include hemes, which impart the red colour to blood and facilitate oxygen transport; chlorophylls, the central pigments of photosynthesis in plants, algae and cyanobacteria; and cobalamin (vitamin B_{12}), an essential micronutrient in human metabolism. Others, such as siroheme, coenzyme F_{430}, heme d1, and bilins, are equally significant across different biological contexts.[1]

Beyond their natural biological functions, tetrapyrroles have attracted attention for their promising roles in renewable energy, biotechnology, medicine, and sustainable agriculture.[2,3]

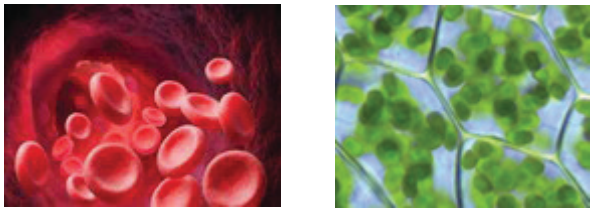


Figure 1: Red blood cells and chloroplasts - two sites of essential tetrapyrroles

Structure and chemistry of tetrapyrroles

As the name implies, tetrapyrroles are built from four pyrrole or pyrrole-like units. These units are interconnected *via* carbon bridges; typically, methine (–CH=) or methylene ($–CH_2–$), forming either linear or macrocyclic structures.

The aromaticity of pyrrole arises from six π-electrons delocalized over the ring, complying with Hückel's rule (4n+2; n=1). The N atom possesses a lone pair of electrons. In pyrrole-based macromolecules, this lone pair of electrons participates in coordination with metal ions, contributing to the stabilization of metal–ligand complexes.

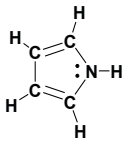
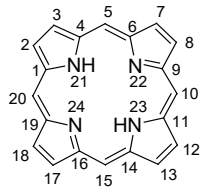


Figure 2: Pyrrole ring - a planar, aromatic heterocycle with six π-electrons

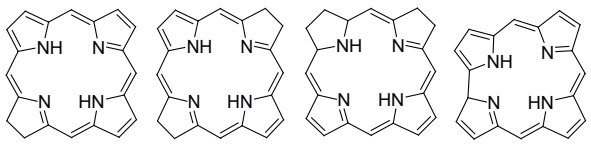
The chemical and structural diversity of tetrapyrroles arises from variations in the ring connectivity, the presence or absence of ring closures, the nature of side-chain substituents, chelated metal ions, and oxidation states of the rings.

Cyclic tetrapyrroles:

Cyclic tetrapyrroles can exist in various forms, like porphyrin, chlorin, bacteriochlorin, isobacteriochlorin and corrin. Substituents at peripheral positions and the coordination of metal ions (e.g., Fe^{2+}/Fe^{3+}, Mg^{2+}, Co^{3+}) expand the functional diversity of these macromolecules.



Porphin (porphine): The simplest porphyrin



Chlorin Bacteriochlorin Isobacteriochlorin Corrin

Figure 3: Basic skeletons of cyclic tetrapyrroles

a. Porphyrins

In porphyrin, the four pyrrole rings are linked *via* methyne (-CH=) bridges to form a planar, rigid, highly conjugated 18 π-electron system. Due to the π-electron delocalization, they exhibit strong light-

absorbing properties, particularly in the visible region of the electromagnetic spectrum, making them deeply coloured. The term 'porphyrin' is derived from the Greek word *porphyra*, meaning purple.[4]

These macrocycles can delocalize π-electrons through six equivalent pathways, contributing to their remarkable aromatic character.

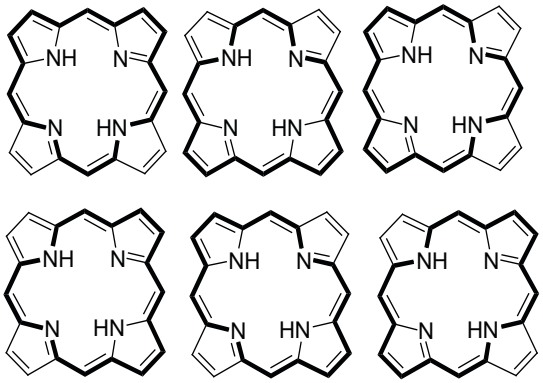


Figure 4: Delocalization pathways in porphyrin

Different substituents can be attached at the eight β-positions of the pyrrole rings or the four meso-positions on the methine bridges.

Prominent examples include heme A, heme B, and siroheme, all of which incorporate iron (Fe^{2+}/Fe^{3+}) in their core. Their distribution and functions are summarized below in Table 1.[1]

b. Chlorins

Chlorins are reduced derivatives of porphyrins (dihydroporphyrin) in which one pyrrole ring is partially saturated. This leads to the loss of aromaticity in that part of the ring but enhances absorption of light in the red region of the spectrum. Natural examples include chlorophyll a and b, which incorporate a central Mg^{2+} ion and a hydrophobic phytol tail.

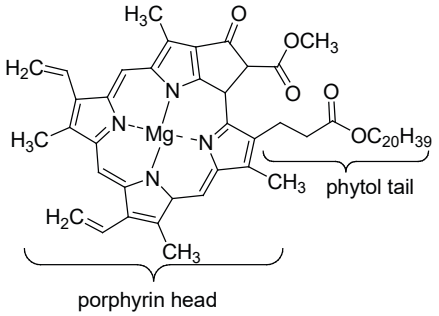


Figure 5: Chlorophyll a with a porphyrin head and phytol tail

c. Bacteriochlorins and isobacteriochlorins

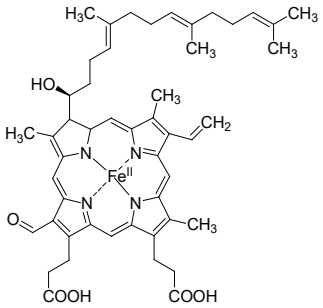
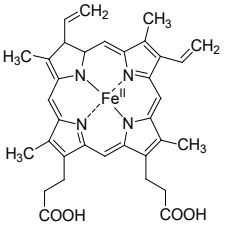
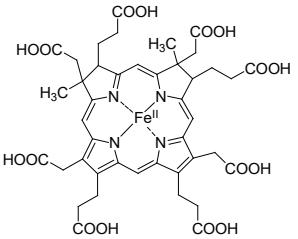
Bacteriochlorins possess two reduced pyrrole rings, further disrupting conjugation. Bacteriochlorophylls, found in photosynthetic bacteria, serve as efficient light-harvesting pigments.

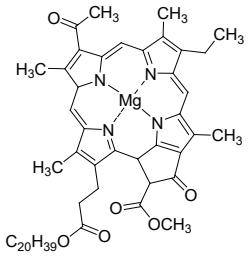
Isobacteriochlorins, such as coenzyme F_{430} (Ni^{2+} center), feature adjacent reduced pyrroles with *cis*-oriented NH groups. Coenzyme F_{430} is essential in methanogenesis.

d. Corrins

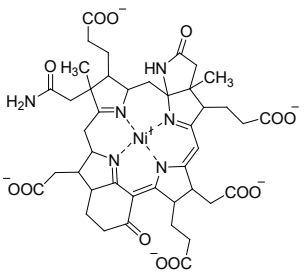
Corrins are structurally similar to porphyrins but lack one methine bridge, resulting in a more flexible macrocycle. Cobalamin (vitamin B_{12}), a cobalt-containing corrin, acts as a cofactor in DNA synthesis and methyl group transfers.

Table 1: The structure and occurrence of heme porphyrins

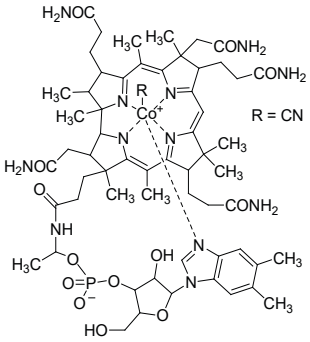
Heme Type	Heme A	Heme B	Siroheme
Occurrence	Cytochrome c oxidase (Complex IV) in mitochondria and bacteria	Hemoglobin, myoglobin, cytochrome b, catalase, peroxidases	Bacteria, fungi and some plants
Structure			



bacteriochlorophyll a



coenzyme F_{430}



cyanocobalamin

Figure 6: Examples of bacteriochlorin, isobacteriochlorin and corrin

Linear tetrapyrroles:

Linear tetrapyrroles arise from the oxidative cleavage of cyclic forms. They lack extended conjugation over the entire molecule but retain aromaticity within each pyrrole unit. Reduced linear tetrapyrroles are termed bilanes and pyrrole units are interconnected by methylene bridges. Hydroxymethylbilane is a universal biosynthetic intermediate to tetrapyrrole pathways.

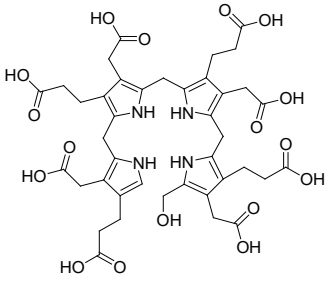
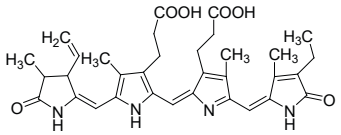


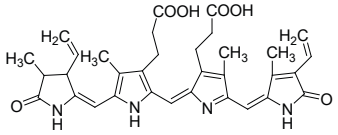
Figure 7: Hydroxymethylbilane

Stabilized linear tetrapyrroles with extended conjugation are known as bilins. Examples include:

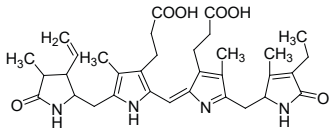
- Bilirubin: yellow bile pigment
- Phycobilin: accessory pigments in cyanobacteria and red algae
    - o Phycocyanobilin (blue)
    - o Phycoerythrobilin (red)
    - o Phycourobilin (orange)



Phycocyanobilin



Phycoerythrobili



Phycourobilin

Figure 8: Structures of some major bilins

Biological roles of tetrapyrroles[1,5,6]

Tetrapyrroles are a biologically indispensable group of organic compounds. Their structural versatility underlies a wide range of biological functions such as,

- **Oxygen Transport and Storage** – Heme: Central to hemoglobin and myoglobin, binds oxygen reversibly, enabling aerobic respiration, fueling cellular metabolism.
- **Photosynthesis** – Chlorophyll: Converts solar energy into chemical energy via light absorption and electron transfer.
- **Electron Transfer and Enzymatic Catalysis** – Cytochromes and catalases: Facilitate electron transfer and protect cells from oxidative stress.
- **Vitamin B_{12} Function** – Cobalamin: Acts in DNA synthesis, methylation, and fatty acid metabolism.
- **Nitrogen and Sulfur Metabolism** – Siroheme: Involved in nitrite and sulfite reduction in bacteria and plants.

Biosynthesis of tetrapyrroles

Tetrapyrroles are ancient molecules considered to have emerged 3 billion years ago. The biosynthetic pathways of tetrapyrroles share a common evolutionary

origin. All major branches -heme, chlorophyll, and vitamin B_{12} - begin with 5-aminolevulinic acid (5-ALA), which condenses to form porphobilinogen (PBG). Four PBG units polymerize into hydroxymethylbilane, which cyclizes to form uroporphyrinogen III, a universal precursor.[1]

The major pathways, along with their key intermediates, can be summarized as follows. Each of these pathways involves multiple enzymatic steps and is highly regulated.

- **Heme pathway:**
  - Uroporphyrinogen III → decarboxylated to coproporphyrinogen III → oxidized to protoporphyrin IX → insertion of Fe^{2+} to yield heme
- **Chlorophyll pathway:**
  - Protoporphyrin IX → Mg insertion to give Mg-protoporphyrin IX → cyclization to give chlorin rings to yield chlorophyll a/b
- **Vitamin B_{12} pathway:**
  - Uroporphyrinogen III → methylation to give precorrin-2 → oxidation and isomerization to Factor II → cobalt insertion to give cobalt-Factor II → multiple methylation and ring contraction → adenosylation to generate vitamin B_{12}

Tetrapyrroles and disease

Defects in tetrapyrrole metabolism can lead to serious disorders. Porphyria, which is a group of rare metabolic diseases, is caused by deficiencies or dysfunction in heme synthesis. Accumulation of porphyrin intermediates in various places in the body causes neurological (abdominal pain, seizures, mental changes), dermatological (blistering, photosensitivity) or urinary (red or brown urine) symptoms.[7]

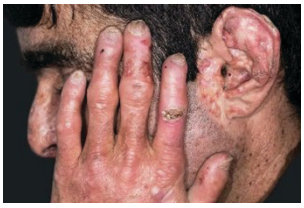


Figure 9: Symptoms of dermatological porphyria

Vitamin B_{12} Deficiency affects DNA synthesis, red blood cell formation, and neurological function, causing symptoms such as anemia, numbness (paresthesia), visual disturbances, depression, memory loss and confusion.[8]

Tetrapyrroles for the future

Research into tetrapyrroles has revealed their importance in various fields.

Renewable energy: One of the most promising future applications of tetrapyrroles lies in their use in renewable energy production. Porphyrin and chlorin derivatives play a key role in converting solar energy into chemical fuel in artificial photosynthetic systems. Porphyrin-sensitized solar cells have achieved over 15% efficiency by optimizing light-harvesting and charge transfer processes. Additionally, researchers have developed microbial electrosynthesis systems in which bacteria, engineered to enhance tetrapyrrole biosynthesis, convert CO_2 into biofuels using electrical currents.[9]

Medicine: Heme-based compounds are used as photosensitizers in photodynamic therapy (PDT). It is a treatment that uses light to activate a drug, selectively targeting and destroying cancer cells. Additionally, bilin-based neuroprotectants from cyanobacteria that reduce oxidative stress in neuronal cells have shown promise for Alzheimer's treatment.[10]

Food and nutraceuticals: Cyanobacterial tetrapyrroles are gaining popularity as nutraceuticals. Phycocyanin has shown higher antioxidant capacity than vitamin E. Iron supplements made from microbial heme are better absorbed by the body than plant-based iron. This helps treat anemia without side effects. Some supplements containing biliverdin activate genes related to longer life and improved health, as shown in lab studies.[11] Chlorophyll and its derivatives are used as natural colorants and antioxidants in food and nutraceutical industries.[2]

Biotechnology: Using synthetic biology, scientists have increased tetrapyrrole production in microbes. By using modified *Corynebacterium glutamicum* strains, 5-aminolevulinic acid production was increased 50 times more than in the normal strains.[12] CRISPR techniques (genetic engineering tools) have enabled *Propionibacterium freudenreichii* to produce vitamin

B_{12} at an industrial scale, making vitamin supplements cheaper.[13]

The ability of metalated tetrapyrroles to undergo redox transformations and bind specific substrates makes them valuable as biosensors for detecting environmental pollutants and biological analytes with high specificity and sensitivity.[14]

Agriculture: Utilizing tetrapyrroles in enhancing crop productivity and stress resistance in sustainable agricultural practices is also being researched.[15]

Conclusion

Tetrapyrroles are fundamental to the chemistry of life, serving as indispensable cofactors in a vast array of biological processes, such as oxygen transport, photosynthesis, electron transfer, and nitrogen metabolism. Their unique structures enable remarkable chemical versatility, facilitating critical functions across diverse organisms and environments. Beyond their natural roles, tetrapyrroles have become valuable tools in renewable energy, medicine, biotechnology, and agriculture. Further studies on tetrapyrrole analogues and biomimetic complexes promise exciting breakthroughs in both fundamental science and applied innovation.

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Guest Articles

Biosynthetic Potential and metabolites of the Bioherbicide *Colletotrichum spinosum*

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Introduction

C. spinosum was first found and reported in Queensland, Australia, as *Colletotrichum* sp.[1] and later discovered in New South Wales.[2] In the late 1940s, this fungus caused severe damage (50–80% mortality) in the Xanthium spinosum population.[3,4] *C. spinosum* was recently identified as a species within the *C. orbiculare* complex,[4] and has previously been investigated as a targeted bioherbicide for *X. spinosum* based on its ability to kill 6-week-old plants in 14 days using spore concentrations of 107 mL^{-1}.[5] Since there have been no reports on secondary metabolites (natural products) isolated from *C. spinosum*, the aim of this study was to discover the chemical potential of *C. spinosum* CBS 515.97. In this study, we performed genome mining on the publicly available genome 6 while also screening chemical extracts obtained from different cultivation conditions. The detailed isolation and structural elucidation of 3"-demethylthielavin M (**1**), a polyketide of the tridepside family, and seven other known compounds (**2**-**8**) that were unknown to be produced by *C. spinosum* was recently published. In addition, detailed bioinformatics analysis enabled us to identify a putative biosynthetic gene cluster (BGC) encoding the biosynthesis of **1**.[7]

Genome Mining

Using fungiSMASH version 7.1.0,[8] on the publicly available genome (NCBI accession number QAPG00000000.1), we determined that *C. spinosum* CBS 515.97 possesses 74 BGCs likely to encode secondary metabolites. Of the 74 BGCs identified, 15 encode Type I polyketide synthases (PKSs), one encodes a Type III PKS, 17 encode non-ribosomal peptide synthetases (NRPS) or NRPS-like enzymes, 16 are identified as potentially encoding ribosomally synthesized and post-translationally modified peptides (fungal RiPPs) or fungal RiPP-like enzymes, and the remainder are comprised of hybrid combinations, as well as seven miscellaneous BGC types. Most of the BGCs detected by fungiSMASH show little similarity to characterized BGCs from other fungi, with only four of these BGCs sharing significant homology to known BGCs (Table 1).

Table 1. Bioinformatic overview of BGCs present within *C. spinosum* CBS 515.97 including fungiSMASH-reported cluster homologs and their percent similarity with query clusters. Miscellaneous includes: five indole, one isocyanide, and one NRPS-like/betalactone BGC(s).

Biosynthetic Gene Cluster Type	Count	Associated Homolog(s) [a]
Type I PKS	15	alternapyrone (100%)
Type III PKS	1	
NRPS	11	chrysogine (100%)
NRPS-like	6	microperfuranone (100%), choline (100%)
Terpene	9	
Fungal-RiPP, fungal-RiPP-like[b]	16	
Type I PKS/NRPS	5	
Type I PKS/terpene	1	
Type I PKS/fungal-RiPP-like[b]	3	
Miscellaneous	7	

[a] FungiSMASH identifies associated homologs as the percentage of genes in the analyzed BGCs that match known products from the Minimum Information about a Biosynthetic Gene Cluster (MIBiG) database,[9] with at least 30% sequence identity to any gene in the query BGC. Associated homologs were only included in this table if the fungiSMASH calculated similarity was greater than or equal to 70%.

[b] These RiPP and RiPP-like BGCs encoded one or more DUF3328 protein, implicated in RiPP biosynthesis[10], however, leader peptide signals were not detected via fungiSMASH.

Metabolites of *C. spinosum*

Although no natural products have been reported from *C. spinosum* CBS 515.97, this fungus clearly has the genetic potential to produce a wide variety of secondary metabolites. Therefore, we proceeded with establishing cultivation and fermentation conditions to study metabolite production. The ethyl acetate micro-extracts obtained from cultivation of *C. spinosum* CBS 515.97 in four media (CM, DPY, OM, and CD) were analyzed using LC-PDA-MS. LCMS traces from extracts prepared from cultivation in DPY and CM indicated production of several unknown secondary metabolites, therefore these media were chosen for large-scale fungal fermentation. The final purification of all compounds using semi-preparative HPLC resulted in amorphous powders except 2 which resulted in yellow oil. The structures of compounds 1 - 8 (Figure 1) were confirmed using spectroscopic methods (MS, 1D and 2D NMR) and comparison with reference compounds and literature data.

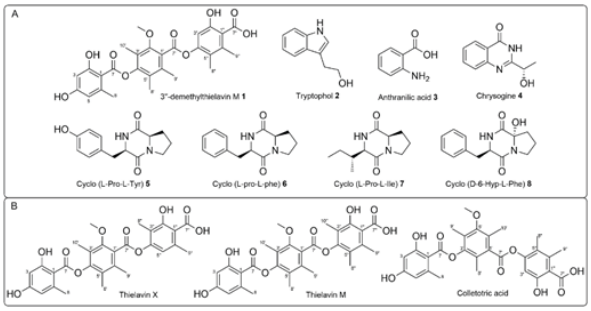

Figure 1. A) Compounds isolated from *Colletotrichum spinosum* CBS 515.97 during this study, which include the polyketide-derived depside 1, primary metabolites tryptophol 2 and anthranilic acid 3, non-ribosomal peptide 4, and cyclodipeptides or diketopiperazines (DKPs) 5-8. B) Reported structures closely related to 3"-demethylthielavin M.

Anthranilic acid (3) is a precursor to both tryptophan and chrysogine (4) biosynthesis.[11,12] The yellow pigment, chrysogine (2-(1-hydroxyethyl)-4(3H)-quinazolinone) was first isolated from filamentous fungus Penicillium chrysogenum in 1973.[13,14] The BGC and biosynthetic pathway of 4 have been characterized and elucidated, explaining the co-isolation of 3 seen in this study. [11,15] As is typically the case in the highly conserved chrysogine BGCs that have been elucidated thus far, strong similarity can be seen in the subsequent BGC and clinker analysis (Figure 4).

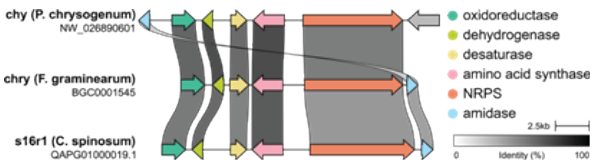

Figure 4. Synteny analysis of the chrysogine BGCs from *Penicillium chrysogenum*[11] and *Fusarium graminearum* PH-1.[9,15]

The pure compounds of 5-8 were subjected to 1H, 13C, and HRESIMS analysis and the proposed structures of these compounds corresponded to four cyclic dipeptides also known as diketopiperazines (DKPs). The DKPs identified were cyclo (L-Pro-L-Tyr) (5), cyclo (L-Pro-L-Phe) (6), cyclo (L-Pro-L-Ile) (7) and cyclo (D-6-Hyp-L-Phe) (8) (Figure 1). The absolute configuration of amino acid moiety of cyclo-dipeptides was determined by Marfey's analysis.

Proposed Biosynthesis of 3"-demethylthielavin M

Depsides are a large family of polyketides, consisting of orsellinic acid (OA) and its derivatives which are polymerized via ester linkages, typically arising from between two to six OA monomers. Biosynthesis of depsides is achieved through the action of a Type I iterative, non-reducing polyketide synthases (NRPKS), which in addition to the essential ketosynthase (KS), acyltransferase (AT) and product template (PT) domains often include multiple acyl carrier protein (ACP) domains, based on studies into the biosynthesis of lecanoric acid[16] and duricamidepside.[17] Studies into the biosynthesis of these compounds have found differing mechanisms for depside bond formation, through either the starter-unit acyltransferase (SAT)[17] or thioesterase (TE)[18] domain.

Thielavins are a sub-class of depsides which are highly c-alkylated and typically feature diverse methylation patterns within the polyketide chain and in the post-translational methylation of hydroxy groups. Thielavins discovered so far demonstrate diverse bioactivities, including antibacterial, anticancer, anti-hyperglycemic, and herbicidal activities.[19–22] Thielavins have been reported from various microorganisms including marine-derived fungi,[23] endophytic fungi,[24] and lichens.[25]

Examining the structure of 1 it appears to be biosynthesized from three different OA-derived subunits, each containing one, three, or two methyl groups respectively, with specific methyl groups being introduced by a dedicated C-methyltransferase (CMeT) domain, common in fungal PKS enzymes. Furthermore, the methoxy group at position 2' of the second ring indicates that in addition to an NRPKS containing a CMeT domain, an O-methyltransferase enzyme is also required for the biosynthesis of 1. Of the 15 Type I PKS BGCs detected by fungiSMASH, seven encode non-reducing PKSs, and only two of these contain a CMeT domain: BGCs [15.1] and [20.1]. Both BGCs also encode an O-methyltransferase required for methylation, typically after post-polyketide assembly.

Recently, the Matsuda group investigated the biosynthesis of the tridepside thielavin A which requires just two enzymes: the NRPKS ThiA and O-methyltransferase ThiX.[18] Through extensive biochemical investigations, the programming of ThiA was thoroughly investigated and it was shown that this NRPKS is capable of synthesizing two different OA analogues and assembling three OA units via depside bond formation catalyzed by the TE domain.[18] Furthermore, the tandem ACP domains of ThiA were individually inactivated and shown to alter the methylation pattern observed in the tridepside product, inferring an unusual influence of the tandem ACPs in methylation pattern.

To further narrow to the most likely possibility between the two candidate BGCs, phylogenetic analyses were performed on the PT, TE, and SAT domains of the candidate clusters alongside depside and non-depside NRPKSs. Analysis of PT domains placed BGCs [15.1] and [20.1] nearest to clades I and VI, respectively, which both contain tetraketide products thus not definitively ruling out either candidate[26]. Additional analyses of SAT domains, as previously described in the literature[17], and TE domains revealed that only the SAT and TE domains of [15.1] claded with depsides, making this BGC the most likely candidate. Furthermore, the NRPKS encoded by BGC [15.1] also contains two tandem ACP domains as well as the domain organization of SAT-KS-AT-PT-ACP-ACP-TE-CMeT, seen and noted as unusual in the NRPKS ThiA.[18] The elucidated thi BGC was compared with the putative depside BGC [15.1] in *C. spinosum* CBS 515.97, resulting in a 68.3% similarity score on the O-methyltransferase and 60.8% similarity score on the NRPKS (Figure 5). Interestingly, BGC [15.1] also encodes two additional polyketide synthases although the NRPKS lacks a CMeT domain indicating it is unlikely to have a role in the biosynthesis of 1.

We therefore propose that the biosynthesis of 1 proceeds as follows; first the NRPKS synthesizes a linear tetraketide lacking any S-adenosylmethionine (SAM)-derived methyl groups. This first tetraketide unit is

cyclized and aromatized by the PT domain before being transferred to the TE domain, where it is not released but instead remains tethered. Next, a linear tetraketide containing SAM-derived methyl groups at positions C'-4 and C'-6 is synthesized, cyclized and aromatized, remaining attached to the ACP domain. Nucleophilic attack by the 4'-OH towards the TE-bound C-7 thioester results in depside formation with the intermediate still tethered to one of the ACP domains, before being transferred to the TE domain. A third linear tetraketide with a C"-6 SAM-derived methyl group is synthesized, cyclized, aromatized, and remains tethered to one of the ACP domains. A second nucleophilic attack by the 4"-OH of the ACP-bound polyketide towards the C'-7 thioester results in tridepside formation. The tridepside is transferred to the TE domain and released via hydrolysis. Finally, the O-methyltransferase catalyzes site-selective methylation of the hydroxyl group of ring B (Scheme 1).

Conclusions

A putative BGC encoding 3"-demethylthielavin M was identified by genome mining and a biosynthetic pathway is proposed that explains the incorporation of three different OA derivatives. Based on the high number of BGCs identified within *C. spinosum* CBS 515.97, there are likely more secondary metabolites produced under specific environmental conditions that may explain the host specificity of *C. spinosum* towards *X. spinosum*.

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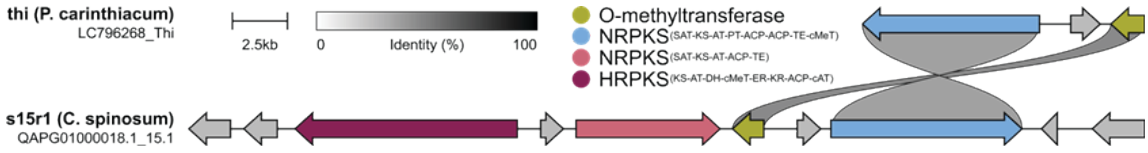
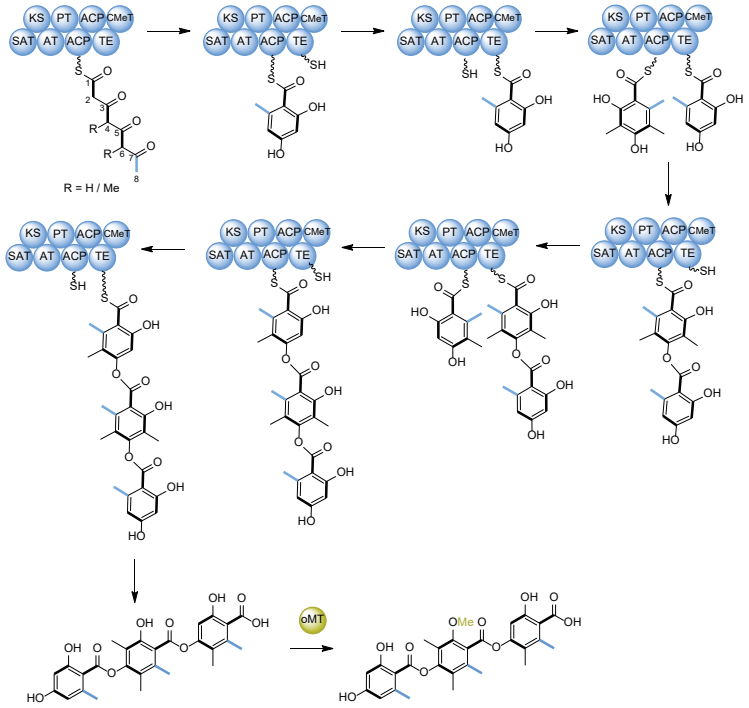


Figure 5. Synteny analysis of the thielavin X BGC in Parahaetomium carinthiacum and the putative 3"-demethylthielavin M BGC in C. spinsosum. Abbreviations not yet described in the text: HRPKS = highly reducing polyketide synthase; DH = dehydratase; ER = enoylreductase; KR = ketoreductase; cAT = carnitine acyltransferase.



Scheme 1. Proposed biosynthesis of 1 with depside bond formation through the TE domain of the NRPKS.

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Student Corner

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Devulcanizable Rubber Systems Inspired by Principles of Organic Chemistry

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Tyre Fires and the Urgent Need for Rubber Recycling

Devulcanization, the selective breaking of sulfur crosslinks in vulcanized rubber, is a key challenge in the modern material science. Millions of tonnes of tyre waste are generated annually, making high-quality recycling increasingly critical. Environmental disasters such as the Hagersville Fire (Ontario, Canada, 1990) and the Sulaibiya Fire (Kuwait, 2021) have alarmed us the urgency of developing innovative devulcanization strategies. The Hagersville Fire burned for 17 days, involving over 14 million tyres, releasing toxic smoke, and contaminating soil and water. The Sulaibiya Fire produced massive clouds of hazardous smoke, severely affecting the air quality and ecosystems. These events highlight the risks associated with unmanaged tyre waste and underscore the importance of advanced devulcanization technologies.

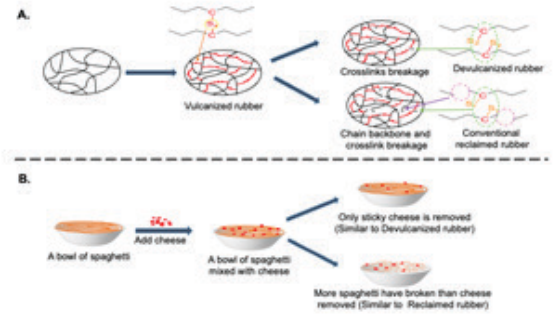

Figure 01: Simple analogy to understand the devulcanization and reclamation:
A. Structural aspect
B. Simple analogy using bowl of spaghetti with cheese

Understanding Devulcanization Through a Simple Analogy

Vulcanized rubber can be visualized as a bowl of spaghetti, where the spaghetti strands represent long polymer chains and the sticky cheese represents the sulfur crosslinks (See Figure 01B). Conventional recycling often breaks both polymer chains and crosslinks, thereby reducing material quality. Devulcanization aims to selectively remove only the sulfur crosslinks, leaving the polymer backbone intact, allowing the rubber to be reprocessed effectively (See Figure 01A).

Physical Methods Used to Break Sulfur Cross Links

Several physical methods are used to break the sulfur crosslinks. Thermal devulcanization uses heat to cleave bonds but may damage the polymer backbone and deteriorate its mechanical properties if not controlled. Mechanochemical devulcanization applies shear forces to generate radicals, which are scavenged using radical scavengers to avoid unwanted reactions. Microwave and ultrasonic methods provide internal heating or microbubbles to target sulfur bonds more selectively than conventional methods. Although effective, these physical approaches can be energy intensive and sometimes lack precise selectivity.

Chemical Approaches for Better Selectivity and Higher Quality Recovery

Chemical devulcanization provides higher control and better-quality recovery by relying on specific organic chemistry principles. Nucleophilic agents, such as amines and thiols, attack polysulfidic and disulfide crosslinks through direct nucleophilic substitution S_N^2 to cleave sulfur crosslinks (See Figure 02A). In addition, mono-sulfur linkages can be oxidized to the corresponding sulfones, followed by classical E_2 elimination, which is another pathway that can be used to selectively cleave sulfur bonds, as depicted in Figure 02B.

Phase transfer catalysis enables reactive species to penetrate the hydrophobic rubber phase, enhancing efficiency based on the "like dissolves like" principle. Oxidative devulcanization uses nitric acid, ozone, and periodic acid to target disulfide and carbon-sulfur bonds, providing controlled oxidation to cleave sulfur bridges

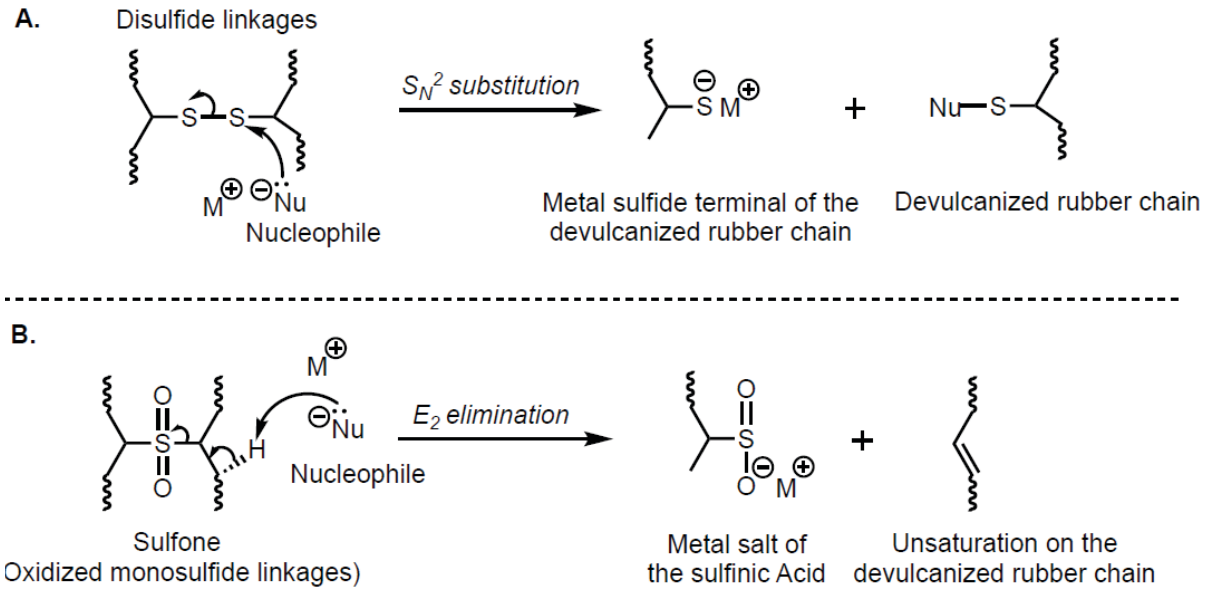

Figure 02: S_N^2 and E_2 mechanisms operate during the devulcanization via nucleophilic additives

while minimizing polymer damage, relying on redox chemistry concepts. Supercritical and subcritical fluids swell rubber and facilitate chemical reactions without harsh conditions, utilizing solvation and molecular diffusion principles. Deep eutectic solvents (DES) interact with sulfur, specifically through its partially positive hydrogens, which induces polarization along the sulfur-sulfur bonds, weakening and eventually breaking the crosslinks. Because sulfur is much more electronegative than hydrogen, it preferentially attacks these protons rather than the nearby carbon atoms, driving the devulcanization process using hydrogen bonding chemistry.

Emerging Strategies

Emerging organic chemistry inspired strategies offer further opportunities. Reversible Diels-Alder cycloaddition reactions between furan functionalized polymers and bismaleimides form crosslinks at low temperatures and break them *via* retro-Diels-Alder reactions at elevated temperatures, allowing recyclability without harsh chemicals. Olefin metathesis can induce the controlled depolymerization of rubber networks, influencing sulfur cross-bridges through double-bond reorganization mechanisms, although heterogeneous waste and fillers can limit catalyst penetration.

Toward a Circular Rubber Economy

By integrating physical, chemical, and organic chemistry inspired approaches, researchers are developing selective devulcanization technologies that preserve the integrity of the polymer backbone and produce high-quality recycled rubber. With tyre fires and waste management failures continuing to threaten communities and ecosystems, advancing devulcanization is not only a materials chemistry challenge but also an essential step toward environmental sustainability.

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