Clitoria Ternatea: A Multifaceted Plant Having Potential in Bioremediation, Cosmeceuticals and Food Engineering Applications

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ABSTRACT

Clitoria ternatea is a perennial climbing legume that grows well at the equatorial and sub-tropical regions of Asia[1]. It is commonly used as an ornamental plant, a revegetation species, forage for livestock, ingredient in culinary arts, nitrogen fixation in soil and as medicine since antiquity. It has been described in ayurvedic texts under the name, Aparajita. Its medical significance derives from the existence of abundant bioactive compounds such as Polyphenols, Alkaloids, Cyclotides and especially Anthocyanins, a class of Flavonoids. The immense medicinal value of this plant has led to key studies on its antimicrobial properties, and subsequent studies were also conducted to assess the feasibility of nanoparticle formation. However, the full potential of this plant remains unexplored. In this review, we aim to impress upon the reader the relatively underexplored potential of *C. ternatea* in three different yet significant industries to mankind: Bioremediation, Cosmeceuticals and Food Engineering. The excellent photocatalytic activity of *C. ternatea* proves to be a promising solution for the degradation of organic dyes which pose a substantial threat to the ecological balance. Its high anthocyanin content chiefly contributes to its rich antioxidant property. This makes it a sustainable alternative to harmful, synthetic chemicals for cosmeceuticals production, and also adds to its applications as a natural food colorant and spoilage indicator in Food Engineering processes.

Keywords: *Clitoria ternatea,* Antioxidant property, Photocatalysis, Sustainability, Circular Bioeconomy.

INTRODUCTION

The word "Sustainability" is now popular than ever before[2]. An ever-rising consumer demand for environment-friendly products is forcing many industries to move towards the adoption of sustainable alternatives to various traditional processes. For example, the cosmetics giant L'Oréal responded to increasing pressure from consumers and set a target to replace around 95% of its ingredients from plant-based, sustainable sources by 2030 [1,2]. This reflects an industry-wide effort to pivot towards natural alternatives. There are various sustainability challenges that pose a threat to the world. For example, unprecedented levels of pollution have resulted in severe contamination and the displacement/extinction of many a flora and fauna, thus disturbing delicate ecological frameworks across the globe [3]. Hence, there is an immediate and quintessential need for novel but efficient methods of environmental remediation [4].

Cosmetics is another domain that is pivoting towards greener alternatives. Various chemical agents like phthalates, formaldehyde, parabens, etc. that used to be commonly used in traditional cosmetics are now understood to cause harmful effects to its users. Growing consumer consciousness towards natural cosmetics has led to an increased adoption of the same. Likewise, synthetic food additives like artificial colorants, preservatives, etc., are currently under intense scrutiny for their negative effects on man and the environment. Consumer confidence in processed foods is diminishing, with an increasing number of people opting for the

[1] Wikipedia: *Clitoria ternatea*
[2] *Google Books Ngram Viewer*: Sustainability

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more expensive, but organic versions of products rather than their ultra-processed counterparts. As such, organizations under pressure to embrace a sustainable path forward and to manufacture their products in alignment to sustainability goals.

In all of the aforementioned domains, plant-based solutions have shown promising results as replacement for conventional processes. One such plant is *Clitoria ternatea*, whose taxonomic hierarchy and common names is described in Table 1. It is a perennial, climbing leguminous plant that grows primarily in tropical and sub-tropical regions across the world. Described in Ayurvedic texts as “Aparajita” [5], this plant has been known since antiquity for its various medicinal properties. Over the years, it has also come to be used for a variety of purposes, including but not limited to, ornaments, revegetation, as a forage plant, etc. Fig. 1 highlights the potential applications of *C. ternatea* in various domains.

Fig. 1 Applications of *Clitoria ternatea* in various sectors

Table I: Taxonomic classification and common names[3] :

Binomial name	*Clitoria ternatea*
Common name	Butterfly Pea, Blue pea, Asian pigeonwings, Cordofan pea, Bluebellvine and Darwin pea
Ayurvedic name	Aparajita
Kingdom	Plantae
Phylum	Streptophyta
Class	Equisetopsida
Order	Fabales
Family	Fabaceae
Subfamily	Faboideae
Genus	*Clitoria*
Species	*C. ternatea*

[3] The taxonomic classification provided is based on data sourced from Plants of the World Online (POWO) by Kew Science, Royal Botanic Gardens.

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Fig. 2a: Flower of *C. ternatea*   Fig. 2b: *C. ternatea* plant

Phytochemical profile of *C. ternatea*

Shekawat *et al*. (2010) reported that *C. ternatea* contains a diverse profile of primary metabolites [6]. There is a plethora of phytochemicals present in various parts of the plant, contributing to its various pharmacological effects. Tiwari *et al.* (1959) reported that the leaves of *C. ternatea* contains β-Sitosterol, 3-Rutinoside, 3-Neohisperidoside, 3-Monoglucoside, 3- o-Rhamnosyl Glycoside, Kaempferol- 3- o-Rhamnosyland essential oils [7].

Phytochemical screening of the roots conducted by Alias *et al.* (2023) showed the presence of n-Hexadecanoic acid, Stigmasterol, β-Sitosterol, Eugenol, 9,12-Octadecadienoic acid, 9-Octadecenoic acid and 13-Docosenamide [8]. The flowers of *C. ternatea* also exhibit a rich phytochemical profile that includes α-Tocopherol, γ-Tocopherol, Sampestrerol, Stigmasterol, β-Sitosterol, Sitostanol, Palmitic acid, Stearic acids, Linoleic acid, Alkaloids, Phenolic acids, Cyclotides, Terpenoids, Anthocyanins, Quercetin, Kaempferol, Myricetin glycosides, as well as other Flavonols and Flavones [9,10].

The rich antioxidant property exhibited by *C. ternatea* is due to a specific class of phytochemical agents called Anthocyanins [11]. It has been confirmed that Ternatin C5 is the simplest form of Anthocyanin present in the plant. Polyacylation of Ternatin C5 with p-coumaroyl group gives them their characteristic blue color. Fig. 3 depicts the Chemical Structure of Ternatin C5. Furthermore, the addition of acyl and glycosyl derivatives to Ternatin C5 derives other forms of Ternatins [12,13,14]. Thus, the vast phytochemical profile of *C. ternatea* makes it a versatile plant, having numerous applications in various sectors.

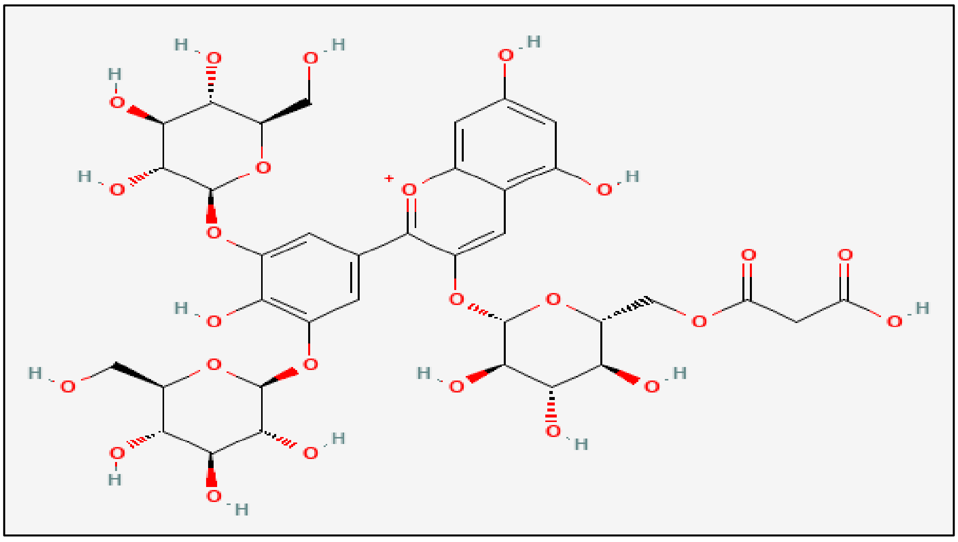

Fig. 3 Chemical Structure of Ternatin C5

Role in Bioremediation:

Environmental remediation is the process of providing a “remedy” to the current state of the environment. This encompasses anything from a simple cleaning of an area, to massive systematic projects aimed at restoring ecological balance. The use of biological organisms, to remediate the environment is termed as Bioremediation. Many plants have been_shown to have excellent bioremediative properties. *Clitoria ternatea* is no exception to that. Numerous studies have been conducted to evaluate the bioremediative properties of *C. ternatea* based products, which are summarized below.

Dyes

Dyes are substances that are able to stick to the surfaces of fabrics, and impart colour to them. As such, they are heavily used in textile industries to colour apparel (with the industry being valued at 12.7 billion USD in 2023[4]). Industrially significant dyes (e.g., azo, anthraquinone, xanthene and triarylmethane dyes) are usually complex, organic substances, which are engineered to be stable and resistant to various agents, like detergents. This helps them to retain their colour for a prolonged amount of time without a significant loss of colour [15]. Some dyes can even remain stable for around 50 years in the environment [15], hence they are not easily degradable. Dyes are a major environmental threat, particularly to aquatic ecosystems. The dyeing industry ranks second only to agriculture in terms of polluting clean water, and is among the most water-intensive sectors globally [16]. Azo dyes, a prominent class of synthetic dyes, are particularly concerning, with up to 70% of them being toxic, carcinogenic, and resistant to degradation [17]. These properties make dyes a major hazard to aquatic environments worldwide, endangering ecosystems and biodiversity. As such, addressing this issue is critical in ensuring water security.

Dye degradation is the process of converting a dye to an inert, non-toxic state called its Leuco dye [18]. Photocatalysis is a method that uses energy from visible light or UV rays to break down organic dyes [18,19]. Nanoparticles based on *C. ternatea* have shown to be promising candidates for bioremediation of dyes.

ternatea – based nanoparticles for Dye degradation

Nanoparticles are fine particles that range from 0.1 to 100 nanometres (10^{-9} m) in size. Owing to this small size, they possess various distinct properties that are not found in bulk particles (e.g., higher surface area, resulting in greater adsorption). There are many ways to produce nanoparticles, out of which biological synthesis (Green synthesis) is the most environment-friendly [20,21]. Metal Nanoparticles and their photocatalytic properties have been well-documented [21]. This makes them promising candidates for dye degradation. The various metallic nanoparticles made with *C. ternatea* and their uses are summarized below:

Sa *et al.* (2024) reported that gold nanoparticles of *C. ternatea* possess excellent photocatalytic activity and reusability towards harmful organic dyes such as Bromophenol Blue, Bromocresol green and 4-nitrophenol from waste water [22].

Khwannimit *et al.* (2022) reported that Ag nanoparticles of *C. ternatea* exhibit photocatalytic degradative activity against Methyl Orange dye [23]. Varadavenkatesan *et al.* (2020) reported the same against Methylene Blue [24]. Mokthar *et al.* (2021) reported the degradative activity of Ag nanoparticles against Crystal Violet [25]. Chan *et al.* (2020) reported sonocatalytic degradation of Congo Red dye by Ag and Fe-doped nanoparticles of *C. ternatea* [26].

Prabhu *et al.* (2022) reported the photocatalytic activity of cupric oxide nanoparticles of the plant against Direct Red (DR) and Crystal Violet dyes [27]. Prabhu *et al.* (2022) reported that the Nickel oxide nanoparticles of the plant also exhibited degradative activity against Fast Green (FG) and Rose Bengal (RB) dyes [28].

[4] Allied Market Research

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Prabhu *et al.* (2022) studied the photocatalytic activity of ZnO/NiO nanocomposites of *C. ternatea* and reported 83.4% and 84.4% degradation efficiency against Bromophenol Blue and Crystal Violet, respectively [29].

Non-metals like Silicon nanoparticles have also been demonstrated to be promising candidates for dye degradation. Fatimah *et al.* (2020) reported the photocatalytic degradation of Rhodamine B, a cationic Xanthene dye using SiO_2 nanoparticles of *C. ternatea* [30]. These studies position *C. ternatea* as a strong contender for the bioremediation of industrial dyes.

Anti-corrosive properties:

C. ternatea has been shown to exhibit excellent anti-corrosive properties. Ghuzali *et al.* (2021) studied the incorporation of aqueous and ethanolic extracts of *C.ternatea* into a sol-gel coating for mild steel, and reported an excellent 89.9% inhibition of corrosion with aqueous extract [31]. Azahar *et al.* (2024) also reported that the aqueous extract of *C. ternatea* showed 89.9% corrosion inhibition efficiency, highlighting its potential as a natural antioxidant [32].

Potential in Polycyclic Aromatic Hydrocarbon remediation

Somtrakoon *et al.* (2018) studied the potential of *C. ternatea* for the phytoremediation of Anthracene and Pyrene in soil, and reported a remarkable decrease in Anthracene and Pyrene levels in soil with the plant. By day 75, Anthracene and Pyrene levels were below the detection limit (2mg/kg of soil). The plant grew well in Anthracene and Pyrene contaminated soil, and no bioaccumulation was observed, resulting in the conclusion that the plant had stimulated the indigenous microbiome (Phytostimulation) to degrade Polycyclic Aromatic Hydrocarbons (PAHs) [33].

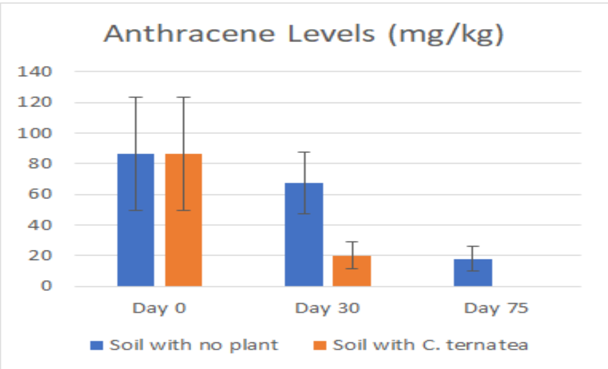

Fig. 4a: Phytoremediation of Anthracene-contaminated soil by *Clitoria ternatea*.

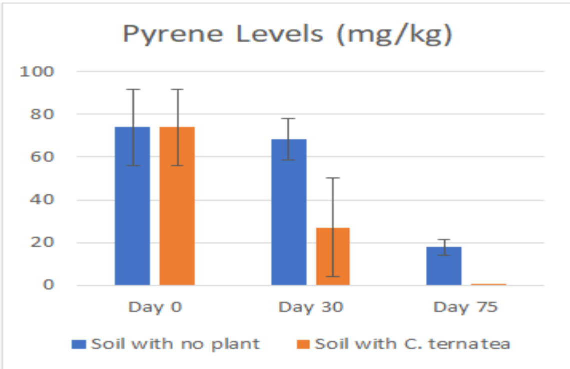

Fig. 4b: Phytoremediation of Pyrene-contaminated soil by *Clitoria ternatea*.

Fig. 4a, 4b: Phytoremediation of Anthracene and Pyrene-contaminated soil by *Clitoria ternatea*. Source: Somtrakoon *et al.* (2018), *Songklanakarin Journal of Science & Technology*, 40(3) [33].

On a similar note, Daudzai *et al.* (2018) investigated the remediation of airborne PAHs, and reported that a remarkable 100% removal efficiency of airborne Ethylbenzene (EB) was achieved in 24 hours [34]. These studies underscore the immense potential that *Clitoria ternatea* possesses in the domain of environmental remediation.

Cosmeceutical potential: Cosmetics are mixtures that are primarily used for appearance enhancement[5]. However, they can also be used for skin care. There are various kinds of cosmetics, be it synthetic or natural-based. Advances in cosmetology has led to the adoption of naturally sourced compounds in cosmetics

[5] Wikipedia: Cosmetics

Current Trends in the Cosmetic Industry:

The movement towards sustainability also had its impact on the cosmetics industry. According to NielsenIQ data, more than 40% of consumers now prefer products that utilize natural ingredients[6], mainly due to rising concerns over their bio-compatibility and environmental impact.

While conventional cosmetics are often cheaper due to the use of low-cost synthetic additives, this often leads to a negative perception among customers. In contrast, customers tend to prefer organic cosmetics, even though they can be more expensive [35]. Hence, the current trend in the cosmetic industry is to make effective products with natural compounds[7]. Various plants are currently being studied for their efficacy and potential to replace synthetic components [36]. In this regard, the antioxidant, anti-ageing and cosmetic applications of *C. ternatea* are currently being studied extensively. It is to be noted that, the medicinal effects of the plant have been well-described in Ayurvedic texts [37].

Bujak *et al*. (2021) reported that the extract of dry *C. ternatea* flower can serve as an excellent dyeing agent in cosmetics, with superior bio-compatibility compared to synthetic materials [35,38]. The anthocyanin extract of *C. ternatea* has been demonstrated to be an excellent colouring agent for the preparation of compact powder eyeshadow [39].

Shoviantari *et al.* (2024) reported that the floral extract of *C. ternatea* exhibited excellent activity against melanogenesis, thereby reducing the darkening of skin [40], with minimized toxicity for prolonged use [37,40].

A *C. ternatea* – based face mask has been shown to inhibit redness, allergies, itching, skin irritation, and also promotes moisture retention in the skin and promotes skin whitening [41]. Studies have confirmed the excellent free radical scavenging activity and the reducing power of *C. ternatea* [38,40,41,42,43,44,50]. The antioxidant properties of the plant are due to the high concentrations of anthocyanins, flavonoids and other phenolics [44,45,46], which function as natural antioxidants and combat free radicals [38,40]. It has been suggested that the antioxidant activity of *C. ternatea* is on par with that of L-ascorbic acid [47]. This also contributes to the anti-ageing properties of the plant [42]. Fig. 5 depicts the antioxidant activity of *C. ternatea* estimated by DPPH Radical Scavenging Assay in comparison with select plants.

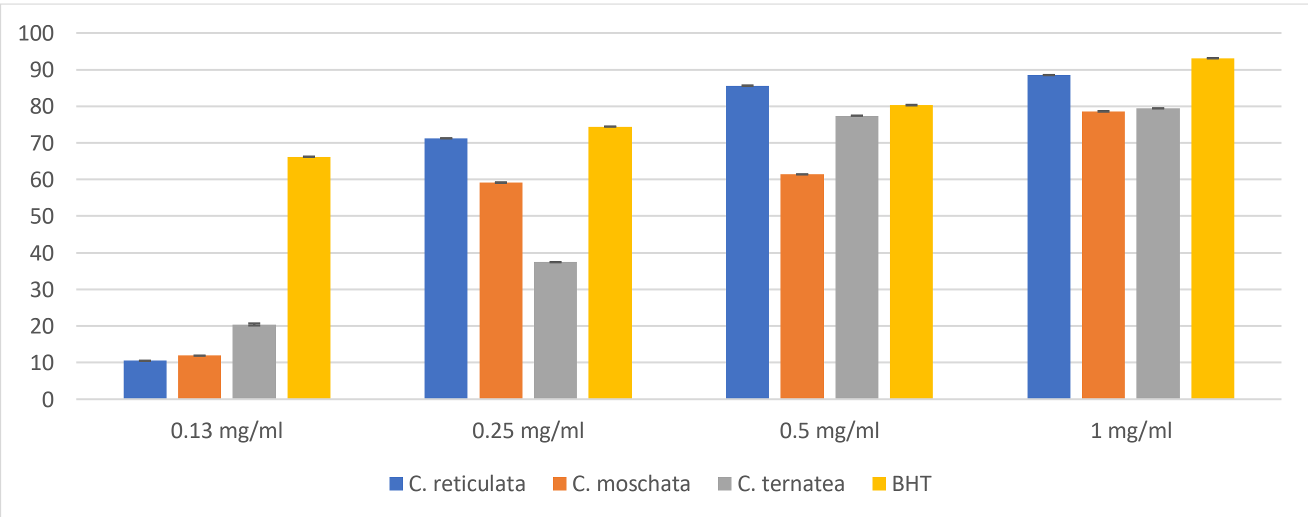

Fig.5 Antioxidant activity of *C. ternatea compared with selected plants.* Source: Tyan *et al*. (2018), *Rapp. Pharm*, *4*(3), p.488-491. [43]

[6] NielsenIQ study
[7] NielsenIQ Study

Sapiun *et al.* (2022) developed a nanoemulgel of size ~14 nm and concluded it to be viable for topical application [48]. This can also be seamlessly combined with existing cosmetics to elevate the cosmeceutical value of a product, thus highlighting the pharmaceutical value of *C. ternatea*,

Wikantyasning *et al.* (2024) assessed the viability of skin lotion formulation with *C. ternatea*, and concluded it to be a potential cosmeceutical product [49], owing to its strong anti-oxidant properties [38,40,44,49]. The anti-melanogenic activity of *C. ternatea* [40] can also serve as an additional factor for the consideration of the plant in manufacturing cosmeceutical products.

Fatimah *et al.* (2024) investigated the post-dermapen wound-healing in people treated with floral extract cream of *C. ternatea*, and reported that histopathological analysis revealed denser collagen deposition in the people treated with the same, particularly those treated with 7% and 10% floral extract cream. This finding further cements the potential of the plant in being a viable treatment for wound healing, by promoting efficient wound healing, particularly in obese individuals, by enhancing collagen production and accelerating the recovery process [50].

Ritonga *et al.* (2020) reported the preparation of a sunblock lotion utilising *C. ternatea* and *Pandanumusa paradisiaca* [51]. Tyan *et al.* (2018) assessed the efficacy of *C. ternatea* via Sun Protection Factor (SPF), which is a measure of the ability of a substance to block Skin damaging radiation from Sunlight. The *C. ternatea* – based sunblock lotion exhibited an SPF value of **23.13** [43], which places it in the category of medium SPF. Table 2 depicts the Sun Protective Activity of *C. ternatea* in comparison with selected plants and a commercial product [43].

Table II: Sun Protection Factor of select plants.

Plant	**Sun Protection Factor**
Curcubita reticulata	10.82
Curcubita moschata	11.54
Clitoria ternatea	**23.13**
Aloe vera	20.02
Sunscreen Product	14.43

Source: Tyan *et al*. (2018), *Rapp. Pharm*, *4*(3), p.488-491. [43]

Applications in Food Engineering:

According to the International Congress for Engineering and Food (ICEF), Food Engineering includes the “applications of engineering in any aspect of production, handling, storage, processing, packaging, and distribution of food” [52]. It is a broad discipline that even includes the construction of facilities for food production processes [52]. However, here we restrict ourselves to the food production, processing, packaging and storage processes, and explore the potential of *C. ternatea* contribution to this domain.

Smart Packaging is an innovative approach where the packaging material interacts with the food produce to elicit a desirable effect. This includes Active Packaging, which contains substances that directly interact with the food (e.g., antimicrobial agents), and Intelligent Packaging, which contain constituents that “monitor the condition of packaged food or the environment surrounding the food” [53].

One of the main ways through which intelligent packaging products work is via changes in pH levels. The pH of food changes overtime due to degradation caused by microorganisms [54]. This phenomenon has been successfully exploited to create intelligent packaging, through a class of organic compounds called Anthocyanins, which change colour with respect to pH [55].

C. ternatea has been used with a wide range of substances to make Intelligent packaging. Santos *et al.* (2015) reported the production of intelligent and bio-degradable Sodium Alginate films to monitor food freshness. They reported a remarkable 380% improvement in tensile strength, increased light barrier capacity, and high colorimetric potential owing to its ability to change colour at different pH (pink to green). The freshness of milk, shrimp and pork could be accurately determined with the films [56].

Szymański *et al.* (2024), reported the development of an antioxidant, bio-degradable packaging material by using *C. ternatea*. They reported strong antioxidant activity, and established non-toxicity towards selected plants and invertebrates. The packaging material showed good biodegradability, thus displaying potential to be a sustainable alternative to current, plastic-dependent packaging methods [57].

Seftiono *et al* (2021) used anthocyanin extract from *C. ternatea* to produce PVA-Chitosan biofilms and reported accurate indication of broiler chicken spoilage [58]. Likewise, Ahmad *et al.* (2020) used Sagu (*Metroxylan sago*) and *C. ternatea* to produce a colorimetric film and tested it against Chicken Breast, and reported good visual indication of spoilage [59].

Netramai *et al.* (2022) reported the production of a pH sensitive colorimetric film consisting of *C. ternatea* floral extract with various carbohydrate-based materials, and determined it to be a capable indicator in evaluating the freshness of various fresh-cut fruits, egg tofu and fermented fish [60]. Sumiasih, I.H. (2021), reported accurate colorimetric indication of beef damage by a PVA-Chitosan biofilm using *C. ternatea* floral extract [61].

Handayani *et al.* (2024) studied the anthocyanin extraction profile of *C. ternatea* under different extraction conditions, and found that using 96% acidified ethanol as solvent yields the maximum quantity of Anthocyanins (551.06 mg/L). The extract was determined to be a reliable spoilage indicator for seafoods [62].

Addition of *C. ternatea* extract results in enhanced morphology, along with increased thermal, mechanical properties in biofilms [56,63,64]. This is in conjunction with an increase in their antibacterial and antioxidant properties [12,56,63,64,66], making it an excellent addition in biofilm production.

Leong *et al.* (2021) studied the impact of incorporating microcapsules filled with anthocyanins from *C. ternatea* in bio-films. They reported enhancement of mechanical properties of bio-films including its thickness, Young's modulus, tensile strength, along with a slight improvement in their thermal properties. A significant increase in antimicrobial activity against a broad spectrum of bacteria was also reported [64].

Singh *et al.* (2021), reported that biofilms incorporated with *C. ternatea* extract presented excellent colorimetric changes at pH ranging from 2-8 and concluded that it has a good potential in indicating beverage spoilage [65].

Furthermore, *C. ternatea* has excellent potential as an organic, antibacterial food colorant. Rashid *et al.* (2020), studied the potential of anthocyanin microcapsules to produce an antibacterial food colorant. Maltodextrin was used as the carrier agent, and the microcapsule showed significant bacterial inhibitory activity when used on baked food products [66]. This suggests that *C. ternatea*-based microcapsules can serve as a viable alternative to conventional preservatives.

Khatib *et al.* (2024) reported that *C. ternatea* is of very low toxicity (LD50>2000 mg/kg BW) to mice, making it suitable to be included in food produce [67].

Potential Challenges:

While *Clitoria ternatea* possesses remarkable applications in a wide variety of domains, its adoption is not without challenges. Currently, the plant is primarily available only in tropical and sub-tropic regions. Widespread adoption of the plant and its derivative products becomes feasible only when its cultivation methods and parameters (soil pH, nutritional profile, etc.) have been optimized for a wide variety of climatic conditions.

Although the plant has well-integrated within sub-tropic and tropical ecosystems, the impact of the introduction of the plant in ecosystems where it can be an invasive species is not yet clear. The phytostimulation and environmental remediation properties of the plant can only be fully harnessed if ecological studies are conducted. As such, Ecological Impact Assessments of sufficient scale regarding the cultivation of *C. ternatea* must be conducted in regions where the plant is not indigenous.

CONCLUSION

In conclusion, *Clitoria ternatea* is a versatile plant that has a great potential to be harnessed in a wide-array of applications including but not limited to, bioremediation, cosmeceutical production and food engineering. The ready availability of the plant in the tropical region makes it a reliable choice in addressing pressing issues like that of sustainability, food safety and health. The plant possesses excellent anti-oxidant activity, which makes it a suitable candidate for food and cosmeceutical applications.

The anti-microbial, anti-melanogenic, anti-inflammatory, anti-diabetic, anti-corrosive and phytostimulation properties, among others make the plant a potential player in addressing various pressing issues. The low toxicity of the plant is an added advantage, making it easier to obtain regulatory approval, especially for food and cosmeceutical applications.

However, its adoption is not without challenges. For example, large-scale bioremediation studies are yet to be conducted. Ecological Impact Assessments that needed to ascertain the impact of the plant on non-native ecosystems are yet to be conducted. The economic feasibility of the incorporation of *C. ternatea* – based formulations in pre-existing products needs to be studied. In food engineering, while its natural colorants are gaining traction, comprehensive safety assessments and consumer acceptance studies are needed to ensure widespread adoption. Future research should focus on optimizing biomass valorization, scaling up production, and integrating *C. ternatea* into circular bioeconomy frameworks.

As industries and researchers increasingly prioritize sustainability, *Clitoria ternatea* exemplifies how natural resources can bridge environmental, health, and food systems. By harnessing its full potential, we can move closer to a sustainable future where ecological balance and human well-being are harmoniously aligned.

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