Coconut oil: unlocking its hidden potential – from health powerhouse to ground-breaking innovations

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Received: 24.10.2024 Revised: 28.03.2025 Accepted: 07.04.2025 Online: 15.05.2025

Abstract Coconut oil has been one of the most widely used cooking oils in Asia for hundreds years. Apart from its primary use in culinary activities, coconut oil is used in a variety of applications. Even though it was earlier recognized and criticized as an oil that had a negative impact on health, in recent years it has been identified as an emerging functional food as it provides many health benefits beyond basic nutrition. Recent studies have highlighted the potential of coconut oil as a functional food, demonstrating its antioxidant, anti-inflammatory, anti-diabetic, and antimicrobial effects. These health benefits are attributed to its unique composition, particularly the presence of phytochemicals and medium-chain fatty acids, which contribute to its therapeutic potential. Additionally, coconut oil is being explored to be used in non-culinary sectors, including cosmetics, pharmaceuticals, and biodegradable products, due to its natural properties and sustainability. This review provides an in-depth examination of coconut oil's biological activities and its emerging roles in various industries, shedding light on its growing significance as a multi-functional resource.

Keywords: fish tonic, foliar application, growth, organic farming

Introduction

The coconut tree is named the "tree of life" due to its numerous benefits associated with a variety of applications. The coconut tree is an important source providing food, oil, fibre, and raw materials for various traditional and commercial uses (Hoe, 2018). Coconuts, the fruits of the coconut tree, are predominantly produced in the Asian region. Indonesia, Philippines and India are the top producers, while Sri Lanka is the fourth largest coconut producer, contributing 4.3% of total world coconut production (Food and Agriculture Organization, 2021).

Among the many products obtained from the coconuts, coconut oil stands out for its versatile applications and numerous health benefits. Coconut oil has been an important edible oil in the food industry for many years and has been the most popular cooking oil in Asian Pacific region (Schwingshackl & Schlesinger, 2023). According to the Food and Agriculture Organization, Indonesia ranked as the highest producer of coconut oil in the world, while Sri Lanka is among the top seven coconut oil-producing countries in the world in 2020 (Food and Agriculture Organization, 2021). As a traditional coconut product, coconut oil has gained widespread popularity among consumers and continues to command a premium price, despite accounting for a smaller share of the global vegetable oil market (Hoe, 2018).

Several types of coconut oil are widely used for both culinary and industrial applications. The most commercially popular varieties include coconut oil derived from copra (CDCO), virgin coconut oil (VCO), and refined, bleached, and deodorized (RBD) coconut oil (Subajiny et al., 2018). Each type is produced using distinct production processes (Yalegama et al., 2016) , which influence the oil's quality, stability, and nutritional composition (Dayrit et al., 2007). The choice of extraction method plays a crucial role in determining the physicochemical properties and health benefits of the final product (Subajiny et al., 2018).

Coconut oil has a unique fatty acid profile; high in medium-chain fatty acids, and the phytochemical content contributes to its biological properties (Chatterjee et al., 2020). Coconut oil has been shown to have many biological properties, such as antioxidant, anti-inflammatory, antimicrobial, and anti-diabetic activities through *in vivo* (Nevin & Rajamohan, 2009; Siddalingaswamy et al., 2011; Nasution et al., 2023) and *in vitro* studies (Aqilah et al., 2018; Seneviratne, 2020). Most of these properties are attributed to the bioactive compounds submerged in coconut oil (Kardinasari & Devriany, 2020). However, these bioactive compounds also vary qualitatively and quantitatively based on their extraction process (Sundrasegaran & Mah, 2020; Aqilah et al., 2018).

Stability of fatty acids and bioactive compounds in coconut oil is affected by many factors, including extraction technique, storage time, storage condition, and temperature (Mulyadi et al. 2019). However, coconut oil exhibits better overall oxidative stability than vegetable oils (Subajiny et al. 2018).

Various industries make extensive use of coconut oil and its derivatives. Both industrial applications and benefits to human nutrition depend on the fatty acids and phytochemical composition in coconut oil (Shijna Kappally, 2015). Coconut oleochemicals are mostly utilized in non-food products; the detergent industry, textile industry, and petroleum sector (Dorni et al., 2018). Coconut oil, with its rich nutrient content, biological and functional properties, and relatively high stability to oxidation, is emerging as a valuable resource for a variety of applications in different industries. The main aim of this review is to focus on the biological properties and novel applications of coconut oil.

Major types of coconut oil

VCO and CDCO are the two major types of coconut oil produced from mature coconuts which are produced through different production processes in Sri Lanka. Both of these oil types are coconut-kernel-based products (Seneviratne & Jayathilaka, 2016). CDCO is a traditional coconut oil type produced mostly at the household level and by microscale processors (Herath et al.,2022). VCO is a value-added coconut oil product which is considered as one of the newest high-valued items among the recently developing value-added goods. VCO is becoming more and more popular in the developed nations of the West, including the USA, and other regions (Jayasekara & Gunathilake, 2007).

According to Asian Pacific Coconut Community's (APCC) definition, VCO is obtained from fresh and mature kernel (12 months old from pollination) of the coconut (*Cocos nucifera L.*) by mechanical or natural means with or without the application of heat, which does not lead to alteration of the nature of the oil. VCO does not undergo chemical refining, bleaching or deodorizing. It can be consumed in its natural state without the need for further processing. VCO consists mainly of medium-chain triglycerides, which are resistant to peroxidation. The fatty acids in VCO are distinct from animal fats, which contain mainly long-chain saturated fatty acids. VCO is colourless, free of sediment, with a natural fresh coconut scent. It is free from rancid odour or taste (Bawalan & Chapman, 2006).

VCO can be produced directly from the fresh comminuted (grated, chopped, granulated) coconut meat or from coconut milk (Jayatunga et al., 2024) following either from wet process or the dry process (Aqilah et al., 2018). In the dry extraction process, mature coconuts are dehusked, shelled, and peeled to remove the brown testa. The kernels are mechanically disintegrated and dehydrated at 70 °C until the moisture content reaches 3-4%. The dried kernels are pressed in a virgin coconut oil expeller at 60 °C to extract the oil. In the wet extraction process, VCO is extracted directly from coconut milk under controlled temperature (Yalegama et al., 2016). VCO extracted by wet or dry processing, devoid of free fatty acids (less than 0.1%), and has a sweet coconut flavour (Jayasekara & Gunathilake, 2007).

CDCO is obtained by expression and/or solvent extraction from the dried kernel (copra) of the coconut. It is free from admixture with other oils and fats. Further, it is clear and free from rancidity, adulterants including mineral oil, sediment, suspended and other foreign matter, and separated from water (APCC standard, 2009). Klin dried or sun-dried copra is crushed by expellers to obtain CDCO. Sun-drying is the cheapest and most efficient method, while the kiln drying method is considered the most suitable method for Sri Lanka in terms of economic aspects (Herath et al., 2022). CDCO often has a light yellow colour after being extracted using the whole coconut kernel. Yellow colour can be attributed to a variety of reasons, including incorporation of testa, which contains natural pigments, caramelizing of sugar in coconut meat, and oxidation. As copra oil contains the coconut testa, which carries a variety of phytochemicals in it (Arivalagan et al., 2018), it has the potential to be used as a functional ingredient by the food industry (Marasinghe et al., 2019). CDCO can be found either unrefined or further processed with refining bleaching, and deodorizing (Kumar & Krishna, 2015). The colourless coconut oil has more commercial acceptability, so that is the rationale for the creation of white colour coconut oil (Seneviratne and Jayathilake, 2016).

Biological properties

Antioxidant property

Coconut oil is often praised for its various health benefits, one of which includes its antioxidant activity. The antioxidant activity of coconut oil is primarily attributed to its unique composition, including phenolic compounds, tocopherols, and other bioactive molecules (Famurewa & Ejezie, 2018). The antioxidant activity of coconut oil has been extensively evaluated using both *in vitro* and *in vivo* methods to determine its potential in combating oxidative stress and related disorders (Yeap et al., 2015). Various *in vitro* assays such as DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay, ABTS (2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)) assay, Ferric Reducing Antioxidant Power (FRAP) assay have been employed to assess the antioxidant potential of coconut oil (Syafitri et al., 2023). *In vivo* studies have been conducted in both animal models (Vysakh et al., 2014) and human subjects (Sabitha et al., 2009) to assess the biological relevance of coconut oil's antioxidant properties.

Antioxidant Potential of Coconut Oil: In Vitro Evaluation Approaches

Mohammed et al. (2021) and Pathirana et al. (2021) reported that the antioxidant activity of VCO varies depending on the extraction technique, as measured by DPPH radical scavenging activity. Mohammed et al. (2021) demonstrated that VCO extracted through fermentation exhibited the highest radical scavenging activity, followed by the chilling method. Additionally, earlier studies by Seneviratne et al. (2009) indicated that hot-extracted coconut oil possesses higher antioxidant activity compared to cold-extracted coconut oil, suggesting that mild heat may be essential for the effective incorporation of antioxidants into coconut oil.

Ahmad et al. (2015) reported that virgin coconut oil (VCO) extracted from the West African Tall (WAT) variety exhibits the highest antioxidant activity compared to other coconut varieties. Furthermore, they suggested that the hybrid of WAT × Thai Tall (THT), known as Chumphon 60, has a greater antioxidant capacity-measured by DPPH radical scavenging activity-compared to other hybrids (Arlee et al., 2013). Mahayothee et al. (2016) observed that several chemical changes occur during coconut maturation, and the geographical region where the coconut is grown also influences the antioxidant capacity of the oil. These findings indicate that antioxidant activity varies depending on the coconut cultivar, geographical location, and stage of maturity.

In addition, Ghosh et al., 2014 reported that DCO extracted using different methods—including aqueous extraction, hexane extraction, commercial processing, and Soxhlet extraction revealed that hexane-extracted oil exhibited the highest antioxidant activity, followed by the aqueous extract. Similarly, Aqilah et al. (2018) reported significant differences in the antioxidant activity of VCO extracted using various techniques. These findings highlight that antioxidant activity within the same type of coconut oil is highly dependent on the extraction method used.

Syafitri et al. (2023) employed several biochemical assays, including FRAP, ABTS, CUPRAC, and DPPH methods, to evaluate the antioxidant activity of VCO, classifying it as a strong antioxidant. It is clear that various factors such as coconut oil type, cultivar and even fruit maturity influence bioactive compound retention and antioxidant activity in coconut oil, highlighting its role in reducing oxidative stress and the importance of optimal extraction methods and sources.

Antioxidant Potential of Coconut Oil: In Vivo Evaluation Approaches

Coconut oil is widely recognized for its antioxidant properties, which are attributed to its rich composition of bioactive compounds. These bioactive components help neutralize free radicals, reducing oxidative stress and preventing cellular damage (Ngampeerapong et al., 2018). While numerous *in vitro* studies have demonstrated the antioxidant activity of coconut oil, *in vivo* evaluation provides a more comprehensive understanding of its physiological effects. *In vivo* approaches, including animal models and human clinical trials, assess the oil's impact on oxidative biomarkers, lipid peroxidation, and antioxidant enzyme activity.

A recent study (Mansouri et al., 2024) conducted to evaluate the effects of VCO consumption on serum brain-derived neurotrophic factor levels and oxidative stress status in adults with Metabolic Syndrome revealed that VCO consumption improved oxidative stress status by reducing serum malondialdehyde levels, improved insulin resistance and increased serum total antioxidant capacity within four weeks of intervention. This indicate that VCO consumption may have potential therapeutic benefits for individuals with Metabolic Syndrome by enhancing antioxidant defense mechanisms and improving metabolic parameters.

The anti-stress and antioxidant effects of VCO have been demonstrated *in vivo* using mice with stress-induced injury by Yeap et al., 2015. In VCO-treated mice, the serum antioxidant, superoxide dismutase enzyme levels were increased, while lipid peroxidation was significantly reduced compared to the untreated control. When compared to the untreated control, the anti-stress effect of VCO was also enhanced. The anti-stress effect of VCO in preventing exercise and chronic cold restraint stress-induced damage and restoring antioxidant balance was demonstrated in this study. It has been suggested that polyphenols and medium-chain fatty acids found in VCO may be responsible for this promising anti-stress activity. Further, the antioxidant effect of coconut oil in *Drosophila melanogaster* showed that a coconut oil-fed diet reduced malondialdehyde (MDA) levels, indicating less oxidative damage caused by free radicals generated by Fe^{2+} by preventing Fe^{2+}-induced lipid peroxidation (Odubanjo et al., 2020).

Sinaga et al. (2019) found that VCO prevents oxidative stress caused by intense physical activity. In their study, VCO reduced lipid peroxidation and increased superoxide dismutase (SOD) activity in the serum of mice subjected to prolonged strenuous exercise. These results demonstrate VCO's protective antioxidant effects, helping to prevent oxidative stress in organs and tissues beyond the muscles after physical exertion.

It is clear that *In vivo* studies highlight the significant antioxidant potential of coconut oil, demonstrating its ability to reduce oxidative stress, enhance antioxidant enzyme activity, and improve metabolic health. Further research is needed to explore long-term effects and optimize its therapeutic applications.

Anti-inflammatory property

The body responds to injury, infection, or destruction with inflammation, which is characterized by heat, redness, discomfort, swelling, and abnormal physiological processes. It is brought on by the production of cytokines, chemical mediators from harmed tissue and migratory cells (Ruiz-Ruiz et al., 2017). Inflammation is a complex process often causing pain and involving membrane changes, protein denaturation, and increased vascular permeability. External stressors like acids, salts, solvents, or heat can denature proteins, disrupting their function and contributing to inflammation. This can lead to hypersensitivity reactions and progressive organ damage (Sangeetha & Vidhya, 2016). Coconut oil has been traditionally used in Ayurvedic practices for centuries to alleviate inflammation and promote healing. Coconut oil exhibits anti-inflammatory properties, primarily due to its rich content of medium-chain fatty acids (MCFAs) and bioactive compounds like polyphenols (Narayanankutty et al., 2022; Ratheesh et al., 2017).

VCO brings out anti-inflammatory activity by inhibiting the various cytokine levels including tumor necrosis factor-alpha, IFNg, IL-6, IL-5 and IL-8 and improves skin barrier function by up regulating Aquaporin -3, filaggrin (FLG), and involucrin (INV) mRNA expression, and also by protecting against UVB irradiation. Therefore, VCO could be useful in treating skin disorders with permeability barrier dysfunction, especially those accompanied by reduced epidermal protein expression, such as atopic dermatitis, eczema (Varma et al., 2017). Similarly, coconut oil reduces IL-6, a cytokine that plays a key role in immune regulation and inflammation. By lowering IL-6 levels, coconut oil may improve state anxiety and functional capacity in patients with multiple sclerosis (Platero et al., 2020).
Polyphenolic fraction of VCO has shown significant anti-arthritic effects by reducing cell influx, release of mediators, lipid peroxidation, and oxidative stress (Vysakh et al., 2014). It is suggested that pretreatment of polyphenols in VCO reduces the oxidative damage either by directly reacting with free radicals in the extracellular environment or through upregulating the cellular antioxidant defense systems (Parathodi et al., 2017). Topical applications of VCO have been demonstrated to be successful in reducing the severity of the disease, improving the disease severity index (SCORAD), and enhancing barrier function in a trial of young patients with mild to severe atopic dermatitis (Evangelista et al., 2014). It has been revealed that the anti-inflammatory activity of VCO is attributed to suppressing inflammatory markers and protecting the skin by enhancing skin barrier function (Varma et al., 2017).
Cultured coconut oil extract (CCE) has been shown to have anti-inflammatory and barrier-enhancing actions against *ex vivo* ultraviolet B (UVB) radiation-induced alterations, proving its effectiveness on human skin. Increased concentrations of polyphenols and fatty acids in CCE may be responsible for the promising anti-inflammatory effect (Kim et al., 2017).

Several studies (Helen et al., 2024; Zicker et al.,2016) have shown that VCO supplementation in diabetic conditions supports anti-inflammatory effects. However, in healthy rats, VCO supplementation has shown an increase in inflammatory markers CRP and IL-6 in healthy rats, indicating that excessive consumption of VCO under normal conditions may trigger inflammation (Helen et al., 2024). On the other hand, Gomes et al., (2023) demonstrated that long-term supplementation of VCO increased pro-inflammatory cytokines such as IL-1β and TNF-α indicating that prolonged consumption of VCO may contribute to an increased inflammatory response.

Coconut oil exhibits significant anti-inflammatory properties by inhibiting key cytokines, improving skin barrier function, and reducing oxidative stress. While coconut oil supplementation benefits inflammatory conditions, excessive intake in healthy individuals may increase inflammatory markers, highlighting the need for balanced consumption.

Anti-diabetic property

Coconut oil has gained attention for its potential anti-diabetic properties, primarily due to its rich content of medium-chain triglycerides (MCTs) and phytochemical profile (Malaeb & Spoke, 2020). Coconut oil is known to enhance insulin sensitivity, regulate blood sugar levels, and reduce inflammation, all of which are crucial for diabetes management (Đurašević et al., 2020). Unlike high-glycemic foods, coconut oil provides a steady energy source without causing blood sugar spikes. Additionally, its antioxidant properties may help protect pancreatic beta cells and prevent diabetes-related complications (Maidin & Ahmad, 2015).

Virgin and filtered coconut oils have been shown to dramatically lower serum glucose and glycated hemoglobin levels, increase insulin sensitivity, and improve lipid profiles in alloxan-induced diabetic rats. Additionally, renal tissues were protected by coconut products from the histological alterations caused by diabetes. All of the examined coconut products were just as effective as metformin at improving the analyzed diabetic indices, underscoring their anti-diabetic effectiveness (Alatawi & Alshubaily, 2021).

Different types of coconut oil extracted with different techniques show different levels of glucose-lowering effects. Anti-diabetic effects of hot-extracted VCO and cold-extracted VCO have been studied using *in vitro* models (Siddalingaswamy et al. 2011). Force-fed alcoholic extracts of commercial coconut oil, cold-extracted VCO, and hot-extracted VCO to diabetic-induced rats showed that hot-extracted VCO reduces blood sugar and lipids such as total cholesterol, triglycerides, low and very low density lipoprotein, and thiobarbituric acid reactive substances. It also increased the antioxidant status by increasing the activities of anti-oxidant enzymes such as glutathione peroxidase, catalase, and superoxide dismutase.

Various *in vitro* and preclinical studies (Akinnuga et al., 2014; Maidin & Ahmad, 2015) on VCO revealed promising health benefits. It has been shown to reduce hyperlipidemia and hyperglycemia complications. Administration of VCO and VCO emulsion with several sweeteners besides glucose has reported the ability to lower blood glucose levels as demonstrated in alloxan-induced diabetic rats. It has been suggested that VCO has antidiabetic effects both on its own and when combined with metformin in an animal model of type II diabetes mellitus. Therefore, using this oil could help reduce the dosage of synthetic medications and lessen their negative side effects (Rahmawati et al., 2020).

Coconut oil has different effects on lipid and glucose homeostasis in rats with and without alloxan-induced diabetes. As evidenced by biochemical parameters; serum haptoglobin levels, liver NF-kB p65 levels, liver enzyme concentrations, and DNA damage to liver cells, coconut oil has anti-inflammatory effects in diabetic rats. In non-diabetic and diabetic animals, VCO supplementation had no effect on heart histology, the thickness of the ascending and abdominal aorta walls, or the development of atherosclerotic plaque, indicating that it is not a risk factor for the onset of cardiovascular illnesses. It has been suggested that supplementing with coconut oil is contraindicated in type 2 diabetic conditions developed by significant insulin resistance and impairment in serum lipid profile (Đurašević et al., 2020). Further, no any significant difference can be found among consuming VCO, butter and virgin olive oil on fasting blood glucose levels (Khaw et al., 2018).

In vitro and animal studies indicate coconut oil's potential anti-diabetic benefits, but further human trials are necessary to validate its effectiveness and safety. While more research is required, incorporating coconut oil into a balanced diet may support blood sugar regulation and overall metabolic health.

Novel applications of coconut oil

As coconut oil contains a large amount of high-value compounds, its importance has been given more and more attention by the industry throughout the years, and it is utilized in the baking industry, processed foods, newborn formulae, medications, cosmetics, and hair oils (Jer et al., 2021; Shijna Kappally, 2015). Traditionally, it was just used as a cooking oil. However, currently it has been applied as an important ingredient for a range of food products and cosmetology products (Hoe, 2018) and in pharmaceuticals (Alpaslan et al., 2021). Once the nutritional potential of coconut oil was discovered, with different extraction methods (Sundrasegaran & Mah, 2020) and novel food products and cosmetic goods have been introduced with value addition. The following sections discuss innovative applications of coconut oil in the food, cosmetology, and pharmaceutical industries.

Food industry

Coconut oil has gained significant attention in the food industry due to its unique composition, functional properties, and health benefits. Its novel applications extend beyond traditional culinary uses, incorporating innovative processing techniques and product formulations.

Coconut oil is always used as a food ingredient to prepare traditional dishes. However, it has started to be used in functional and health-oriented foods such as nutraceutical and functional beverages and fortified foods. Sarpong et al, 2022 proposes the utilization of coconut oil as a substitute for cocoa butter in chocolate production, with enhanced polyphenolic content to improve nutrient density while recommendation places less emphasis on mouth feel, taste and appearance. According to Nizori et al., 2021, incorporating VCO as an ingredient in dark chocolate resulted in elevated antioxidant activity, improved stability, and enhanced sensory properties. In addition to the phenol and flavonoid content inherent in cocoa, the presence of VCO significantly influences the antioxidant potential of the resulting chocolate. Harahap et al., 2023 further support the utilization of coconut oil as a primary ingredient in chocolate preparation, citing its ability to enhance the nutritional profile and physicochemical characteristics of the end product.

Coffee creamers, also known as non-dairy creamers or coffee whiteners, are powders that are microencapsulated and contain syrups, edible oils (such as partly hydrogenated soybean or rapeseed oil), sodium caseinate, and other ingredients. They are commonly used to improve the texture and colour of coffee (Wanthong & Klinkesorn, 2020). However, most commercial non-dairy creamers use partially hydrogenated vegetable oils, which raise health concerns due to their trans fat content. Liu et al., 2023 demonstrated that utilization of coconut oil as a core material in the production of non-dairy creamers can mitigate these health risks, as coconut oil possesses a unique fatty acid profile.

Lipid coatings have long been used to reduce post-harvest losses in fruit processing. The ideal coating depends on fruit characteristics, formulation, storage conditions, and duration. Edible coatings, particularly lipid-based ones are effective due to their hydrophobic nature, providing strong moisture barriers. Common lipid sources for coating include waxes (carnauba, candelilla, beeswax), petroleum-based wax, resin, mineral oil, vegetable oil, and fatty acids (Md Nor & Ding, 2020). Permana, Sampers & Van der Meeren, 2021 evaluated the antifungal activity of emulsion-based edible coatings with cinnamaldehyde against Glomerella cingulata using the modified Gompertz model and minimum inhibitory concentration (MIC). VCO, oleic acid, and their mixtures (up to 40%) slowed fungal growth and extended the lag phase but did not completely inhibit it. The slowest fungal growth was observed in emulsions containing beeswax, VCO, and oleic acid, with VCO performing better than oleic acid. These findings suggest that VCO is a promising ingredient for emulsion-based edible coatings. Further, Nasrin et al. 2020 found that coating lemons with a coconut oil-beeswax mixture or just coconut oil in modified atmospheric packaging (MAP) effectively extended their shelf life by maintaining quality during storage. Cold-pressed coconut oil reduces respiration and transpiration rates and slows ethylene production. Its high lauric acid content also provides antimicrobial, antiviral, and antifungal properties, enhancing its effectiveness. Furthermore, Da Silva et al. 2023 found that a coconut oil and cassava starch coating helped extend the quality of strawberries during refrigerated storage. This combination preserved the strawberries' physical and chemical properties and reduced mold and yeast growth. Lower coconut oil concentrations (1% and 1.5%) effectively prolonged the shelf life and safety of minimally processed strawberries.

Cosmetology industry

Coconut oil has evolved as a cosmetic ingredient over time, gaining popularity due to its natural properties and versatility. Coconut oil has been used for centuries in tropical regions, especially in countries like India, the Philippines, and Indonesia. Traditionally, it was applied to the skin and hair for its moisturizing, soothing, and healing properties. As consumer demand for natural and organic beauty products grew in the early 2000s, coconut oil started to gain attention in the mainstream cosmetic market. People became more aware of the harmful chemicals in many beauty products, leading to a shift toward more natural alternatives. Coconut oil has demonstrated its effect on the cosmetology area, showing ultraviolet protection effect, moisturizing effect and anti-inflammatory effects being an excellent alternative oil ingredient (Varma et al. 2017; Pathirana et al 2021) and for cosmetology products as well as its therapeutic potential in various skin diseases (Sandupama et al., 2022).

Coconut oil, known for its rich fatty acids and antioxidants and anti-inflammatory properties, became a desired ingredient in organic skincare and hair care lines (Satheeshan et al., 2020; Polj & Ko, 2022). Further, it provides a moisturising effect (Ahmad et al., 2015) and its high skin sun protection factor provides greater therapeutic action for the sunscreen formulations (Pathirana et al., 2021).

Novel cosmetic products; body lotion has been produced using the VCO as the base ingredient showing better sensory properties and storage stability and free from skin irritancy, has long self-life and is quite stable and safe (Satheeshan et al., 2020). As many of the skin care products available in the market are based on chemical formulations and are harsh, irritating and toxic which underscores the need to identify and develop a research protocol for natural products. With an increasing demand for natural, hypoallergenic products, coconut oil is being used in formulations aimed at sensitive skin. Products such as coconut oil-based cleansing balms and masks soothe irritation and redness, while maintaining the skin's natural moisture barrier.
moisturising effect of coconut oil has been studied intensively with newborns (Pupala et al., 2019), and application of raspberry seed oil, sesame seed oil, and coconut oil exhibits a positive impact on the hydration of the stratum corneum after a single use (Ziembla et al., 2023). Further, a recent a randomized clinical trial of standard skin care vs. topical coconut oil on early-life skin-microbiome succession and potential effects of emollient skin care in preterm infants reported that microbiome assembly was less diverse in infants receiving coconut oil vs. standard skin care. Further, that study provided novel data on preterm-infant skin-microbiome composition and highlights the modifying potential of emollient skin care (Ghori et al., 2023).

Apart from its protective effects on skin conditions such as xerosis (dry skin) and atopic dermatitis (eczema) (Chew, 2019), coconut oil has also been studied for its potential role in preventing skin damage caused by excessive use of alcohol-based hand sanitizers (ABHS), particularly during the COVID-19 pandemic (Saraogi et al., 2021). Frequent exposure to alcohol in sanitizers can strip the skin of its natural moisture, leading to dryness, irritation, and compromised skin barrier function. Coconut oil’s moisturizing and barrier-protective properties may help mitigate these effects, making it a potential natural remedy for maintaining skin health in such conditions. The study established the protective benefit of regular coconut oil application regime against the increased exposure of skin to ABHS during these COVID times.

Another study (El-fiky et al., 2022) evaluated some natural medicinal products such as Curcumin, Aleo-vera, Coconut oil, Lavender oil, Royal jelly, and *Apis mellifera* honey to detect their efficacy against aging, confirmed by targeting enzyme as telomerase using tissue culture cells. It stated that coconut oil, efficiently act as anti-aging agent by acting on the fibroblast cell and telomerase activity leading to maintain telomere length through its anti-oxidative activities. Further, vitamin E, lauric acid, and oleic acid found in virgin coconut oil (VCO) serve as powerful antioxidants that help protect the skin from free radical damage, a major contributor to premature aging (Doloksaribu & Suryani., 2022).
Nanoemulsions made from coconut oil is considered as effective cosmetic delivery system. Nanoemulsion formulation consisted of DI water, Tween 80, *Curcuma aromatica* (CA) extract, coconut oil and Span 80 at 72.50, 12.93, 7.07, 5.00 and 2.5%w/w, respectively showed less lipid peroxidation and most stable physicochemical characteristics which might be because of coconut oils fatty acid profile (Wuttikul & Sainakham, 2022).

In the cosmetic industry, coconut oil’s versatility continues to make it a demanding ingredient in both natural and innovative formulations. Its natural properties make it a valuable asset, and as consumer preferences lean toward organic and multi-functional products, coconut oil is likely to remain a popular and evolving ingredient.

Pharmaceutical sciences

Coconut oil has been used in many pharmaceutical applications due to its various medicinal effects. It exhibited many unique properties that are extremely significant in stomatitis treatment, including antioxidant, anti-inflammatory, antibacterial, wound healing, and moisturizing. Coconut oil, derived from natural sources, has been approved as an excipient in pharmaceutical formulations (Manchun et al, 2019).

Coconut oil, particularly its medium-chain triglycerides (MCTs), is being used as a carrier in drug delivery systems. MCTs are known to enhance the absorption of fat-soluble drugs, improving their bioavailability. Coconut oil is also utilized in liposomal formulations and nanoemulsions, helping to deliver drugs more effectively to targeted areas in the body. Findings of novel studies (Fayez et al., 2023; Shehata et al., 2024) with coconut oil open avenues toward the exploration for improved oral bioavailability of poorly bioavailable drugs for their improved efficacy. Fahmy et al. 2020, reported a novel treatment for ethanol-induced ulcers by loading thymoquinone (TQ) onto a nanostructured lipid carrier (NLC) using Compritol® 888 and coconut oil. While the blank NLC showed minimal effect, coconut oil's antioxidant properties likely helped protect the stomach by controlling prostaglandin synthesis and reducing oxidative damage. The TQ-loaded coconut oil NLC significantly protected 78.95% of the gastric mucosa in an alcohol-induced ulcer model, suggesting that the enhanced protection was due to better drug availability from the nanosized formula.

In order to create diclofenac-loaded solid self-microemulsifying drug delivery systems (DCF-loaded solid SMEDDS), coconut oil has been combined in different ratios with Tween 80, polyethylene glycol 400 (PEG400), and propylene glycol. These components were then encased in hard gelatin capsules, and their drug content, emulsification time, and *in vitro* drug release were assessed. According to the study, self-microemulsifying drug delivery systems for the distribution of diclofenac can be prepared using coconut oil, Tween 80, polyethylene glycol 400, and propylene glycol. The coconut oil-based SMEDDS of diclofenac sodium demonstrated rapid emulsification (Onyeisi, 2021).

Research has shown that the MCTs in coconut oil can help increase metabolism and fat oxidation, which may aid in weight management. It is being considered as a potential therapeutic ingredient for managing obesity, diabetes, and metabolic disorders. Coconut oil is being investigated in the development of supplements aimed at improving fat metabolism and enhancing energy expenditure.

Coconut oil is being used as a solvent or excipient in various pharmaceutical preparations, especially in the formulation of solid and liquid dosage forms. Its ability to dissolve both hydrophilic and lipophilic compounds makes it a suitable medium for the formulation of oral and topical pharmaceutical products. Nano emulsions loaded with mangosteen extracts prepared from mangosteen peel extracts recovered by VCO, mixed VCO and propylene glycol (VCO-PG), and pure propylene glycol (PG) have been compared based on their bio functional characteristics. When compared to their corresponding bulk extracts, nano emulsions prepared with VCO demonstrated superior antioxidant and antibacterial activities. Thus, nano emulsions containing mangosteen extracts have the potential to be a promising delivery system for bioactive polyphenols in food supplements, pharmaceuticals, and cosmetics. The mixed VCO-PG nano-emulgel was recognized as an excellent formulation for cosmetic gel applications due to its smooth gel appearance, optimal viscosity, and effective release of mangosteen extract (Sungpud et al., 2020). Research shows that coconut oil body wash formulas with good physicochemical properties can be developed into new body wash cosmetic products (Ngan et al., 2020).

VCO has been identified as a potential cognitive strengthener associated with Alzheimer's disease (AD). It contains medium-chain fatty acids (MCFA), which are absorbed and easily metabolized by the liver to form ketone bodies. Ketone bodies are converted to acetyl-

CoA in the brain, which then enters the citric acid cycle to provide ATP and also serves as a precursor of acetylcholine in neurons. According to John et al. (2020), VCO showed promise in countering colchicine-induced cognitive dysfunction by boosting acetylcholine levels in key brain regions and curbing oxidative stress. It outperformed sunflower oil by not only reducing malondialdehyde levels but also enhancing catalase and superoxide dismutase levels. This superiority is attributed to VCO's medium-chain fatty acids, swiftly metabolized into ketone bodies in the liver. Additionally, VCO's polyphenols like p-coumaric acid, ferulic acid, caffeic acid, and catechins act as potent antioxidants, combating oxidative stress, curbing inflammation, and modulating intracellular signaling pathways.

Conclusion

Coconut oil, a traditional culinary ingredient that has been utilized for thousands of years across various cultures. Over time, different extraction methods have been developed to optimize the oil's nutritional profile and commercial quality. It is considered an emerging functional food ingredient, rich in natural bioactive compounds, which contribute to its diverse biological properties. Its unique composition, including medium-chain triglycerides (MCTs), antioxidants, and essential fatty acids, has led to its widespread application in food, cosmetics, and pharmaceuticals. Coconut oil's evolving versatility in these industries highlights its potential as a valuable multifunctional ingredient with both nutritional and therapeutic benefits.

Conflict of interest

The authors declare that there are no conflicts of interest.

Author Contributions

The corresponding author takes primary responsibility for communication with the journal during the manuscript submission. All authors listed on the manuscript must have made significant contributions to the study; Writing – original draft, reviewing and editing.

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