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Review Article

Terpenoids as Phytoconstituent and their Pharmacological Significance in *Cocos Nucifera L.* (Coconut) – A Review

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Abstract

The coconut or *Cocos nucifera L.*, is a traditional plant that is treasured across the world for its many uses beyond its delicious taste and refreshing water. Coconuts harbor a rich array of phytochemicals, that include terpenoids contributing to their nutritional value and therapeutic potential. This review embarks on a journey to unveil the diverse profile and nutritional perspectives of terpenoids in coconut possessing health-promoting properties. Terpenoids, comprising a variety of compounds such as monoterpenes, sesquiterpenes, and triterpenoids, exhibit antioxidant, antimicrobial, and anti-inflammatory properties, thereby bestowing health benefits on consumption. Understanding the pharmacology of terpenoids in coconut and its nutritional implications helps for maximizing its utilization in functional foods, dietary supplements, and pharmaceutical formulations. This comprehensive review underscores the importance of phytoconstituent (terpenoids) in coconuts as a source of bioactive compounds and highlight avenues for future research that harness their full potential for human health and well-being.

Keywords: terpenoids, phytoconstituents, nutritional perspectives, antioxidant, antimicrobial, anti-inflammatory.

1. INTRODUCTION

The coconut tree, scientifically known as *Cocos nucifera L.*, is a tropical palm tree renowned for its versatility and numerous practical uses. Belonging to the family Arecaceae, it is native to the coastal regions of Southeast Asia and is now cultivated in tropical areas worldwide [1]. The coconut tree is characterized by its tall, slender trunk topped with a crown of large, feather-like leaves. It typically grows up to 30 meters (100 feet) in height, although dwarf varieties exist for smaller spaces [2]. The tree produces clusters of coconut fruits, each containing a single seed known as a coconut.

Coconut palms grow well on sandy coastal soils and can tolerate saline in tropical climates. They offer shade and are commonly found near beaches in tropical environments [3]. The coconut palm is considered valuable not just commercially but also culturally and religiously in many of the nations where it is grown [4]. It is commonly referenced in rituals, folklore, and customary cultural practices across the tropics. As shown in Figure 1, *Cocos nucifera L.* is an exceptional plant that benefits tropical ecosystems and human societies all over the world with a wide range of beneficial applications [5, 6].

Figure 1: ***Cocos nucifera L***

2. Chemistry of Terpenoids as Phytoconstituent

Terpenoids are an important secondary metabolite found in plants, widely distributed in nature and play a vital role in growth of plants [7]. They support the medicinal potential, chemical defences, and ecological interactions of species throughout the biological kingdom. Terpenoids are formed from the fundamental five-carbon isoprene unit (C_5H_8) [8]. They have numerous isoprene units joined together to create linear, cyclic, or polycyclic structures. Terpenoids are synthesized from methylerythritol phosphate (MEP) and mevalonic acid (MVA) that comprises of two steps – synthesis of dimethylallyl pyrophosphate (DMAPP) and isopentenyl pyrophosphate (IPP), which are building blocks for the production of different terpenoid classes [9]. Terpenoids are not directly engaged in the main processes of growth, development, or reproduction in organisms since they are secondary metabolites. Rather, they fulfill specific functions in communication, defence, and environmental adaptability [10]. The distinctive odours of spices, essential oils, and resins are all attributed to terpenoids, which also contribute to the distinctive flavours and scents of many other plants. Terpenoids have a diverse range of biological actions, including as antibacterial, neuroprotective, anti-inflammatory, antioxidant, and anticancer effects [11]. The potential therapeutic uses of these bioactive chemicals in industry, agriculture, and medicine have generated a lot of attention [12]. Studying and identifying the full potential of terpenoids in a variety of research and application sectors requires an understanding of their production and activities [13].

3. Terpenoids as a Phytoconstituent in Coconut

Terpenoids are unique and varied phytochemicals found in coconuts with interesting chemistry. Terpenoids, or isoprenoids, are a broad family of naturally occurring chemicals generated from isoprene units (C_5H_8) that exhibit a wide range of structural diversity. Terpenoids play a variety of roles in the biology of coconuts, including defence mechanisms, scent, and possible health advantages. The chemistry of the terpenoids found in coconuts is summarised as follows [14]:

3.1 Functional Groups:

Terpenoids found in coconuts may include hydroxyl (-OH), carbonyl (C=O), and double bonds (C=C), among other functional groups. Terpenoids' chemical characteristics and biological actions are influenced by these functional groups.

3.2 Classification:

Isoprenoids, another name for terpenoids, are a large and varied class of compounds that occur naturally having a broad variety of biological activity. They may be divided into a variety of subclasses according to the number of isoprene units and the configuration of functional groups [15]. They are generated from the fundamental five-carbon isoprene unit (C_5H_8). Based on their chemical structures, terpenoids found in coconuts may be divided into numerous subclasses, such as monoterpenoids (C_{10}), sesquiterpenoids (C15), diterpenoids (C20), and triterpenoids (C30). Many compounds with a variety of functional groups and biological activity may be found in each category [16, 17]. The primary groups of terpenoids are as shown in Figure 2 (Gershenzon & Kreis, 1999):

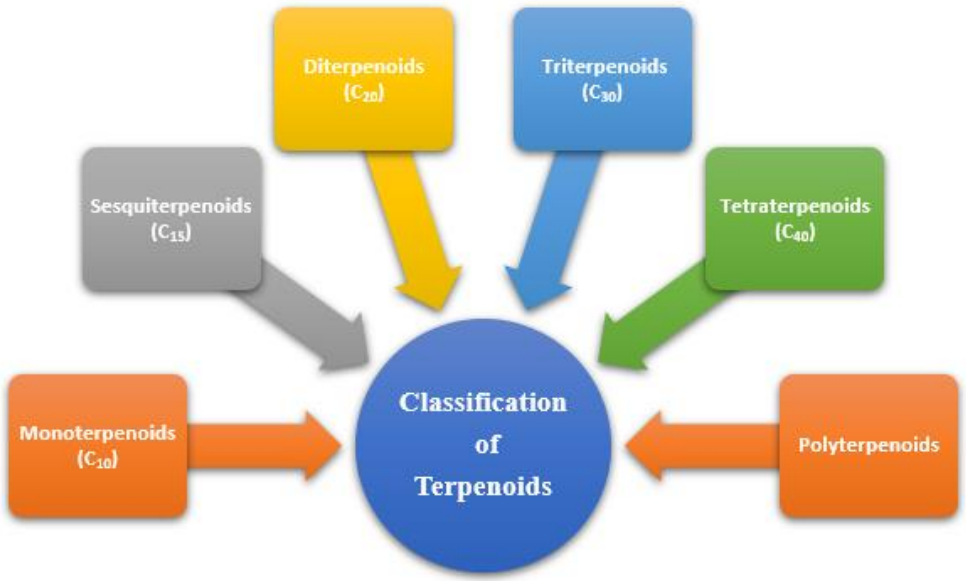

Figure 2: Classification of Terpenoids

a. Monoterpenoids (C_{10}):

These consists of two isoprene molecules ($C_{10}H_{16}$). Linalool, pinene and limonene are a few examples. Monoterpenoids are generally found in the essential oils of many different plants, giving those oils their distinct flavours and scents.

b. Sesquiterpenoids (C_{15}):

These consists of three isoprene molecules ($C_{15}H_{24}$). Farnesene, humulene, and β-caryophyllene are a few examples. Sesquiterpenoids are present in spices, resins, and essential oils and often possess antibacterial and anti-inflammatory qualities.

c. Diterpenoids (C_{20}):

These consists of four isoprene molecules ($C_{20}H_{32}$). Phytol, taxol, and gibberellins are examples of compounds found in plant resins, waxes, and some medicinal plants that exhibit a variety of biological activities, such as regulating plant growth and exhibiting antitumor properties.

d. Triterpenoids (C_{30}):

These consists of six isoprene molecules ($C_{30}H_{48}$). Squalene, β-sitosterol, and lupeol are a few examples, involved in the integrity of cell membranes and the metabolism of cholesterol; found in plant waxes, latex, and several medicinal plants.

e. Tetraterpenoids (C_{40}):

These consists of eight isoprene molecules ($C_{40}H_{64}$). Carotenoids like lutein, lycopene, and β-carotene are a few examples. Tetraterpenoids are present in fruits, vegetables, and algae. These substances function as antioxidants and pigments, potentially giving beneficial health effects.

f. Polyterpenoids:

These are made up of more than one isoprene unit (> C_{40}). Gutta-percha and rubber are two examples. Polyterpenoids are generally present in some plants' latex, where it is used for both structural purposes and economic purposes in fields like rubber manufacture.

These classes serve as a representation of the primary structural kinds of terpenoids; nevertheless, there is a great deal of structural variety within each class, which results in a diverse array of biological activity and possible uses. For example, the distinct flavour and aroma of coconut oil are attributed to the presence of many terpenoids in it. The most well-known of these terpenoids are [19–21] :

α-Terpineol:

Occurring in coconut oil, this scent-like substance resembles lilac and is occasionally added to soaps and fragrances.

β-Caryophyllene:

This terpene is present in coconut oil and adds a spicy scent to black pepper. It interacts with the body's endocannabinoid system and is also a cannabinoid receptor agonist, which makes it fascinating.

Limonene:

This ubiquitous terpene may be found in coconut oil as well as citrus fruits. It smells like citrus and may have antioxidant qualities.

Linalool:

It is a terpene that may be found in coconut oil, which has a flowery scent. Due to its alleged relaxing properties, it may also be found in a wide variety of other plants and is occasionally used in aromatherapy.

These terpenoids offer potential health advantages in addition to enhancing the sensory profile of coconut products. Terpenoids and other phytochemicals found in coconuts may offer a variety of health benefits, including antibacterial, anti-inflammatory and antioxidant capabilities [22]. Terpenoids are widely distributed in nature and play a role in many species' pharmacological characteristics, chemical defences, and ecological interactions [23].

4. Pharmacology of Terpenoids

The pharmacological characteristics of terpenoids, which are present in coconuts (*Cocos nucifera L.*) is increasing research focussed on because of its possible health advantages. This review primarily focusses on the pharmacological properties of terpenoids that are derived from the oil, husk, leaves, and roots of coconuts as shown in Figure 3 and explained below.

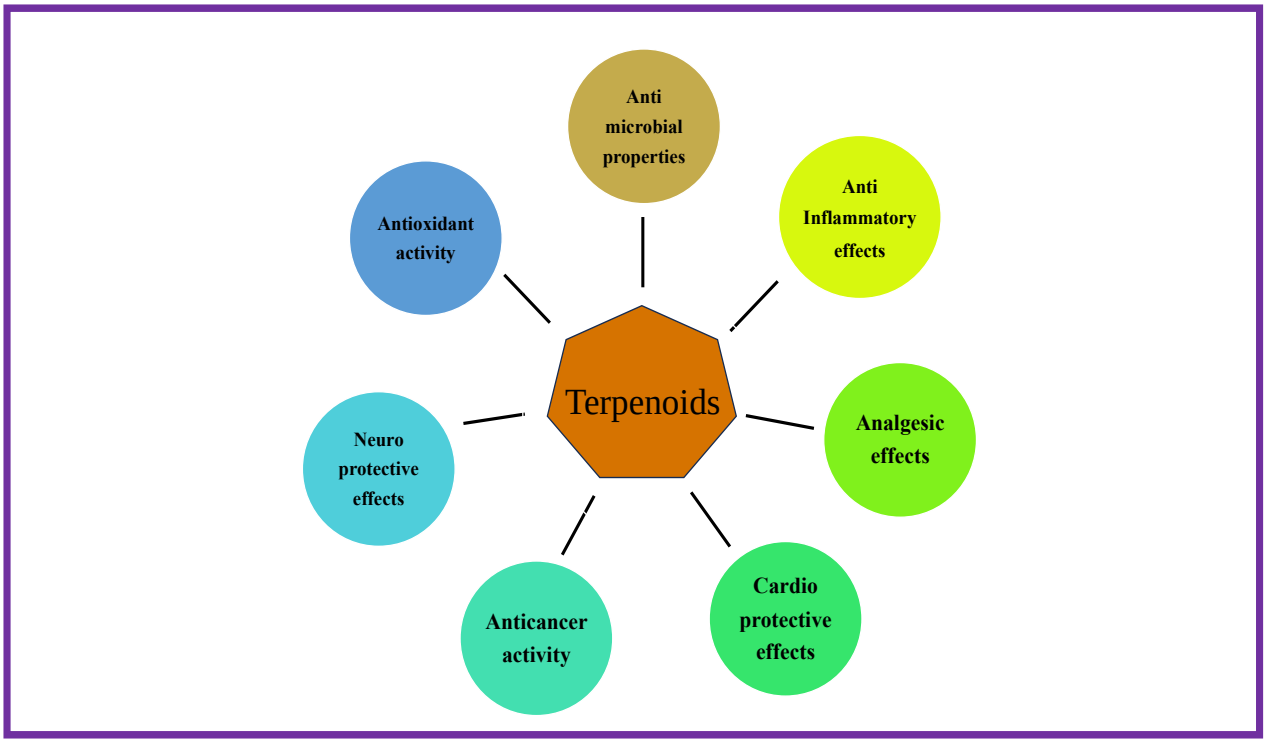

Figure 3: Pharmocological activities of terpenoids in *Cocos nucifera L*

4.1. Antioxidant Activity

Compounds known as antioxidants have the ability to neutralise free radicals and stop them from damaging cells. The terpenoids present in coconuts, which possess antioxidant properties, are essential for shielding cells from oxidative stress, a factor linked to several ailments such as age-related illnesses, neurological disorders, and cardiovascular diseases.

Tocotrienols are powerful antioxidants and belong to the vitamin E family. There are four types of them: delta, gamma, beta, and alpha. The potential of these chemicals to guard against oxidative damage has been investigated. They are present in coconut oil. By directly scavenging free radicals, tocotrienols lower oxidative stress. They also increase the activity of other antioxidant enzymes such glutathione peroxidase, catalase, and superoxide dismutase. Research done by Marina *et al.*,(2009), has demonstrated that tocotrienols can lower cholesterol, lessen lipid peroxidation, and shield against neurodegenerative illnesses by shielding neurons from oxidative damage. This study examined virgin coconut oil's antioxidant potential and found that phenolic acids were present, which greatly increased the oil's antioxidant activity. According to the study's findings, virgin coconut oil's phenolic components may efficiently scavenge free radicals and lessen oxidative stress [24].

One more powerful class of antioxidants included in coconut oil are phenolic compounds. These substances enhance the coconut's total antioxidant capability. Phenolic chemicals neutralise free radicals by giving them hydrogen atoms or electrons, which breaks the chain reaction that causes lipid peroxidation. They can also catalyse the production of free radicals by chelating metal ions. Coconut oil's phenolic components aid in lowering inflammation and oxidative stress, two major contributors to the onset of chronic illnesses including diabetes, cancer, and cardiovascular disease. The study conducted by Nevin and Rajamohan (2006) showed that giving rats more virgin coconut oil in their diet improved their antioxidant level. According to the study, the liver had higher than normal amounts of antioxidant enzymes, which implies that consuming

virgin coconut oil might strengthen the body's defences against free radicals [25].

A broad class of phytonutrients called flavonoids is present in many plants, including coconuts. They have high antioxidant qualities. By giving hydrogen atoms or electrons to free radicals, flavonoids can neutralise them. Additionally, they inhibit oxidative enzymes like xanthine oxidase and modify the action of antioxidant enzymes. By stopping low-density lipoprotein (LDL) cholesterol from oxidising, flavonoids help prevent atherosclerosis. Additionally, they contain neuroprotective properties that lower the chance of neurodegenerative illnesses and cognitive loss [5].

Thus, one of the main components of coconut's possible health advantages is the antioxidant activity of its terpenoids. The presence of tocotrienols, phenolic compounds, and flavonoids in coconut oil is associated with a lower risk of developing chronic illnesses by shielding cells from oxidative damage. These substances boost the body's natural antioxidant defences while also directly scavenging free radicals. To properly understand the processes and effectiveness of these substances in relation to human health, further investigation and clinical testing are required.

4.2. Antimicrobial Properties

Significant antimicrobial action is exhibited by many terpenoids that are present in coconuts. These substances function efficiently against a variety of pathogens, such as viruses, fungus, and bacteria.

Lauric Acid, found in large quantities in coconut oil, possesses strong antimicrobial properties. It is transformed into monolaurin in the body, then breaking microorganism’s lipid membranes [26]. The antibacterial activity of coconut oil against both Gram-positive and Gram-negative bacteria was revealed in research by Nevin and Rajamohan (2004). According to the study, coconut oil worked very well against Escherichia coli and Staphylococcus aureus [27]. The study conducted by Oyi, A. R., Onaolapo, J. A., & Obi, R. C. (2010) investigated the antibacterial properties of coconut oil and how it was formulated into a cream. Significant inhibitory effects of the cream were seen against a range of bacterial species [28]. Geraniol and Citronellol present in coconut oil demonstrate antifungal and antibacterial properties [5]. The antiviral qualities of coconut oil and its monoglycerides were assessed in the study done by Verallo-Rowell and Agero (2004). The findings demonstrated that viruses including the herpes simplex virus and HIV might be rendered inactive by coconut oil [29].

Terpenoids found in coconuts have been shown to have antimicrobial properties and show great promise in defending against a range of infections. The methods involve interference with microbial communication networks, suppression of essential enzymes, and rupture of microbial membranes. Because of the potent antimicrobial properties of terpenoids including lauric acid, geraniol, citronellol, and capric acid, coconut-derived products are useful for both medical and cosmetic purposes. It will take further investigation and clinical trials to properly utilise these antimicrobial properties for medicinal purposes.

4.3. Anti-inflammatory Effects

A biological response to infections, injured cells, or irritants, inflammation is a defensive process that involves blood vessels, immune cells, and molecular mediators. On the other hand, chronic inflammation has been linked to a number of illnesses, including as cancer, cardiovascular disease, and autoimmune disorders. Significant anti-inflammatory qualities are exhibited by terpenoids, which are present in coconuts and aid in regulating inflammatory responses as well as lowering the generation of pro-inflammatory mediators. An extensive examination of the processes, particular chemicals, and study findings is provided below.

Coconut terpenoids have anti-inflammatory qualities via lowering the synthesis of pro-inflammatory mediators and altering inflammatory pathways. As studied by Berlin Grace, ethanol extract of *Cocos nucifera L.* flower showed presence of 152 phytocompounds. Amongst which, Campesterol, t-butylhydroquinone, stigmadorol, catechol, eugenol, and a derivative of quercetin were identified that showed excellent antioxidant and moderate anti-inflammatory activities [30]. α-Humulene that is often present in the essential oils of coconut leaves, this sesquiterpene exhibits noteworthy anti-inflammatory properties [31].

Terpenoids found in coconuts have anti-inflammatory properties that are mediated by a number of pathways, such as immune cell function modification, cytokine production suppression, and inhibition of pro-inflammatory enzymes. Terpenoids with substantial ability to reduce inflammation, such β-caryophyllene, α-humulene, lauric acid, and tocotrienols, are useful in the treatment of inflammatory illnesses. To completely comprehend their processes and therapeutic effects in people, further investigation and clinical studies are required.

4.4. Anticancer Properties

Uncontrolled proliferation and growth of cells are characteristics of the complicated illness known as cancer. Studies have demonstrated that the terpenoids present in coconuts has anti-cancer characteristics via many pathways. These strategies include sensitising cancer cells to chemotherapy, stopping cell growth, apoptosis (programmed cell death) induction in cancer cells, and metastasis prevention. Numerous terpenoids found in coconuts have been linked to strong anti-cancer effects.

Aggarwal *et al.*, (2010) showed the potential of tocotrienols as anti-cancer drugs in their study. Tocotrienols have been shown by the researchers to restrict angiogenesis, prevent cell division, and trigger apoptosis in a variety of cancer cell lines [32]. The investigations by Carnesecchi *et al.*, (2002) demonstrated geraniol's anti-tumor properties in human colon cancer cells. The results of the study showed that geraniol prevented polyamine production and cell development, both of which are necessary for the formation of cancer cells [33]. According to many researches by Priyadarshani, L. I. R., & Rakshit, S. K. (2019), D-limonene - monoterpene exhibits anticancer effects [34]. The anti-cancer effects of lauric acid, which is present in coconut oil, were examined in the studies by Mandal (2011) and DebMandal. It has been demonstrated that lauric acid inhibits the proliferation of breast and colon cancer cells and increases the efficiency of chemotherapy drugs [5].

Coconut terpenoids have anti-cancer activities that are aided by many mechanisms, such as apoptosis induction, cell growth suppression, and metastasis prevention. Terpenoids with great potential to prevent cancer development and improve chemotherapy efficiency include tocotrienols, lauric acid, geraniol, and β-caryophyllene. These results imply that terpenoids obtained from coconuts may be useful in the creation of innovative cancer treatments. To completely comprehend their processes and therapeutic effects in people, further investigation and clinical studies are required.

4.5. Analgesic Effects

An important field of medical study and practice is pain management. The potential of terpenoids, especially those present in coconuts, to relieve pain without the negative effects of opioids or other traditional medications has drawn attention to their analgesic properties. Terpenoids work by inhibiting inflammation, interacting with pain receptors, and modifying neurotransmitter activity, among other processes, to provide analgesic effects.

In 2014, Klauke *et al.*, investigated the analgesic properties of β-caryophyllene using mice models of neuropathic and inflammatory pain. The results demonstrated that via activating the CB2 receptor, β-caryophyllene decreased pain [35]. Using animal models, Lima *et al.*, (2013) examined the analgesic and anti-inflammatory properties of geraniol. The promise of geraniol as an analgesic drug was highlighted by the researchers' finding that it considerably decreased pain and inflammation [36]. The investigation by Peana *et al.*, looked at the analgesic and anti-inflammatory qualities of linalyl acetate and linalool. The findings supported the use of both substances as natural analgesics by showing a considerable reduction in pain and inflammation [37]. Menthol, known for its analgesic and cooling properties, is an ingredient in coconut essential oils [38].

Terpenoids, which are present in coconuts, have analgesic effects that are backed by a number of processes, such as their anti-inflammatory qualities, interactions with pain receptors, and adjustments to neurotransmitter activity. Terpenoids with considerable promise for lowering pain and inflammation include myrcene, β-caryophyllene, geraniol, and linalool. These results imply that terpenoids extracted from coconuts may be useful in the creation of natural painkiller treatments. To completely comprehend their processes and therapeutic effects in people, further investigation and clinical studies are required.

4.6. Neuroprotective Effects

The gradual loss of neuronal structure and function is a feature of neurodegenerative illnesses, including Parkinson's disease, ALS (amyotrophic lateral sclerosis) and Alzheimer's disease. The neuroprotective properties of terpenoids, which are present in coconuts, may be able to prevent or lessen the development of some illnesses. Terpenoids have neuroprotective benefits that are mediated by many pathways, such as antioxidant activity, anti-inflammatory action, neurotransmitter system regulation, and suppression of neurotoxic factors.

Chen *et al.*, investigated geraniol's neuroprotective properties. In models of Parkinson's disease, geraniol was found to protect against neurotoxicity, decrease oxidative stress, and regulate inflammation[39]. The study conducted by Sen *et al.*, examined tocotrienols' neuroprotective properties. In models of neurodegenerative disorders, the researchers discovered that tocotrienols can lessen inflammation, shield neurons from oxidative damage, and enhance cognitive performance [40]. The neuroprotective properties of β-caryophyllene were the main topic of this study. The results demonstrated that in a mouse model of Alzheimer's disease, β-caryophyllene protected neurons and decreased oxidative stress and inflammation [41]. The investigation by Peana *et al.*, looked at linalool's anti-inflammatory and neuroprotective qualities. The outcomes showed that in models of Alzheimer's disease, linalool greatly decreased neuronal damage and cognitive impairments [37]. Studies have demonstrated the neuroprotective and cognitive-enhancing effects of medium-chain fatty acids, such as lauric acid [42].

The anti-inflammatory, antioxidant, and neurotransmitter-modulating qualities of terpenoids, which are present in coconuts, are thought to be responsible for their neuroprotective benefits. Terpenoids with great potential in preserving neurons and enhancing cognitive function include β-caryophyllene, geraniol, tocotrienols, and linalool. These results imply that terpenoids obtained from coconuts may be useful in the creation of treatments for neurological illnesses. To completely comprehend their processes and therapeutic effects in people, further investigation and clinical studies are required.

4.7. Cardioprotective Effects

Globally, cardiovascular diseases (CVDs) constitute a major cause of death. Because of their possible cardioprotective properties, terpenoids, which are present in coconuts, have attracted a lot of attention. Their capacity to lower oxidative stress, suppress inflammation, balance lipid profiles, and improve endothelial function is thought to be responsible for these benefits. Terpenoids' cardioprotective qualities may help prevent and treat diseases including hypertension, atherosclerosis, and myocardial infarction.

In the study by Sen *et al.*, tocotrienols' cardioprotective properties were identified. Tocotrienols have been shown by the researchers to lower oxidative stress, suppress inflammation, and enhance lipid profiles, all of which lower the risk of atherosclerosis and other cardiovascular disorders [40]. The study conducted by Basha and Sankaranarayanan concentrated on the cardioprotective properties of β-caryophyllene. The results shown that in diabetic rats, β-caryophyllene protects against heart damage, improves lipid metabolism, and lowers oxidative stress and inflammation [43]. Tocotrienols compounds have the ability to lower cholesterol and stop lipid peroxidation [24].

Terpenoids, which are present in coconuts, have lipid-lowering, anti-inflammatory, and antioxidant qualities that contribute to their cardioprotective benefits. Terpenoids with substantial potential to protect the circulatory system and improve general heart health include β-caryophyllene, geraniol, tocotrienols, and linalool. According to these results, terpenoids obtained from coconuts may be useful in the treatment and prevention of cardiovascular illnesses. To completely comprehend their processes and therapeutic effects in people, further investigation and clinical studies are required.

5. CONCLUSION

The macro and micronutrients included in coconuts are excellent for maintaining health and supporting the body's regulating systems. Numerous pharmacological characteristics, such as anticancer, anti-inflammatory, antimicrobial, antioxidant, neuroprotective, analgesic and cardioprotective actions, are displayed by the terpenoids found in coconuts. These results demonstrate the potential of terpenoids obtained from coconuts in the development of therapeutic agents for a range of medical ailments. To properly comprehend their mechanisms of action and effectiveness in people, further investigation and clinical studies are required. This review emphasises the importance of coconuts as a plentiful supply of bioactive substances with a range of nutritional aspects. After a thorough analysis of its phytoconstituent composition and health-promoting qualities, coconut stands out as an effective choice to improve human health and wellbeing. Through a comprehensive utilisation of the nutritional capabilities of phytochemicals produced from coconuts, investigators and industry stakeholders may facilitate the production of novel therapeutic foods, nutritional supplements, and pharmaceutical products with the objective of enhancing public health worldwide.

6. Future Perspectives and Research Directions

Possible future investigations on terpenoids obtained from coconuts should be to isolate and characterise new compounds, comprehend their molecular processes, and carry out clinical trials to confirm their potential as therapeutics. Enhancing effectiveness requires looking at how different bioactive substances work in concert with one another as well as maximising bioavailability through cutting-edge delivery methods. Biotechnological techniques and other sustainable production methods are essential for satisfying demand without diminishing natural resources. Furthermore, examining various coconut cultivars and assessing their nutraceutical uses might reveal special health advantages. Thorough safety and regulatory evaluations guarantee the efficacy and safety of terpenoid-derived products for end users. Therefore, this paper lays the foundation for future developments in coconut-based nutrition and healthcare by offering suggestions for performing clinical research, investigating innovative extraction methods, and evaluating the effectiveness of chemicals obtained from coconuts in various health situations.

Author's Contribution: Dr. Jalpa Kotecha has contributed in gathering all relevant information, references and compilation of regarding the topic.

Conflict of Interest: Authors declare no conflict of interest.

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