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Review Article

Secondary Metabolite as Therapeutic agents with Significant Highlight on Terpenoids

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ABSTRACT

The belief that plants possess biologically active compounds with healing properties beneficial for treating various health conditions has endured since ancient times. The therapeutic importance of these plants highlights their vast potential for the discovery and development of new pharmaceuticals, attributed to their chemical constituents that positively impact human health. Numerous naturally occurring phytochemicals, both dietary and non-dietary, have demonstrated significant potential in preventing and treating various diseases. Secondary metabolites are organic compounds naturally produced by plants, microbes, and certain animals, serving vital roles that extend beyond essential survival functions. Compounds such as alkaloids, flavonoids, terpenoids, and phenolics have garnered considerable interest due to their varied chemical structures and powerful biological effects. They demonstrate a broad spectrum of pharmacological properties, including antidiabetics, anticancer, anti-inflammatory and antioxidant as well as antimalarial, which make them important therapeutic agents in contemporary medicine. Terpenoids, or terpenes, form the largest group of natural compounds and are known for their biological activities, making them valuable in the treatment of human diseases. In the present work we have highlight the potential therapeutic benefit of terpenoids. Among the secondary metabolites terpenoids having more potential to be therapeutic agents for various disorders. Over the past two decades, bioprospecting natural products from the marine environment has led to the discovery of hundreds of terpenoids with unique structures and promising bioactivities, with many more yet to be uncovered.

Keywords: Anticancer, Antidiabetic, Antimalarial, Antioxidant, Secondary Metabolites, Terpenoids.

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INTRODUCTION

In recent years, the use of plant-derived components and dietary complements has significantly increased. The use of plants having medicinal properties as herbal therapy for averting and managing serious illnesses differs across various communities. Recently, the biological science community has shown interest in medicinal plants traditionally used for treatment. Ethnopharmacologists, botanists, microbiologists, and natural product chemists are collaboratively working to develop strategies for combating infectious diseases.[1,2] Plants generate and accumulate a wide variety of small molecules or natural compounds that play a crucial role in essential physiological and ecological functions. For thousands of years, humans have utilized the healing properties of specific natural compounds, incorporating them into traditional herbal medicine. In contemporary times, with a deeper understanding of their biological synthesis, regulation, as well as functions, plant-derived natural products have gained significance for diverse applications, including medicine, flavors, fragrances, colorants, and health-enhancing agents. Plant-derived natural compounds can be classified into distinct categories which includes terpenoids and alkaloids, as well as compounds such as phenolics, according to their chemical structure and biological pathways of synthetis.[3]

Phytocompounds

There is an increasing growth of resistance of multiple therapy has driven the hunt for another medicinal sources, particularly plant-derived compounds known as phytochemicals. While plants are clearly effective in providing both food and shelter, their importance as a medicinal resource is frequently overlooked. For almost the same length of time, human society has depended on plants for food, shelter, and medicinal needs. These naturally occurring plant compounds possess powerful antioxidant properties, providing substantial health benefits for humans. Traditionally, phytochemicals are classified in two ways as firstly primary and secondly secondary metabolites built on their functions in metabolism of plants. Primary metabolites

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encompass joint compounds like sugars and amino acids as well as purines and pyrimidines found in nucleic acids or chlorophylls. On the other hand, metabolites specifically of secondary one includes the residual plant elements such as alkaloids, flavonoids and terpenoids, the distribution of phytochemicals within plants and their significance in human healthcare is outlined as follows: 45% of Flavonoids, 27% constitutes of terpenoids and steroids, 18% of alkaloidal components and further chemicals composed of ten percent.[4,5]

Secondary Metabolites (SM)

They are synthesized by plants as diverse range of organic compounds, distinguished by unique structures of carbon components. Although SM are considered as nonvital for the existence of cells and their components, they play a crucial role in interactions with the environment, helping ensure the organism's persistence within its ecosystem. They protect plants from a range of stresses, including biotic factors like bacteria, fungi, nematodes, insects, and herbivory, as well as abiotic factors such as high temperatures, excessive moisture, shading, physical damage, and heavy metal exposure. Due to their considerable economic importance, secondary metabolites are utilized in various human applications, including the production of pharmaceuticals, flavors, fragrances, insecticides, and dyes. In plants, SM are classified into three groups like terpenoids, polyketide as well as phenylpropanoid which are based on the biological synthesis.[6] basic hydrocarbons are known as terpenes, whereas an altered category of terpenes is named as terpenoids, chiefly notable by the surplus of functional groups and either the rearrangement or removal of groups of methyl in oxidized form at various positions.[6,7]

Alkaloids

They are natural compounds with composition of nitrogen atoms structured in heterocyclic ring, consistently exhibiting basic properties. The name originates from their specific characteristics of being alkaline and was initially cast-off to label any nitrogen-containing base. Bitter taste is basic identification of entire alkaloids. Their vast diversity in molecular structures makes systematic classification difficult.

Examples:

1. **Atropine** - Derived from *Atropa belladonna* (deadly nightshade), used in medicine to dilate pupils and as an antidote for certain poisonings.
2. **Caffeine** - Present in regular drinks such as coffee, *Camellia sinensis* (tea), and *Theobroma cacao* (cocoa), known for its stimulant effects.
3. **Nicotine** - Found in *Nicotiana tabacum* (tobacco), known for its stimulant and addictive properties.
4. **Morphine** - Found in *Papaver somniferum* (opium poppy), used as a potent analgesic.[8]

PHENOLIC COMPOUNDS (PC)

They characterize the prime group of SM and are dispersed widely across kingdom of the plants. As SM, PC serves an essential part as defensive compounds. Phenolics display numerous properties advantageous to humans, with their antioxidant activity being especially vital in their character as protective mediators in contradiction of diseases caused by free radicals. The 3 key groups of primary dietary phenolics are flavonoids and phenolic acids as well as polyphenols.

Examples:

1. **Anthocyanins** - Accountable for the red and purple as well as blue stains in berries, grapes, and cherries; known for their anti-inflammatory properties.
2. **Catechins** - Present in green tea (*Camellia sinensis*); beneficial for heart health and metabolism.
3. **Hesperidin** - Found in citrus fruits; supports cardiovascular health.
4. **Caffeic acid** - Found in coffee, fruits, and vegetables; has strong antioxidant properties.
5. **Ferulic acid** - Present in rice, wheat, and oats; supports skin health and reduces oxidative stress.
6. **Resveratrol** - Found in red grapes, wine, and peanuts; known for its cardioprotective and anti-aging properties.
7. **Ellagic acid** - Found in pomegranates, strawberries, and walnuts; supports cancer prevention and skin health.[9,10]

TERPENOIDS

Initially, the term "terpene" referred to hydrocarbons of cyclic structure represented with the molecular formula $C_{10}H_{16}$, which are resultant from the plant's essential oils. However, their description has expanded toward covering a broader range of plants SM. These are natural arising hydrocarbons mainly composed of different units of isoprene. Structural modifications when occurs they are termed as terpenoids. This, together through steroids, constitutes a large assembly of SM jointly referred to as isoprenoids. Although some of the steroids and some terpenoids have a connection of biogenicity, all are classified separately because their chemical properties have evolved independently.[8] Terpenoids occurs in two forms such as terpene hydrocarbons as well as primarily derivatives of various oxygen-containing components, like alcohols and aldehydes, carboxylic acids as well as ketones and esters lastly the glycosides. The synthesis comprises both the pathways such as MVA and the 1-Deoxy-D-Xylulose-5-Phosphate (DXP) pathway. Isopentenyl diphosphate acts as the key intermediate in the metabolic

process in both pathways. The previous pathway arises inside the cytoplasm and is mainly responsible for synthesizing SM such as sesqui and tri terpenes and sterols. In contrast, the DXP pathway primarily takes place in plastids of cells and serves as the key course for producing mono, di as well as tetra terpenes. [11,12]

Classification

Terpenes are categorized grounded on the numeral of Isoprene Units (IU), in their structure, with the prefix denoting their necessary figure of units of terpene for their formation.

A) Hemiterpenes: consist of a single IU, comprising 5 atoms of carbon. Genuine hemiterpene is Isoprene. However, it is important to mention that hemiterpene and hemiterpenoid are occasionally cast-off interchangeably, and the difference is not always sternly maintained.

B) Hemiterpenoids, by contrast, are isoprene derivatives that include added functional groups, frequently containing oxygen atoms. Samples of hemiterpenoids comprise isovaleric acid and isoprenol. The given compounds are resultant from isoprene nevertheless have been modified, usually through the addition of oxygen atoms.

C) Monoterpenes entail of two IU and have a universal molecular formula of $C_{10}H_{16}$. Each IU delivers 5 carbon atoms, resulting in a total of ten carbon atoms in each of the molecule. They regularly have a structure of cyclic ring and play a crucial character in the biological synthesis of numerous natural compounds, counting essential oils extant in several plants. Specimens of monoterpenes embrace limonene and myrcene as well as pinene. Below is a transitory summary of these monoterpenes.

Terpineol, a monoterpene alcohol with a delightful floral fragrance, is found in lilacs and is frequently cast-off in perfumes as well as cosmetic industry.

Geraniol, various plants originate this class of essential oils, has a fragrance reminiscent of roses. It is commonly present in geraniums and roses as well as citronella.

Limonene, found in the skins of fruits specifically citrus like lemons and oranges, emits a refreshing citrus scent. This is primarily utilized in the production of products having citrus flavor and by way of a solvent. Inalool, which is extant in lavender and several flowers and spices, possesses a flowery scent with a hint of spice. It is commonly utilized in fragrance and cosmetics trades.

Pinene, originate in trees of pine, is the composite that gives distinctive aroma to pine forests. It arises in 2 forms of isomeric i.e. alpha-pinene and β-pinene.

Myrcene chiefly present in hops that plays a character in giving beer its characteristic aroma. It is also found in other plants, such as cannabis, and contributes to their distinctive aromas.

These compounds not only contribute to the unique scents of several florae nonetheless serve applied purposes in trades like perfumes, fragrance and flavor and pharmaceuticals.[13]

D) Sesquiterpenes are indicated via the prefix "sesqui-" meaning 1.5, are shaped from 3 IU and consist the $C_{15}H_{24}$ molecular formula. Specimens of sesquiterpenes and sesquiterpenoids include humuleneand farnesol as well as farnesenes.

E) Diterpenes have the molecular formula $C_{20}H_{32}$ and are primarily made up of 4 IU. These are resultant from the compound geranylgeranyl pyrophosphate. Compounds alike cembrene, cafestol and kahweol, taxa diene, are examples of diterpenes and diterpenoids. Furthermore, biological compounds like phytol and retinol as well as retinal are derived from diterpenes.

F) Sesterterpenes, consisting of 25 carbon atoms and 5 IU, are less common than terpenes of other sizes. An example is Geranyl farnesol.

G) Triterpenes ($C_{30}H_{48}$) consist of six IU. A vital component of shark liver oil as well as a linear triterpene is squalene. It is primarily synthesized through the reduction process of 2 molecules of farnesyl pyrophosphate. In the pathways of biological synthesis, squalene is additionally processed to generate compounds such as cycloartenol and lanosterol, which act as precursors for all steroids structurally.

H) Sesquiterpenes are composed of 7 IU and denoted by ($C_{35}H_{56}$) and are typically derived from microbial sources. Examples include ferrugicadiol and Tetra-prenyl-cur cumene.

I) Tetraterpenes ($C_{40}H_{64}$) are made up of eight IU. Biologically the tetraterpenoids contain monocyclic gamma carotene and bicyclic beta and alpha carotenes, as well as the lycopene with acyclic structure.

J) Polyterpenes primarily entail of extended manacles with multiple IU. Some florae produce gutta-percha, which is a poly-isoprene having double bonds in the configuration at trans space. Natural rubber is a type of cis double bond containing polyisoprene.

K) Nor isoprenoids, Alexendra leaves of Muscat consist of C_{13}-nor isoprenoids, which serve as a specimen of 3-oxo-α-ionol. They can all be produced through the action of fungal enzymes such as peroxidases as well as glycosidases.[12-14]

PHARMACOLOGICAL PROPERTIES OF TERPENOIDS

Anti-diabetic Activity

Diabetes mellitus is generally characterized into 3 main types-Type 1 Diabetes Mellitus (T1DM), Type 2 Diabetes Mellitus (T2DM), and Gestational Diabetes Mellitus-based on its underlying causes and clinical symptoms present at Diagnosis (DM) is a long-term condition of metabolism considered by

raised glucose levels in blood, resulting from reduced insulin effectiveness, decreased sensitivity to insulin, or a combination of both. T1DM is categorized into two types based on its underlying cause: type 1A, which is immune-mediated, and type 1B, which is idiopathic (Sun *et al*., 2022). Insulin resistance occurs when insulin-responsive cells, such as skeletal muscle tissue and fat cells (adipocytes), become less sensitive to insulin stimulation. This process results in reduced glucose absorption by the cells, which is a crucial step in glucose metabolism. Reduced insulin sensitivity plays a vital part in the onset of disorders related to metabolism such as overweightness, abnormal lipid levels, metabolic syndrome, high blood pressure, atherosclerosis, and, most significantly, diabetes mellitus (Vecchio *et al*)., Terpenoids serve as strong inhibitors of α-glucosidase and α-amylase. The enzyme α-amylase facilitates the hydrolysis of 1,4-glycosidic bonds in polysaccharides like starch and glycogen, leading to the formation of disaccharides. This disaccharide is subsequently broken down into monosaccharides through the action of α-glucosidase. These enzymes enhance carbohydrate absorption in the intestine, leading to a rise in postprandial insulin levels.[15]

Activity against inflammation

It is a frequent and decisive pathological response, typically presenting as redness, swelling, heat, and pain. This is a reaction which is protective for living organisms with a vascular system to different injurious features and is closely linked to ailments like arthritis, asthma and arteriosclerosis. If the progression of inflammation remains unchecked, it can lead to severe health conditions. A monoterpene glycoside which is extracted from the root part of *Paeonia lactiflora* named as Paeoniflorin, explored the anti-inflammatory activity and primary mechanisms, its derivatives as well as added monoterpenoids present in peony. The research findings revealed that most of the monoterpenes could inhibit the construction of inflammatory mediators such as Nitric Oxide (NO) and interleukin-6 (IL-6) as well as Tumor Necrosis Factor-Alpha (TNF-α) which were initiated by Lipopolysaccharides (LPS). Additionally, this effect was significantly dose-dependent.[16,17]

Anti-Cancer activity

Cancer is an ailment caused by genetic mutations that lead to the uncontrolled growth and division of cells, either in a specific area or by spreading to other parts of the body. This mutation arises due to DNA damage caused by external or internal factors. Under normal conditions, cells detecting this damage activate a repair mechanism that halts the cell cycle to prevent further harm. A key tumor suppresser gene viz P53, that controls arrest of cell cycle and activates apoptosis when desired. The given mechanism chunks the transmission of mutations to the generation of future cells. Terpenoids are very effective inactivation of P53 genes.[18,19] Some examples of anti-cancer terpenoids with their mechanism are presented in Table 1.[18-20]

Antidepressant Activity

Depression is prevalent health condition of CNS in contemporary culture. Overall, individuals with depression experience emotive symptoms such as sadness, low grade self-esteem, cynicism, and decreased loss of interest, along with bodily symptoms like disturbances of sleep and appetite reduction, significantly impacting their quality of life. Paeoniflorin as well as Albi florin, the bicyclic monoterpene phytocompounds extracted from Chishao, expressed prominent effects against depression. The previous is allied with its part in enhancing neurotransmitter activity of neurons of monoamines and growing neurotrophic factor which are brain-derived, suppressing the increased activity of the HPA axis, stimulating hippocampal neurogenesis, reducing inflammatory responses. The second one, achieves its effects against depression by influencing metabolism of amino acid and harmonizing microbiota of gut. [21-23]

Antioxidant Activity

As demonstrated in this chapter, terpenes exhibit antioxidant properties by regulating the body's natural antioxidant system and directly neutralizing Reactive Oxygen Species (ROS). ROS are a cluster of chemical molecules reactive in nature originating from oxygen, exhibiting significantly higher reactivity than oxygen in its ground state. Intracellular ROS can oxidize lipids, proteins,

Table 1: Anti-cancer terpenoids with their mechanism.

Sl. No.	Terpenoid	Anti-cancer mechanism
1	Parthenolide	Inhibiting nuclear factor KB and STAT pathways, downregulation of pro-apoptotic genes.
2	Dehydrocostus Lactone	Increased the generation of proteins apoptotic in nature like Bax and Bak, lessening the levels of proteins anti-apoptotic in nature, such as AIF, Bcl-2 and Bcl-XL as well as endonuclease G.
3	Crocetin	Inhibitory effect on cellular growth, chiefly targeting the PI3K/AKT and ERK1/2 pathways of signaling, lowers the level of P38, and upregulating 53 and p21 proteins.
4	Phytol	Destruction of expression of Bcl-2 protein as well as amplified Bax protein activation, ultimately leads to activation of caspase-9 and caspase-3 as well as apoptosis.
5	Ursolic Acid	Modulates the activation and action of enzymes involved in function of mitochondria, suppression of growth factors as well as apoptosis crossways various cell lines *in vitro*. (Viz. HuH7, M4Beu, HaCaT).

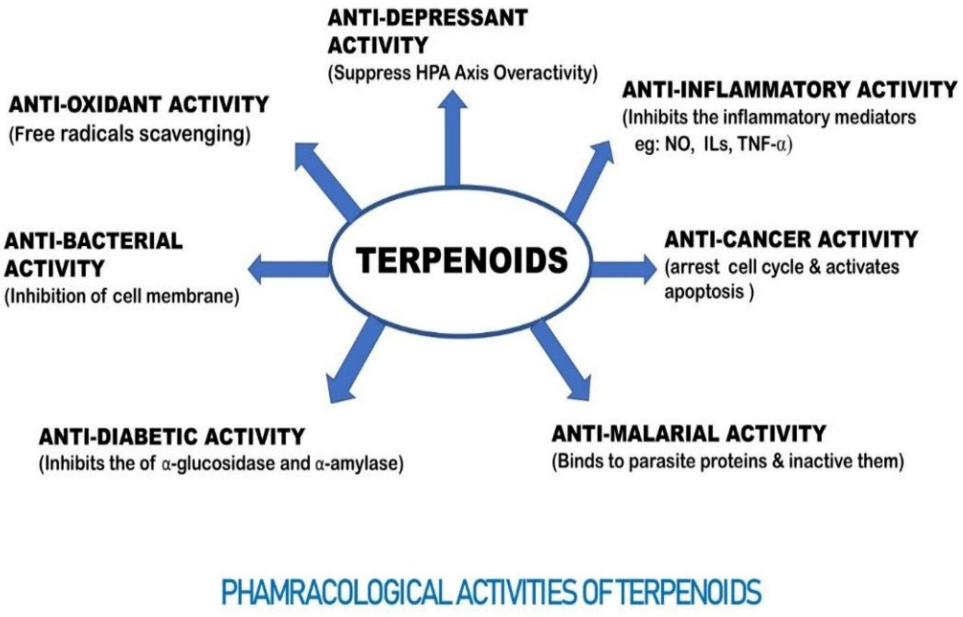

Figure 1: Pharmacological activities of terpenoids with their mechanism.

and DNA, leading to damage in various cellular components and potentially causing genetic mutations and cell death, primarily through apoptosis.

The primary triterpenes originate in olive oil specifically in extra virgin. It constitutes two oleanolic acid, triterpene acids and maslinic acid, along with uvaol as well as erythrodiol. In the continuous quest for novel bioactive natural compounds with antioxidant and anti-inflammatory properties, terpenes have proven to be a valuable source. Certain monoterpenes exhibit both antioxidant and anti-inflammatory effects.[16,17] Limonene and 1,8-cineole exhibited potent antioxidant, anti-inflammatory, and anticancer activities, as evidenced by assessments using the DPPH method, pleural cell migration assays, and tests on human cancer cell lines.[24-26]

Antibacterial Activity

The drug antibiotics are medication by potent bacteria killing and bacteriostatic properties, cast-off for intravenous therapy in persons and also for treating poultry animals, fish, and other species of aquaculture. The determined usage of antimicrobial medications, joint with the substantial presence of humanoid and animal waste matter. It has elevated the levels of enduring antibiotics in water and other surroundings. This has determined the expansion of resistance of bacterial drug, presenting a significant risk to the health of papulation. Plant-derived polysaccharides frequently exhibit antimicrobial properties. Various plant-derived polysaccharides have demonstrated antimicrobial properties contrary to a series of bacteria. The antibacterial effects of plant polysaccharides differ due to variations in the external structures of bacteria of Gram-positive as well as Gram-negative one. While few polysaccharides specifically constrain gram-positive bacteria and further target Gram-negative bacteria. Their action begins by attaching to the bacterial cell membrane, leading to inhibition.[27,28]

Antimalarial Activity

In the 1970s, a sesquiterpene lactone named Artemisinin is mined from *Artemisia annua* Linn. It is a highly active antimalarial drug, following pyrimethamine and chloroquine as well as primaquine. This is known for its little toxicity and increased efficiency. Subsequently, artesunate and artemether, were developed as antimalarial drugs by chemically altering the assembly of artemisinin. These drugs consist of minimal side effects and are highly effective in eliminating Plasmodium during the red blood cell stage. Recent studies indicate that when Plasmodium engulfs red blood cells, a high concentration of heme molecules is released. Artemisinin is activated by heme in areas of intense Plasmodium metabolism, where it binds to parasite proteins, rendering them inactive and effectively eliminating the Plasmodium. Additionally, sarcoplasmic endoplasmic reticulum calcium ATPase, translationally controlled protein of tumor, and glutathione S-transferase were recognized as non-heme proteins which interrelate through artemisinin within Plasmodium. The regulation of glycolysis-related gene expression, phosphorylation

of mitochondrial ATP of liver, and destruction of activity of nicotinamide adenine dinucleotide oxidase enzyme jointly contribute to dipping blood sugar levels.[29-31] In the Figure 1 pharmacological activities of terpenoids with their mechanism of action is presented.

DISCUSSION

The healing properties of herbals arise from their capability to performance as probable sources of medicine, mainly owing to the occurrence of SM, especially terpenoid composites. Herbal treatments play a vital role in managing and treating a widespread range of ailments. Therefore, the only solution to mitigate the harmful effects of modern drugs is the use of natural, plant-based medicine. This offers a safe alternative that aligns with social partialities, viability of economics, and sustainability, eventually delaying and preventing difficulties related to disorders of neurons.[32,33]

Among the SM of medicinal plants, terpenoids are the utmost abundant and diverse group. They are widely found in florae at high concentrations, usually produced in various parts of vegetables, flowers, and sometimes even in roots as well as stem. Terpenoids having the vast diversity is probably due to their plentiful natural roles of biological system, also making them an extensively used resource in both traditional and modern human practices. Naturally occurring terpenoids present new opportunities for discovering drugs with minimal side effects. They are commonly found in essential oils, which have economic value as flavoring agents and fragrances. They are repeatedly cast-off as natural garnishing of flavors in the industries of food. Terpenoids are vital for human nutrition and hold considerable economic value in pharmaceuticals and aromatics as well as probably future biofuel industry. Engineering in the field of metabolism and synthetic biologicals initiatives are progressively targeting terpenoids as a main emphasis. Various terpenoids have been studied for their potential activity against inflammation. These specific studies have been carried out in all types of animal models and well-established cultures of inflammatory cells in *ex vivo* models. They are too capable to diminution markers of inflammatory process, thereby dipping inflammation. Furthermore, there is supporting indication the usage of terpenoids rich herbal extracts. This specifies the likelihood of probable entrants that could performance as powerful medications against inflammation. Previous reports have also proved that diverse types of terpenoids help alleviate disorders caused by increased oxidative reactions in the body. So, terpenoids are also documented as powerful substances that inhibit oxidation reactions, a crucial factor in the commencement and progression of various disorders. Preceding literature also reports the protective impact of terpenoids on liver cells. Triterpenoids, diterpenoids, and sesquiterpenoids all have a protective effect on the cells of liver.[34,35]

Various scientists have similarly documented the activities of numerous kinds of terpenoids such as against fungal infection and cancer. These organic components inhibit growth of fungal colony as well as to exert toxic effects on the cell's proliferation process. Additionally, powerful anticancer activity was showed by terpenoids. Almost all terpenoids have the ability to inhibit cell growth. They primarily impact pathways like cell cycle arrest, inhibition of cancer cell differentiation, and the induction of apoptosis. They are also able to suppress metastasis by targeting cell signaling pathways.[36]

The herbal empire offers a promising source of such components. Many terpenoids performance as hormones of plants, which controls various functions of physiology, such as gibberellins. Few terpenoids serve as SM, protecting them from latent pathogens in equally plants and animals. The increasing interest in natural products as driven the search for new bioactive compounds that could be customized for specific therapeutic purposes. Terpenoids, a major class of plant SM identified for their properties like anticancer, emerge as gifted candidates for pharmaceutical drug development.

CONCLUSION

Terpenoids have the most abundant plant SM and also represent a highly diverse class of phytoconstituents. Terpenoids have been proven to be among the most widely used phytochemicals in traditional medicine systems. Recent reviews have focused on several terpenoid compounds because of their promising pharmacological properties. Terpenoids exhibit a range of pharmacological effects against conditions like inflammatory reaction, cancer, joint inflammation, hyperglycemia, and blood pressure. Through advanced techniques analytical chemistry, researchers have efficaciously isolated and recognized various plant metabolites, paving the way for development of novel drug. The wide variety of pharmacological actions of terpenoids makes them an influential possible therapeutic agent for substitute treatment of several ailments and disorders. So, there is currently growing interest in using medicines derived from medicinal and herbal plants as a substitute therapy owing to their lesser risk of adverse reactions. The given afresh identified chemical edifices show significant potential as therapy for a variety of diseases. Currently, there is considerable potent activity to utilize these reactive metabolites in developing pharmaceutical agents that are both more effective as per cost concern and sustainable to environment.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of Interest.

ABBREVIATIONS

SM: Secondary Metabolites; **PC:** Phenolic Compounds; **MVA:** Mevalonate; **DXP:** 1-deoxy-D-Xylulose-5-Phosphate; **IU:** Isoprene Units; **T1DM:** Type 1 Diabetes Mellitus; **T2DM:** Type 2 Diabetes Mellitus; **NO:** Nitric Oxide; **TNF-α:** Tumor Necrosis Factor-Alpha; **LPS:** Lipopolysaccharides; **DNA:** Deoxyribonucleic Acid; **P53:** Tumor Protein; **Kum** Inhibiting Nuclear Factor; **STAT:** Signal Transducer and Activator of Transcription; **Bax:** Bcl-2-Associated X Protein and **Bak:** Antagonist/killer**; AIF:** Apoptosis-Inducing Factor; **Bcl-2:** B-cell Leukemia/lymphoma 2 and **Bcl-XL:** B-cell Lymphoma-Extra-Large; **PI3K/AKT:** Phosphatidylinositol 3-kinase/protein kinase B and **ERK1/2:** Extracellular Signal-Regulated Kinase 1/2; **P38 MAPKs:** Mitogen-Activated Protein Kinases (MAPKs); **P53:**Tumor Suppressor Protein; **p21:** Cyclin-Dependent Kinase Inhibitor; **caspase-9:** Cysteine-Aspartic Protease 9; **caspase-3:** Cysteine-Aspartic Acid Protease 3; **HuH7:** Human Hepatoma; **M4Beu:** Melanoma cell line; **HaCaT:** Human immortalized keratinocyte cell line; **CNS:** Central Nervous System; **HPA:** Hypothalamic-Pituitary-Adrenal axis; **ROS:** Reactive Oxygen Species; **DPPH:** 2,2-diphenyl-1-picrylhydrazyl; **ATPase:** Adenosine Triphosphatase.

SUMMARY

Terpenoids are a broad and varied group of naturally occurring organic compounds found in medicinal plants. Widely present in plants, they demonstrate diverse biological effects and hold considerable promise for therapeutic applications. Previous researchers also reported varied therapeutic application of terpenoids in animal models. Their varied structures and biological activities position them as strong contenders for drug development in multiple areas of medicine.

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