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Anti-inflammatory and Antioxidant Properties of Herbal Extracts: Mechanism and Therapeutic Potential

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REVIEW ARTICLE

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ABSTRACT

Bioactive compounds mostly with potent anti-inflammatory and antioxidant properties that found in herbal extracts, have acknowledged for their various medicinal benefits. Herbal extracts have the ability to suppress pro-inflammatory cytokine, and abundant in bioactive substances like flavonoids, polyphenols, terpenoids, and alkaloids, fight inflammation and oxidative stress in one of the two important elements in the etiology of chronic liver diseases like alcoholic liver disease and non-alcoholic fatty liver disease. Cellular damage results from oxidative stress brought on by drugs, alcohol, and environmental contaminants that throw off the equilibrium of important enzymes like superoxide dismutase, glutathione, and catalase. In addition to restoring these enzymes function, herbal antioxidants also lessen inflammation and lipid peroxidation. In both acute and chronic states, several substances, including curcumin, betaine, and l-theanine, exhibit hepatoprotective properties. Potentially useful anti-inflammatory and antioxidant properties of herbal extracts could pave the way for plant-based, natural remedies for the management and prevention of chronic diseases. Bioactive substances, like carotenoids and polyphenols, have demonstrated anti-atherosclerosis, cancer prevention, and rejuvenation properties. Various compounds and chemicals contribute to synthetic antioxidants and enhance the production of functional foods with potential medicinal uses. Furthermore, the solubility, bioavailability, and therapeutic potential of herbal extracts greatly increased when they are included into nanoparticle delivery systems. This collaboration between technology and nature creates new, less harmful treatment options for inflammatory and oxidative diseases. The use of these phytomedicines' therapeutic potential in a better way, more studies and standardization are required.

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Introduction

Herbal extracts, due to their major pharmacological and therapeutic potential, has utilized in traditional medicinal systems for centuries [1]. These beneficial effects are primarily attributed due to the presence of bioactive compounds such as alkaloids, flavonoids, terpenoids, phenolic acids and tannins, which exhibit a wide range of biological activities including antimicrobial, anti-inflammatory, antioxidant and anti-cancer effects [2]. In the recent years, the increase in resistance to current pharmaceutics and side effects associated with synthetic drugs has led to the revival of herbal remedies as alternate therapeutic option. Notably, it estimated that 25% of currently prescribed medication trace their roots to plant-based sources [3]. The structure complexity and chemical diversity of phyto-constituents is what makes them surpass what can be achievable through synthetic methods. This makes herbal extracts play a vital role in novel therapeutic agents.

Oxidative stress contributes substantially to pathogenesis of various metabolic, degenerative and inflammatory diseases. The main source of oxidative stress is the imbalance of reactive oxygen species (ROS) production and disturbance of antioxidant defense, which contributes to cellular and molecular damage [3][4]. ROS can be produced endogenously by means of mitochondrial respiration and inflammatory process and exogenously through environmental pollutants, pharmaceuticals, xenobiotics and heavy metals like cadmium and lead [5][6]. In particular, heavy metals can be leading cause of inducing oxidative damage through redox homeostasis disruption, antioxidant (like glutathione) depletion and pro-inflammatory cytokine production [7][8]. Major health issues, including diabetes mellitus, neurodegenerative disorder, cardiovascular disease, hypertension, liver and renal injury are caused due to oxidative stress [3].

Inflammation is a complex biological response involving various cellular and molecular mechanisms. Excess ROS give rise of lipid peroxidation, protein oxidation and DNA damage, which often ends up in initiation of chronic inflammation through the activation of NF-κB and other redox-sensitive transcription factors [9]. The cytokines (TNF-α, IL-1β, IL-6), chemokines and other adhesion molecules when produced in response of ROS initiate inflammatory response [10]. Inflammasomes like NLRP3, when activated by oxidative stress induces maturation and secretion of IL-1β and IL-18, which further contributes to the inflammatory cascade [11]. The synergistic effect of these events initiates endothelial dysfunction, leukocyte recruitment, tissue injury, forming a mechanistic link between oxidative stress and chronic inflammation in various diseases [12].

Herbal extracts, rich in diverse bioactive compounds, have demonstrated significant anti-inflammatory potential. Many herbal extracts can inhibit the production of pro-inflammatory cytokines, such as TNF-α, IL-1β, and IL-6. Certain compounds can suppress the activation of critical inflammatory signaling pathways, including NF-κB and MAPK. By reducing oxidative stress, antioxidants can indirectly alleviate inflammation. Curcumin is a polyphenol derived from turmeric; it has potent anti-inflammatory effects. It inhibits the activation of NF-κB and reduces the production of inflammatory cytokines. Gingerols and shogaols, the active compounds in ginger, have anti-inflammatory properties [13]. Allicin, a Sulphur-containing compound in garlic, has shown to possess anti-inflammatory effects [14]. Moreover, other herbal extracts with antioxidant properties include green tea, rosemary, and berries [15].

With advances in research, scientists can identify and isolate the active antioxidant compound from herbal products and use it for therapeutic purposes [16]. While growing evidence supports the therapeutic potential of herbal extracts, further research is required to understand their proper mechanisms and optimize their use fully. Clinical research is essential to evaluate the effectiveness and safety of herbal extracts in various disease conditions. This review provides an overview of current findings on the mechanistic role of herbal extracts in combating oxidative stress and inflammation and to explore their therapeutic potential against various chronic diseases.

Herbs as a Source of Various Therapeutical Agents

A number of therapeutic medications have been logically created and synthesized in recent years based on new insights, that obtained by studying the properties of physiologically active substances obtained from food, plants, and medicinal plants. These naturalistic compounds' capacity to interact with several bodily targets and have a cumulatively positive effect is one of their main advantages [17]. Traditional Chinese medicine (TCM) is a compassionate approach that promotes holistic well-being and restores harmony with herbal treatments. TCM practitioners employ herbal and botanical compositions support optimal health and increase organ function [14]. Understanding the basic properties of various herbal ingredients enables the TCM therapist to provide a therapeutic effect that goes beyond the physical and chemical characteristics of the herbs. Chinese herbal formulas, some of which date back more than 2200 years, were made of ingredients chosen for their complimentary roles. Unlike the individualistic approach that is common in Western medicine, TCM often uses a combination of botanicals in order to achieve a synergistic impact. Moreover, the survival of herbs threatened by increased demand for plants used in traditional medicine and pharmacological research. Because future generations will be able to manage and use these species more appropriately and wisely, it is imperative that genetic resources that are threatened, vulnerable, and misused to be preserved to the greatest extent possible [18].

Anti-inflammatory and antioxidant properties of herbal extracts

Compounds that slow down or inhibit oxidation and generally extend the life of oxidizable matter known as antioxidants or inhibitors of oxidation [19]. Free radicals are the fundamental elements of all metabolic reactions and are crucial to aerobic life and metabolism. The majority of illnesses primarily caused by oxidative stress brought on by free radicals [20]. Species that have a relatively short half-life, high reactivity, and destructive action towards macromolecules like proteins, DNA, and lipids known as oxidants or free radicals. These species could produce from nitrogen (RNS) or from oxygen. Superoxide anion (O_2), hydrogen peroxide (H_2O_2), peroxyl radicals (ROO), and reactive hydroxyl radicals (OH) are the most prevalent reactive oxygen species. Nitric oxide (NO), per-oxynitrate anion (ONOO), nitrogen dioxide (NO_2), and dinitrogen trioxide (N_2O_3) are the free radicals produced from nitrogen. Reactive oxygen species generally circulate in the body and react with other molecules' electrons to affect different enzyme systems and cause damage. This damage may further exacerbate conditions like rheumatoid arthritis, cancer, ischemia, aging, and adult respiratory distress syndromes [21].

Classification of anti-oxidants Based on solubility

(a). Hydrophilic antioxidants: - They are water soluble. Oxidants in the cell cytoplasm and blood plasma react with water-soluble antioxidants.

(b). Hydrophobic antioxidants: - They are fat soluble. Antioxidants that dissolve lipids shield cell membranes from lipid peroxidation [22].

Based on line of defense

(a). First line defense (preventive antioxidant)

These include minerals like Se, Mn, and Cu as well as enzymes like glutathione reductase, glutathione peroxidase, catalase (CAT), and superoxide dismutase (SOD). Superoxide (O_2) is mostly quenched by SOD, and H_2O_2 is catalyzed to break down into oxygen and water by catalase [23].

(b). Second line defense (Radical scavenging antioxidant)

These include flavonoids, carotenoids, albumin, bilirubin, vitamin E, uric acid, glutathione, and so on. One of the best scavengers of singlet oxygen is β carotene. Radicals like O_2 and OH directly impacted by vitamin C. Glutathione (GSH) may aid in the detoxification of numerous ingested oxidizing air contaminants, such as ozone, and is an effective scavenger of numerous free radicals, including O_2, OH, and different lipid hydroperoxides [24].

(c). Third line defense (Repair and de-novo enzymes)

These intricate set of enzymes that not only inhibit the chain propagation of peroxyl lipid radicals but also repair damaged DNA, proteins, oxidized lipids, and peroxides. These enzymes reconstruct the broken cell membrane and fix damage to biomolecules [25].

Naturally occurring antioxidants in herbal extract

Herbal plants are abundant sources of natural antioxidants. The biological benefits of these natural antioxidants, particularly polyphenols and carotenoids, are diverse and include anti-inflammatory, anti-aging, anti-atherosclerosis, and anti-cancer properties. Many herbal extracts contain polyphenols and flavonoids, which are particularly abundant and play a major role in their capacity to scavenge radicals. For example, turmeric's high curcumin content and green tea's abundance of catechins and flavonoids are widely known for their potent antioxidant benefits. Furthermore, the potential of herbal antioxidants to provide a natural substitute for synthetic antioxidants—which, although beneficial, have sparked questions about possible harmful side effects with prolonged use—has increased interest in these products. Studies have demonstrated that antioxidants produced from plants have anti-inflammatory, anti-cancer, and immunomodulatory properties in addition to reducing oxidative stress, which increases their therapeutic potential [26]. Moreover, a detailed overview of various types of natural antioxidants in selected herbal plants are listed in Table 1.

Antioxidant and total phenolic content of common herbs

There are a number of analytical techniques that can used to determine the antioxidant activity, antioxidant efficacy, or efficiency of spices and herbs. Figure 1 shows the most often used analytical assays include total phenolic concentration, ferric reducing antioxidant power (FRAP), oxygen radical absorbance capacity (ORAC), and 2,2-diphenyl-1-picrylhydrazyl (DPPH) [34].

This bar graph shows that Salvia officinales exhibits the highest phenolic content, indicating strong potential antioxidant qualities based on phenolic components, while Mentha has the highest antioxidant content (FRAP), suggesting it is effective in the ferric reduction ability.

Based on DPPH and phenolic content, Ocimum basilicum and Origanum vulgare exhibit well-balanced antioxidant capacities [17].

Naturally occurring anti-inflammatory agents in herbal plant

Since ancient times, plants extensively used in human health care. Plants create a number of compounds that have biological effects as a defense against pathogens and environmental stress. These tiny organic molecules

Table 1. Various antioxidant compounds along with their uses and their antioxidant properties

Herbal Plant	Family	Antioxidants	Antioxidant Activity / Properties	Other Uses	Ref
Sphaeranthus indicus Linn	Asteraceae	Flavonoids, carbohydrates, alkaloids, gums, and mucilage	Ethanolic extract scavenges radical cation, DPPH, SOD, and NO	-	[27]
***Ocimum basilicum* (Basil)**	Lamiaceae	Rosmarinic acid, ellagic acid, catechin, liquiritigenin, and umbelliferone.	Ethanol extracts also exhibited the highest antioxidant activity in DPPH, FRAP and H_2O_2 assays.	-	[28]
Diospyros malabarica kostel	Ebenaceae	Phenolic compounds	Inhibits the generation of nitrite and peroxynitrite anions (free radicals)	Stem bark for intermittent fever, fruit juices for wound healing	[29]
Eucalyptus globules	Myrtaceae		Antioxidant activity via DPPH radical scavenging and inhibition of Fe-ADP-ascorbate induced lipid peroxidation	-	[21]
Mentha arvensis	Labiatae	L-menthol (80%)	Antioxidant activity via DPPH radical scavenging and inhibition of Fe-ADP-ascorbate induced lipid peroxidation, decreases lipid peroxidation	-	[10]
***Rosmarinus officinalis* (Rosemary)**	Labiatae	Volatile oil (rosemary oil, mainly borneol), resin, ursolic acid	Antioxidant activity due to borneol	Used in tea to avert cancers, heart diseases	[30]
Acacia arabica bark	Mimosae	Catechin, epicatechin, quercetin, gallic acid	Radical scavengers and Protects against TBH-induced lipid peroxidation and CCl4-induced hepatic damage	Used to treat asthma, bronchitis, diabetes, dysentery, and skin diseases	[31]
***Salvia officinales* (Sage)**	Lamiaceae	Carnosol, carnosic acid, rosmanol, rosmadial, methyl and ethyl esters of carnosol, rosmarinic acid	Free radical scavenger	-	[18]
***Oreganum vulgare* (Oregano)**	Lamiaceae	thymol, carvacrol, limonene, terpinene, ocimene, and caryophyllene	Free radical scavenger. Antioxidant activity was determined by DPPH assay.	-	[32]
***Zingiber officinale* [Ginger]**	Zingiberaceae	Volatile oil, starch, acrid resinous matter, shagoals, zingerone, peradols	-	-	[33]
Citrus lemon	Rutaceae	Citral, limonene	DPPH radical scavenging and inhibition of Fe-ADP-ascorbate-induced lipid peroxidation	Antioxidant property due to citral	[21]

***DPPH**: Diphenyl picryl hydrazyl, **SOD**: Superoxide dismutase, **NO:** Nitric oxide, **TBARS**: thiobarbituric acid reactive substances, **GP$_x$**: glutathione peroxidase, **GST**: glutathione-S- transferase, **TBH**: tertiary butyl hydroperoxide* exhibit variety of biological functions and produced by secondary metabolism. Anti-inflammatory properties stand out among the many uses [35][36].

Inflammation recognized as a vital survival mechanism and an evolutionary conserved protective function [37]. In order to eradicate the original cause of the cell injury, which could have been brought on by physical agents (such as radiation, burns, and trauma), chemicals (such as caustic substances), or infectious agents or substances from their metabolism (such as microorganisms and toxins), it consists of intricate, sequential changes in the tissue. Rich in bioactive components with strong anti-inflammatory effects, herbal plants offer a natural treatment option for illnesses linked to inflammation. Many of these anti-inflammatory substances are secondary metabolites that plants make to defend against infections, herbivores, and environmental stresses. Polyphenols, flavonoids, terpenoids, alkaloids, and saponins are some of the main substances that cause these effects. It has demonstrated that these substances decrease inflammatory mediators such cytokines, enzymes, and reactive oxygen species [38][39]. A detailed overview of different types of natural anti-inflammatory compounds in selected herbal plants are listed in Table 2.

Major herbal antioxidants and compounds interactions against inflammation in body

Alcohol consumption, particularly in excess, poses significant health risks, alcoholic liver disease (ALD) is more frequently linked with unhealthy drinking habits based on time and frequency of consumption. Alcoholic liver disease appears as uncomplicated steatosis initially; however, it progresses to alcoholic hepatitis, alcohol-associated fibrosis, cirrhosis, and alcoholic hepatocellular carcinoma [47]. The etiology of ALD is multifactorial and complex, from oxidative stress since ethanol metabolism produces ROS causing mitochondrial injury and essentially resulting in hepatocyte injury. Ethanol metabolism occurs primarily in two pathways stimulated by enzymes. The majority of ethanol metabolism occurs via alcohol dehydrogenase and cytochrome P450 enzyme CYP2E1. Ethanol metabolism creates the propensity for ROS generation; therefore, oxidative stress in the liver overwhelms the liver's antioxidant response [48].

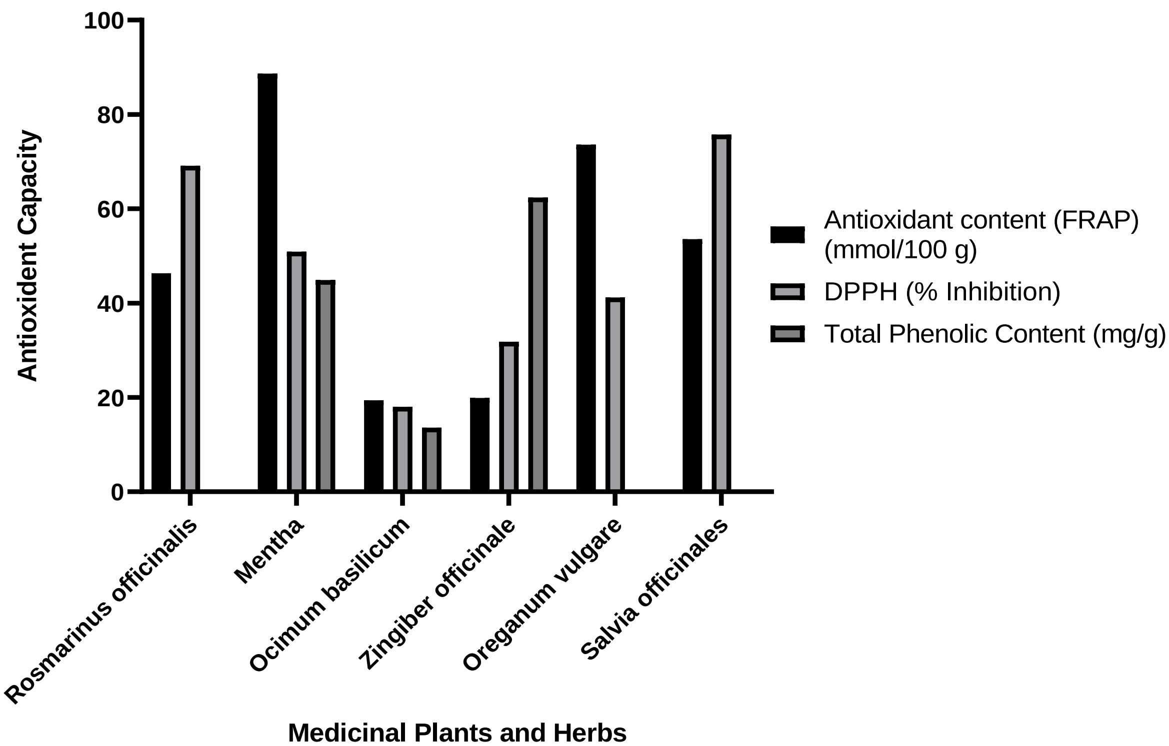

Figure 1. Antioxidant capacity of selected medicinal plants and herbs on the basis of FRAP, DPPH inhibition, and Total Phenolic Content [34]

Table 2. Various antioxidant compounds along with their uses and their antioxidant properties

Herbal Plants	Family	Anti-inflammatory compounds	Anti-inflammatory Activity/Properties	Other uses	Ref
***Curcuma longa* (Turmeric)**	Zingiberaceae	Curcumin	Anti-inflammatory; effective in reducing rheumatoid arthritis (RA)	Treats rheumatoid arthritis (RA), uveitis, gastric ulcers, irritable bowel syndrome (IBS), delayed graft rejection (DGR), ulcerative colitis, psoriasis.	[12]
***Zingiber officinale* (Ginger)**	Zingiberaceae	Gingerol, Shogaol	Reduces TNF-α and high-sensitivity C-reactive protein	Effective in treating osteoarthritis, diabetes, musculoskeletal pain; inhibits cyclooxygenase/lipoxygenase pathways	[15]
***Rosmarinus officinalis* (Rosemary)**	Lamiaceae	Rosmarinic acid, Essential oils	Anti-inflammatory, gastroprotective; decreases hs-CRP, reduce proinflammatory mediators TNF-α and IL-1	Used for osteoarthritis, rheumatoid arthritis, fibromyalgia, and gastric ulcers.	[40]
***Borago officinalis* (Borage)**	Boraginaceae	Gamma-linolenic acid (GLA)	Suppresses TNF-α and reduces inflammation in RA	Used for rheumatoid arthritis and atopic dermatitis.	[41]
***Oenothera biennis* (Evening Primrose)**	Onagraceae	Gamma-linolenic acid (GLA), Phenolic compounds, Tetracosanol, Sterols	Anti-inflammatory effects; modulates nitric oxide (NO), TNF-α, IL-1β, COX-2 gene expression	Used in rheumatoid arthritis, multiple sclerosis (MS); reduces morning stiffness, may reduce reliance on NSAIDs.	[42]
***Urtica dioica* (Stinging Nettle)**	Urticaceae	Flavonoids, Tannins	Synergistic effect with NSAIDs; inhibits NF-κB in RA patients; reduces CRP and inflammation	Used for acute arthritis, osteoarthritis, allergic rhinitis; has anti-inflammatory and analgesic properties.	[43]
***Salvia officinalis* (Sage)**	Lamiaceae	Carnosol, Carnosic acid	Anti-inflammatory; inhibits PGE2 production via microsomal PGE2 synthase-1 inhibition	Used for atopic dermatitis, inflammatory conditions, but caution with essential oil use due to possible seizures.	[44]
***Ribes nigrum* (Blackcurrant)**	Grossulariaceae	n-6 PUFA, Gamma-linoleic acid, Alpha-linolenic acid	Reduces stiffness and proinflammatory markers IL-1β, TNF-α; inhibits PGE2 biosynthesis	Used for rheumatoid arthritis; moderate immune response reinforcement and anti-inflammatory effects.	[45]
***Olea europaea* (Olive)**	Oleaceae	Polyphenols, Oleic acid	Modulates proinflammatory cytokines, TXB2, and LTB4; reduces risk of coronary heart disease; accelerates wound healing	Used in inflammatory conditions, wound healing, burn treatment, and to reduce cardiovascular disease risk.	[46]

***TNF-α**: Tumor necrosis factor alpha, **CRP**: C-reactive protein, **IL-1**: Interleukin 1, **NF-κB**: Nuclear factor-kappa B, **PGE2**: Prostaglandin E2, **iNOS**: Inducible nitric oxide synthase, **MMP-1**: Matrix metalloproteinase-1, **TXB2**: Thromboxane B2, **LTB4**: Leukotriene B*

Research has shown ethanol-induced inflammation mediates changes in alcohol-related mortality via inflammatory pathways, such as SOD and CAT. For example, animal studies relative to alcohol exposure show reduced SOD and CAT levels and increased malondialdehyde (MDA) determined by 4,6-diamidino-2-phenylindole (DAPI) and malondialdehyde assay kits. MDA correlates with acute and chronic hepatic injury; further, increased in ALD was found in patients according to serum assay data and histological findings. Ultimately, the stress response of the body via inflammation overloads the pathway but uses increased malondialdehyde and antioxidant enzymes as compensatory pathways through duration and dosage of alcohol exposure [49].

Oxidative stress is not exclusive to alcohol, it's interesting to note that oxidative stress is also a prevalent biomarker of drug-induced hepatotoxicity. Many drugs—anti-inflammatory, analgesic, anticancer - produce hepatic oxidative stress inclusive of ROS and reactive nitrogen species (RNS). For example, sulfasalazine, paracetamol, and doxorubicin are drugs cited in experimental animal studies that produce significant upregulation of malondialdehyde (MDA) and significant downregulation of SOD, GSH, and CAT activity. While MDA is related to lipid peroxidation, the downregulated activities of the enzymes further decrease the hepatocyte's naturally occurring arsenal, rendering it ineffective in terms of DNA damage. Ultimately, SOD, GSH, and CAT are downregulated for decreased resiliency of the liver, in general [5].

Environmental pollutants like heavy metals (e.g., mercury and lead) and microcystins (toxins from cyanobacteria) similarly induce oxidative stress. For instance, veterinarians have demonstrated that exposure to mercury chloride decreases SOD levels while increasing alanine aminotransferase - a marker of hepatocellular injury - and γ-glutamyl transferase. In addition, the most studied hepatotoxin relative to microcystins is microcystin LR; it decreases activities of antioxidant enzymes while increasing levels of lipid peroxidation, suggesting that oxidative stress of the liver is critical to hepatic injury [50].

Antioxidants play a significant role in limiting the oxidative damage caused by liver diseases. ALD, a best medically addressed by encouraging abstinence but this is hard to achieve given the high rates of relapse. Natural sources of antioxidants, have found effective against liver injuries. Polyphenols, Flavonoids, and other plant-rich antioxidants sourced from green tea, vegetables, fruits, and medicinal plants fight against free radicles to strengthen the liver's antioxidant abilities. In experiments on animals, supplementation with green tea of ethanol treated rats not only restored antioxidant strengthening enzyme activities but also helped reduce lipid peroxides [49].

Some specific compounds known to exhibit protective properties including l-theanine (from green tea) together with vitamins E and C. L-theanine boosts the action of SOD and CAT, also reduces the onset of fatty liver due to ethanol. Vitamin E has also noted to retain both antioxidant stability and the ability to alleviate oxidative damage. Another compound, betaine, lowers ethanol-induced oxidation stress and promotes liver protection by adjusting GSH levels. Betulinic acid found in certain plants is also considered to increase the levels of several antioxidants (e.g., SOD, GSH-Px, CAT) and decrease MDA content in several ethanol-treated animal models. Also, demethyleneberberine, which is contained in *Cortex Phellodendri chinensis* an antioxidant, has been confirmed to decrease oxidative stress and steatosis during both acute and chronic exposure to ethanol [51].

Non-alcoholic fatty liver disease, also observed to associate with oxidative stress resulting from obesity, insulin resistance, and inflammation. Animal studies have shown that certain antioxidants such as acai berries and vitamins C and E combat oxidative stress by stimulating the activities of antioxidant enzymes and reducing lipid peroxides [52].

The significant role of antioxidants in quenching the main inflammatory pathways is interesting because antioxidants can block the pro-inflammatory cytokines such as the TNF-α. TNF-α not only has an important role in liver inflammation and damage but also activates other kinases (e.g., JNK, IKKβ) that trigger stress responses and further increase oxidative stress while reducing insulin sensitivity. Anti-TNF therapies in animal models have shown reduced liver injury indicating the possible benefits of antioxidants in the inflammatory cascades [53].

Melatonin, which is an antioxidant naturally found in the body and has strong ROS scavenging capability has demonstrated hepatoprotective action in several animal studies. Melatonin has been proven to be more effective than vitamin E in reducing lipid peroxide and restoring antioxidant enzymes under some models of liver injuries showing its promise in clinical treatment [54].

Onion, another source of quercetin rich in flavonoids has been shown in several studies to maintain levels of antioxidants and protect cells from oxidative damage in vitro and in vivo models of nicotine exposure. These bioactive compounds are reported to employ different antioxidant mechanisms including free radical scavenging and lipid peroxidation inhibition while upregulating antioxidant enzyme activities, and modulating inflammatory pathways [5].

Overall, curcumin, garlic, as well as onion contributes positively to the health of individuals through their anti-oxidative and anti-inflammatory mechanisms. These in addition assist in the management of diseases which arise due to stress and that which are related to inflammation [5].

Nanoparticles made with herbal extracts in therapeutics

Nanoparticles constitute a broad category of materials that encompass particulate substances measuring less than 100 nm in size [55]. This century has witnessed significant advancements in nanotechnology, encompassing therapy, detecting, diagnosis, and regulation of living systems [56]. Nanoparticles have achieved significant progress in nanotechnology owing to their adjustable physicochemical and biological properties compared to their equivalents. Currently, herbal medications occupy a prominent role in the pharmaceutical sector due to their established efficacy of treatment and few adverse effects. Furthermore, the herbal compound exhibits a symmetrical approach to nanoparticle fabrication in contrast to manufactured medications [57].

Nanostructured and nanocarriers systems can be classified into inorganic and organic categories. The physiochemical structure and abilities of such carriers can be modified by adjusting their composition or dimensions. The utilization of nanocarriers in herbal remedies will increase surface area, improve solubility and bioavailability, and enable precise drug targeting, aiming to discharge a molecule of drug over a specific part of living system for an extended duration and imply a positive effect on diseased tissue. Nanoparticles exhibit diverse shapes and sizes. 0-D, 1-D, and 2-D represent the various dimensions of nanoparticles, mesoporous structures [58], liposomes, and micelles, all composed exclusively of lipids, characterized by their amphiphilic spherical shapes; dendrimers are classified as branching compounds. Natural and synthetic polymers entirely compose polymer nanoparticles and hydrogels, which typically exhibit greater stability in nature.

Herbal drug loading

Contemporary society increasingly favors herbal medications due to their efficacy in treating various ailments with less toxicity and enhanced therapeutic outcomes. On the other hand, herbal extracts can be unstable in highly acidic environments and go through a lot of first-pass metabolism, which can cause drug levels to drop below the therapeutic concentration in the bloodstream, reducing or eliminating the therapeutic effect. Innovative carriers encapsulate herbal medications to eliminate such effects, reducing drug degradation and mitigating severe adverse effects caused by accumulation in non-targeted areas [59]. A general mechanism for drug loading to nanoparticles by using herbal extracts describes in Figure 2.

Importance of Antioxidant activity

Medicinal plants predominantly contain antioxidants, which are substances that inhibit oxidation chain reactions in various compounds. Herbal plants possess a significant concentration of phenolic chemicals that function as antioxidants. Antioxidant chemicals possess redox characteristics that manifest their effects by neutralizing free radicals and degrading peroxides. People regard natural antioxidants as safe and effective, while they avoid artificial antioxidants because of their harmful effects on the human body. For many decades, the United States has utilized culinary herbs to enhance the flavor of food items [59].

The antioxidant enzyme establishes an interaction network to avert cellular damage caused by oxidative stress. Superoxide is released during this process. Initially, oxidative phosphorylation transforms into H_2O_2, which subsequently reduces to yield water. The many enzymes culminate in a detoxification process.

Importance of Anti-inflammatory activity

Inflammation is a multifaceted protective mechanism wherein leukocytes traverse from the capillaries into infected tissues to eliminate substances that could induce tissue damage. Many mechanisms, including the immediate scavenging of hydroxyl radicals, recognize anti-inflammatory medicines' influence on oxidant damage at inflammation sites. Nearly all tested chemicals associated with compound 12 considerably hindered the hydroxyl-mediated oxidation of dimethylsulfoxide (58-83% and 65-100% for 12, 5, and 25 mmol/L, respectively) and also interacted with the stable free radical DPPH (4-82%) [60].

Future of herbal extracts in medicinal therapies

The potential of herbal extracts in the treatment of different diseases continues to be on the rise. The future of therapies lies in harnessing these natural products which are potent medical tools, engineering synthetic antioxidant enzymes and producing functional foods which possess antioxidant properties [54]. There is also the possibility of obtaining new antivirals based on herbal extracts that would be extremely useful for the treatment of inflammatory viral infections for which there are no vaccines or medication available. The integration of these biological products with modern therapeutics has the potential to improve effectiveness and decrease adverse effects as well as the therapeutic options available which presents a very important place for herbal extracts in the contemporary medicine [61]. There have been attempts in the developing countries to test the reliability of information concerning the use of medicines from herbs by natives that had been reported in respect to these plants. It is, however, important to point out that while herbal medicine is widely used by people across the world due to health inequalities, the -

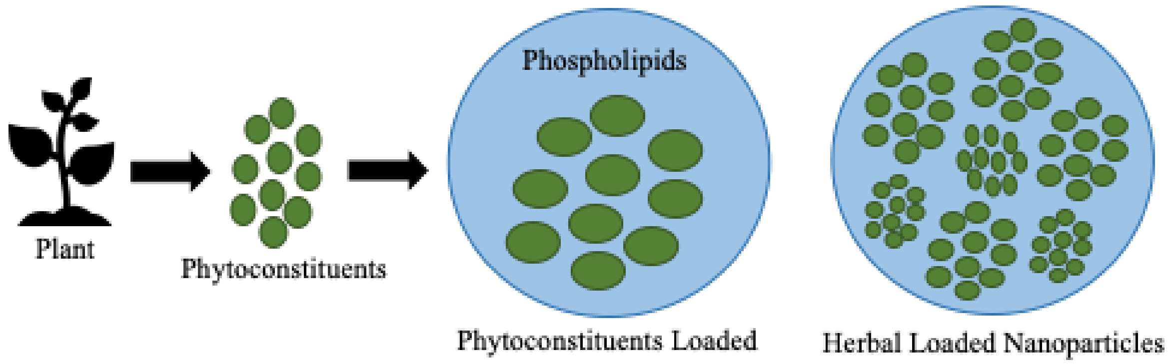

Figure 2. Herbal drug loaded nanoparticles [59]

Industrial production of herbs and herbal products is not fully developed due to a lack of information regarding their economic significance. The use of synthetic drugs approach to isolate plant active compounds with known activities is also important. These studies would help solving the most important tasks 'How to obtain effective, natural preparations for therapeutic purposes and proper utilization of plants for additional economic impact [62].

Conclusion

To conclude, herbal extracts offer a viable natural substitute for traditional therapies because of their well-known anti-inflammatory and antioxidant qualities. In addition to providing therapeutic advantages with fewer adverse effects than manufactured medications, they efficiently treat oxidative stress and inflammation, two major causes in many chronic diseases. These extracts are becoming more and more recognized as beneficial alternative therapies as interest in herbal therapy increases. To fully realize their potential and create standardized usage, more research is necessary. With more research, herbal extracts could be able to help with ailments including viral infections and other inflammatory disorders that don't have good medicines. Furthermore, their significance for general health is highlighted by their capacity to counteract oxidative damage, which is connected to aging and a number of health problems. Herbal extracts may become increasingly important as research progresses, providing safer and better treatment alternatives for a variety of illnesses.

Authors' contributions

ICMJE criteria	Details	Author(s)
1. Substantial contributions	Conception, OR	1,3
	Design of the work, OR	2,5,6
	Data acquisition, analysis, or interpretation	4,7,8
2. Drafting or reviewing	Draft the work, OR	1,2,3,5
	Review critically for important intellectual content	4,6,7,8
3. Final approval	Approve the version to be published	1,2,3,4,5,6,7,8
4. Accountable	Agree to be accountable for all aspects of the work	1,2,3,4,5,6,7,8

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Declarations

Ethics approval and consent to participate

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Consent for publication

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Competing interests

The authors declare no competing interests.

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