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A Review of Phytochemical Constituents and their Pharmacological Activities.

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ABSTRACT

Medicinal plants have been a cornerstone of traditional medicine, providing a rich source of bioactive compounds with diverse therapeutic potential. This review aims to explore the phytochemical composition and pharmacology activities of various medicinal plants, highlighting their potential application in modern medicine. By examining key phytochemicals such as flavonoids, alkaloids, saponins, and terpenoids, we provide an overview of their roles in treating disease, including anti-inflammatory, antioxidant, anticancer, and antimicrobial effects. The review discusses the mechanisms through which these phytochemicals exert their effects. Focusing on their interaction with biological pathways and molecular targets. Additionally, we discuss the challenges and limitations associated with the use of medicinal plants. Such as viability in phytochemical content, bioavailability issues, and the need for standardized extraction methods. Our findings underscore the importance of integrating traditional knowledge with modern scientific approaches to optimize the therapeutic use of medicinal plants. We also highlight the need for further research to fully elucidate the mechanism of action of these compounds and to develop novel formulations that enhance their efficacy and safety. In conclusion, the phytochemical diversity of medicinal plants represents a valuable resource for drug discovery and development. This review provides critical insight into the pharmacological potentials of these natural compounds and suggests future directions for research to harness their full medicinal potential.

Keywords: Phytochemistry, pharmacology, medicinal plants, bioactive compounds, flavonoids, alkaloids, saponins, drug discovery and traditional medicine

1 INTRODUCTION

A recent study reported that a higher intake of bioactive compounds is significantly associated with a lower risk of cancer [1]. Some of them also act as neuroendocrine regulators, which may help prevent or cure certain metabolic diseases. Moreover, a diet high in phytochemicals is not only beneficial to human health, but it also benefits plants by reducing the risks of developing various stress and diseases in the plants [2]. This leads to a reduction in the usage of pesticides in agriculture. In general, consumers' acceptance of the consumption of functional food has increased. The study also reported that modern consumers are more likely to use a variety of information sources [3]. These consumers might be concerned or interested in the health benefits rather than the food itself. Bioactive compounds, which are present in our natural food, have received much attention in recent years. Not only are they an important part of our daily diet, but they can also act as health and disease-preventing agents. These compounds are referred to as functional ingredients. There are about 1000 bioactive compounds identified in plant foods, and the list is ever-increasing. Many of these compounds have been reported in scientific literature for their pharmacological activities. The biological effects of these compounds are diverse, as they may act as immunomodulators, anti-inflammatory agents, anti-cariogenic compounds, antimicrobial agents, anticarcinogenic agents, and other biological activities [4-6].

1.1. Definition and Classification

Due to the increasing interest in the pharmacological properties and effects of phytochemicals, there is a genuine need to introduce an updated formula for phytochemicals and to develop methodologies to confirm their safe and effective use in humans. Phytochemicals are non-essential nutrients derived from the diet. In general, phytochemicals play a major role in the treatment and diagnosis of diseases, boosting immunity, and providing a nourishing impact and medicinal value. Given the growing proof of the positive pharmacological role played by phytochemicals in patients who have chronic health could be beneficial, people have used phytochemical treatments for a considerable length of time without well-established proof of their pharmacological action. Although 35,000-70,000 medicinal plants are currently estimated, the list is still growing. Due to the continuous search for a safe and effective alternate treatment for cruel diseases, a plausible number of cure plants have to be explored, which have been widely used to maintain and improve health [7-9]. Phytochemicals refer to the biologically active molecules present in plants. They are not crucial or essential for sustaining life but are crucial for the prevention and prognosis of diseases associated with health and longevity. They also have a pharmacologic role in chronic conditions that are not linked to caloric failure. The phytochemicals in plants are used as a biochemical defense system for their well-being. The sub-groups of phytochemicals include terpenoids, polyphenols, alkaloids, and plant organosulfur compounds. Each sub-class has a distinct collection of medicinal properties and corresponds to the following plant-related therapeutic properties: antibacterial (rich in phenols), anticancer (high terpenoid levels), highly alkalizing (alkaloids), and high antioxidant and anti-inflammatory properties (organosulfur compounds) [10-12]. The fields of gastroenterology, endocrinology, bone and arthritic changes, cardiovascular diseases, kidney diseases, rabbit papillomavirus, and neurological ailments were reviewed, and potential medication alternatives are promising to some extent for the patients suffering from the adverse effects of some phytochemicals.

1.2. Importance in Medicine and Health.

Plants are a source of many pharmaceutical molecules used in medical practice, as well as many others that are still in specific clinical trial phases or in epidemiological methodological observation to define their total medical and social significance. Phytotherapy is a part of the health-cultural tradition of every person and is sometimes the first important line of public health. Phytotherapy is a fraction of the so-called "complementary medicine" and in many cases supports the option of soft medicine, which is preventive and avoids visits to high environmental circulation hospitals and the use of chemical drugs. In many developing countries, the drugs of Western Pharmacopeias are often beyond the financial means of the majority of the population, and for this reason, ethnomedicinal resources must be employed as the first choice [13-15]. In traditional and Ayurveda medicine, human beings are considered to be the result of macrocosmic energy systems known as the tridoshas. Ayurveda-like traditional systems consider a healthy human being to be one in which these three entities are in a state of dynamic equilibrium. This equilibrium in the specific tridoshas is determined by many internal and external factors. Excessive synthesis or destruction of the three tridoshas, as well as changes in nature, can cause several diseases in human beings. In Ayurveda medicine, medicines are prepared from single herbs or combinations of several herbs. These medicines are prepared in many different forms: powder, syrup, decoction, solid extract, pills, small pills, and others. A single herb or its associated extracts can also have more than one pharmacological and medical activity[16-18]. Due to their existence in diverse areas of the globe, many medicinal plants are not readily available to the majority of people. The medicinal plants by their predominant phytochemicals and details their pharmacological activities along with the part used as shown in Table 1.

Table 1: Thematic Organization of Medicinal Plants by Phytochemicals and Pharmacological Activities.

Plant Name	Phytoconstituents	Pharmacological Activity	Parts Used
Alkaloid			
Abroma augusta (Devil's cotton)	Taraxerol, friedelin, β-sitosterol, α-amyrin, lupeol, abromine, abromasterol, digitonide	Hypoglycemic	Roots & Leaves
Achyranthus aspera (Chirchiri)	Glucopyranosyluronic acid	Hypoglycemic	Entire plant
Gymnema sylvestre (Gudmar)	Hentriacontane, pentatriacontane, phytin, resins, tartaric acid, formic acid, butyric acid, lupeol, β-amyrin	Hypoglycemic	Leaves
Momordica charantia (Karela)	Momordicine, ascorbic acid	Hypoglycemic	Fruit
Ajauga iva (Bugle weed)	Ferulic acid, quercetin, coumaric acid, luteolin	Plasma glucose level decrease	Entire plant
Flavanoid			
Abies pindrow (Morinda/Rodha)	Luteolin, quercetin, rutin, naringenin, pinitol	Hypoglycemic	Entire plant
Acacia arabica (Babool)	Arabin, quercetin, gallic acid	Hypoglycemic	Seed
Allium cepa (Pyaz)	Allyl propyl disulphide	Potentiate utilization of glucose and antioxidant enzyme	Bulb
Aloe barbadensis (Gheequar)	Barbaloin, isobarbaloin, resin	Stimulate the release and synthesis of insulin	Leaves
Azadirachta indica (Neem)	Nimbidin, nimbin, nimbidol, nimbosterol, azadiradione, gedunin, 17-hydroxyazadiradione, cholesterol	Blocked epinephrine action leads to glycogenolytic activity	Leaves
Beta vulgaris (Chukandar)	Vulgaxanthin I & II, indicaxanthin, betanin, prebetanin, isobetanin, neobetanin	Regeneration of β cells reduced blood glucose level	Leaves
Phenolic Compounds			
Ficus religiosa (Peepal)	β-sitosteryl-D-glucoside, vitamin K, N-octacosanol, kaempeferol, quercetin, myricetin	Insulin release initiation	Entire plant
Eclipta alba (Bhringraj)	Wedelolactone, eclalbasaponins, ursolic acid, oleanolic acid, luteolin, apigenin	Glucose-6 phosphatase, fructose-1, 6-bisphosphatase activity decreases	Leaves
Boerhaavia diffusa (Punarnava)	Punarnavaine, punarnavoside	Increase in hexokinase activity, decrease in glucose-6-phosphatase and fructose	Leaves and the entire plant

		bis-phosphatase activity, increase in plasma insulin	
Enicostemma littorale (Chhota chirayata)	Swetiamerin, vanilic acid, ferulic acid, p-coumaric acid, apigenin, genkwanin, isovitexin, swertisin, seponarin, gentiocrucine, enicoflavine	Glycosylated Hb & glucose 6 phosphatase decreases	Entire plant
Triterpenoids			
Momordica cymbalania (Kadavanchi)	Charantin, momordicine, ascorbic acid	Blood glucose level decreases	Fruit powder
Panax ginseng (Pannag)	Ginsenosides, glycans, panaxans IJK & L	Blood glucose level decreases	Root & entire plant
Cassia auriculata (Tarwar)	3-O-Methyl-dglucose, α-Tocopherol-β-D-mannoside, resorcinol, n-hexadecanoic acid	Increase utilization of glucose through increased glycolysis	Flower
Catharanthus roseus (Sadabahar)	Vincristine, vinblastine	Glucose metabolism increases	Leaves, twigs & flower
Volatile Oils			
Allium sativum (Lehsun)	Allin, allicin	Antinociceptive effect and reduction in glucose	Roots
Ocimum sanctum (Tulsi)	Caffeic acid, p-coumaric acid	Blood glucose level decreases	Leaves
Coriandrum sativum (Dhania)	Anethole, linalool	Glucose metabolism increases	Seed

2. Comprehensive Analysis of Phytochemicals

Plants are endowed with the ability to produce an enormous variety of chemicals that may act as defense mechanisms against herbivores, parasites, and predators. The genus Artemisia, with nearly 400 species, is the most chemically diverse group of plants and it is utilized mainly for the production of essential oils, for the manufacture of sweets, for the production of absinthe, and in phytotherapy. These plants are endowed with the ability to synthesize an impressive diversity of bioactive pure compounds that have important applications[19]. For example, artemisinin, a sesquiterpene lactone endoperoxide produced by Artemisia annua, is the principal treatment against malaria, a disease that affected 229 million people in 2019, caused by Plasmodium spp., and is responsible for the death of 409,000 individuals [20][21]. Medicinal plants are capable of producing various types of bioactive compounds, of which alkaloids, flavonoids, and terpenoids are considered to be unique because they produce chemically and structurally diverse and bioactive substances. Historically, they are well-known in the practice of traditional medicine and have been used for a long time in popular therapies. Alkaloids, flavonoids, and terpenoids are the most attributed classes associated with the pharmacological activities of the bioactive compounds present in plants. The alkaloids are a very large and diverse group of natural nitrogen compounds derived from amino acids. The flavonoids belong to one of the most numerous polyphenols and are secondary metabolites, whose synthesis is related to plants' adaptation and protection mechanisms. The terpenoids are the largest and most diverse group of specialized metabolites and it's the only compound participating in major metabolic processes, it performs housekeeping functions for the assignment of specialized metabolites [22-24].

2.1. Alkaloid

Alkaloids are a diverse group of naturally occurring organic compounds that contain nitrogen atoms. They are primarily found in plants and are known for their wide range of pharmacological effects, including analgesic, antimalarial, and anticancer properties. Notable alkaloids include morphine, quinine, and atropine [25].

2.1.1. Mechanism of Action

Effects on Analgesia: Alkaloids, such as morphine, block pain signals in the central nervous system by binding to opioid receptors. Antimalarial Activity: Quinine and its derivatives successfully treat malaria by interfering with the parasite's DNA replication mechanism. Alkaloids with anticancer properties, including vinblastine and vincristine, stop the synthesis of microtubules, which stops cancer cells from proliferating and causes apoptosis [26].

2.1.2. Efficacy

Pain management: Although opioid alkaloids, such as morphine, are very efficient in treating severe pain, they carry a danger of addiction and tolerance. Treatment for Malaria: Quinine has been a mainstay in the fight against malaria, but resistance is becoming an increasing worry. Cancer Therapy: Vincristine, one of the alkaloids used in chemotherapy, has demonstrated a strong track record of success in treating a variety of malignancies, including lymphoma and leukemia [27].

2.1.2. Potential Application and Critical Evaluation.

Pharmaceuticals: Alkaloids are essential for the creation of medications that treat cancer, malaria, and pain. Traditional Medicine: Due to their therapeutic benefits, a variety of plants containing alkaloids are employed in traditional medicine. Side effects and toxicity: Alkaloids can have serious side effects and are often very strong. It's crucial to monitor and dose medication carefully. Problems with Resistance: One of the biggest challenges with antimalarial alkaloids is the emergence of resistance. Regulatory and Ethical Concerns: To avoid abuse and guarantee patient safety, the use of strong alkaloids necessitates strict regulatory control [28].

2.2. Flavonoids

Flavonoids are a group of polyphenolic compounds found in a wide variety of fruits, vegetables, and beverages. They are known for their antioxidant, anti-inflammatory, and anti-cancer properties. Common flavonoid include quercetin, kaempferol, and catechins [29][30].

2.2.1. Mechanism of Action

Antioxidant Activity: By chelating metal ions and counteracting free radicals, flavonoids lessen oxidative stress. Anti-inflammatory Effects: They influence signaling pathways like NF-κB and prevent the synthesis of pro-inflammatory cytokines. Cancer Prevention: Flavonoids stop the growth of tumors by causing cancer cells to undergo apoptosis and by blocking angiogenesis[31].

2.2.2. Efficacy

Cardiovascular Health: Consuming flavonoids is linked to lower blood pressure and better endothelial function. Neuroprotection: By lowering oxidative damage and inflammation in neurons, flavonoids guard against neurodegenerative illnesses. Diabetes Management: They decrease blood glucose levels and increase insulin sensitivity [32][33].

2.2.2. Potential Application and Critical Evaluation

Nutraceuticals: To improve health and fend off chronic illnesses, flavonoids are included in dietary supplements. Pharmaceuticals: They are being studied in several medication formulations as possible medicinal agents. Functional Foods: Foods and drinks enhanced with flavonoids provide health advantages. Bioavailability: Because flavonoids are quickly metabolized and have poor absorption, they frequently have low bioavailability. Standardization: Extracts must be standardized to maintain consistent efficacy due to variations in phytochemical concentration [34]. Toxicity and Safety: Although generally safe, excessive dosages may have unfavorable effects. Long-term research is required [35].

2.4. Terpenoid

Terpenoids, also known as isoprenoids, are the largest class of plant secondary metabolites. They are involved in various ecological interactions and have numerous medicinal properties, including anti-inflammatory, anti-cancer, and antimicrobial effects. Examples include artemisinin and paclitaxel[36].

2.4.1. Mechanism of Actions

Terpenoids' anti-inflammatory effects include the modulation of inflammatory pathways and the reduction of inflammatory mediator production. Their anticancer properties include apoptosis induction, inhibition of cell proliferation, and disruption of tumor angiogenesis[37]. Terpenoids exhibit antimicrobial activity by disrupting bacteria cell membranes and inhibiting vital enzymes [38].

2.4.2. Efficacy

Treatment for Malaria: Artemisinin is very effective against the parasites that cause malaria, Plasmodium spp. Cancer Therapy: The drug paclitaxel is used to treat several cancers, such as ovarian and breast cancer [39]. Applications for Antimicrobials: Terpenoids exhibit broad-spectrum antibacterial activity against viruses, fungi, and bacteria.

2.4.3. Potential Application and Critical Evaluation

Pharmaceuticals: Terpenoids are essential ingredients in medications that treat infectious disorders, cancer, and malaria. Cosmetics: Used for possible skin advantages and scent. Terpenoids have applications in agriculture as organic insecticides [40]. Terpenoids have the potential to be unstable, so to preserve their effectiveness, certain formulations are needed.

Resistance: Terpenoid-based treatments may lead to the development of resistance, just as alkaloids. Economic and Environmental Impact: To reduce the environmental impact, sustainable sourcing and production techniques are required [41].

2.5. Other Bioactive Compounds

Other notable bioactive compounds in medicinal plants include polyphenols, glycosides, and tannins. These compounds contribute to the therapeutic properties of plants and are widely studied for their health benefits.

2.5.1. Mechanism of Action

Polyphenols: Reduce inflammation and oxidative stress by acting as antioxidants[42]. Glycosides: Affect several biological functions, such as glycemic regulation and heart health[43]. Tannins: Show antibacterial and astringent qualities[44].

2.5.2. Efficacy

Chronic Disease Management: Glycosides and polyphenols are useful in the treatment of diabetes and cardiovascular illnesses [45]. Tannins have antimicrobial properties and can effectively combat a variety of diseases. Digestive Health: A few bioactive substances help with gut health and digestion [46].

2.5.3. Potential Application and Critical Evaluation

Functional Foods: Foods can be made more nutritious and healthful by adding bioactive chemicals to them. Nutraceuticals: Because of their ability to promote health, they are used in dietary supplements. Pharmaceuticals: Investigated in the creation of new drugs as possible medicinal agents. Metabolism and Bioavailability: A lot of bioactive substances have fast metabolism and low bioavailability. Standardization and Quality Control: Using standardized extraction and formulation techniques to guarantee constant quality and efficacy [47]. Safety and Regulatory Permission: Before a product is used widely, it must undergo thorough safety assessments and receive regulatory permission. By understanding the mechanism of action, efficacy, and applications of alkaloids, flavonoids, terpenoids, and other bioactive compounds. We can better harness their benefits for health and medicine.

3. Comparative Analysis of phytochemical composition and Pharmacological activities

Different medicinal plants possess unique phytochemical compositions and pharmacological activities that offer various health benefits [48-53]. Turmeric, Green Tea, ginseng, garlic, aloe vera, milk thistle, and echinacea each have distinct phytochemicals that contribute to their specific therapeutic effects. A comparative understanding of these plants highlights their strengths and applications, aiding in the selection of appropriate herbal remedies for specific health conditions as shown in Table 2.

3.1. Turmeric vs. Green Tea

Phytochemicals: Green tea is recognized for its catechins, particularly EGCG, whereas turmeric is abundant in curcuminoids, specifically curcumin. Activities: Turmeric and green tea both exhibit high antioxidant and anti-inflammatory qualities, while green tea is better at managing weight and protecting neurons. Turmeric also demonstrates stronger anticancer potential.

3.2. Genseng vs. Garlic

Phytochemicals: Garlic is high in organosulfur compounds like allicin, while ginseng contains ginsenosides and polysaccharides. Activities: Garlic is well-known for its antibacterial and cardioprotective qualities, whereas ginseng is mainly recognized for its immunomodulatory and antifatigue qualities. Ginseng boosts the immune system, while garlic lowers cholesterol and blood pressure.

3.3. Aloe Vera vs. Milk Thistle

Phytochemicals: Milk thistle is well-known for its silymarin content, whereas aloe vera has anthraquinones and polysaccharides including acemannan. Activities: Milk thistle is better at hepatoprotection, whereas aloe vera is better at treating wounds and providing skin-related benefits. The anti-inflammatory properties of aloe vera are mainly topical, but milk thistle has systemic advantages that are concentrated on liver function.

3.4. Echinacea vs. Other Plants

Phytochemicals: Alkamides and derivatives of caffeic acid, which are uncommon in other plants, are part of the special composition of echinacea. Activities: Compared to other plants, echinacea has more immunostimulatory and antiviral qualities. These are its main advantages. It has a long history of usage in treating and preventing colds and the flu.

Table 2: Comparative Analysis of Phytochemical Composition and Pharmacological Activities of Different Medicinal Plants.

Plant	Phytochemical Composition	Pharmacological Activities	Comparison and Contrast
Turmeric (Curcuma longa)	• Curcuminoids (Curcumin) • Essential oils (turmerone)	• Anti-inflammatory • Antioxidant • Anticancer	• Curcuminoids are unique to turmeric and are potent anti-inflammatory agents. • Turmeric's anticancer properties are widely studied and show promise in inhibiting cancer cell proliferation.
Green Tea (Camellia sinensis)	• Catechins (EGCG) • Flavonoids	• Antioxidant • Neuroprotective • Anti-obesity	• Catechins, particularly EGCG, are potent antioxidants that are not found in high concentrations in many other plants. • Green tea's neuroprotective effects are significant compared to other plants, reducing the risk of neurodegenerative diseases.
Ginseng (Panax ginseng)	• Ginsenosides • Polysaccharides	• Immunomodulatory • Antidiabetic • Antifatigue	• Ginsenosides are unique saponins that modulate the immune system effectively.

			• Ginseng's antifatigue properties are superior due to its adaptogenic effects.
Garlic (Allium sativum)	• Organosulfur compounds (Allicin) • Flavonoids	• Cardioprotective • Antimicrobial • Antihypertensive	• Organosulfur compounds like allicin are unique to garlic and are effective antimicrobial agents. • Garlic's cardioprotective effects are due to its ability to lower cholesterol and blood pressure.
Aloe Vera (Aloe barbadensis miller)	• Anthraquinones • Polysaccharides (Acemannan)	• Wound healing • Anti-inflammatory • Immunostimulatory	• Anthraquinones in aloe vera are specifically effective for skin-related conditions and wound healing. • Aloe vera's immunostimulatory effects are due to polysaccharides like acemannan.
Milk Thistle (Silybum marianum)	• Silymarin (flavonolignans) • Flavonoids	• Hepatoprotective • Antioxidant • Anti-inflammatory	• Silymarin is particularly effective in protecting the liver from toxins, a property not shared by all medicinal plants. • Milk thistle's hepatoprotective effects are superior compared to other plants.
Echinacea (Echinacea purpurea)	• Alkamides Polysaccharides • Caffeic acid derivatives	• Immunostimulatory • Anti-inflammatory • Antiviral	• Alkamides and caffeic acid derivatives in echinacea uniquely stimulate the immune system and show antiviral activity. • Echinacea is particularly noted for its immune-boosting properties.
Ginkgo (Ginkgo biloba)	• Flavonoids • Terpenoids (ginkgolides, bilobalide)	• Neuroprotective • Antioxidant • Cognitive enhancer	• Ginkgo's terpenoids, unique to this plant, provide neuroprotective effects not seen in others. • Compared to green tea, ginkgo is specifically used for cognitive enhancement.
Ashwagandha (Withania somnifera)	• Withanolides • Alkaloids	• Adaptogenic • Antistress • Immunomodulatory	• Ashwagandha's withanolides provide unique adaptogenic properties. • Compared to ginseng, ashwagandha is more widely used for its stress-relieving effects.
Chamomile (Matricaria chamomilla)	• Flavonoids (apigenin) • Terpenoids (bisabolol)	• Anti-inflammatory • Antispasmodic • Sedative	• Chamomile's flavonoid apigenin is particularly effective as a mild sedative. • Chamomile is preferred for its calming effects, unlike turmeric or garlic.
Peppermint (Mentha piperita)	• Menthol • Flavonoids	• Antispasmodic • Analgesic • Antimicrobial	• Menthol provides a cooling analgesic effect unique to peppermint. • Peppermint is distinctively used for gastrointestinal relief compared to other plants.
St. John's Wort (Hypericum perforatum)	• Hypericin • Flavonoids (hyperforin)	• Antidepressant • Antiviral • Anti-inflammatory	• Hypericins in St. John's Wort are effective as natural antidepressants. • St. John's Wort is specifically used for mood disorders, unlike ginkgo or garlic.
Saw Palmetto (Serenoa repens)	• Fatty acids • Phytosterols (beta-sitosterol)	• Antiandrogenic • Anti-inflammatory • Diuretic	• Saw palmetto's phytosterols provide unique antiandrogenic effects.

			• Compared to milk thistle, saw palmetto is used specifically for prostate health.
Elderberry (Sambucus nigra)	• Anthocyanins • Flavonoids	• Antiviral • Immunostimulatory • Antioxidant	• Elderberry's anthocyanins are potent antiviral agents not found in many other plants. • Elderberry is especially noted for its effectiveness in treating viral infections, unlike ginseng or aloe vera.
Licorice (Glycyrrhiza glabra)	• Saponins (glycyrrhizin) • Flavonoids	• Anti-inflammatory • Antiviral • Antispasmodic	• Glycyrrhizin in licorice has a unique anti-inflammatory and antiviral profile. • Licorice is distinctively used for its soothing effects on mucous membranes, unlike other plants such as turmeric.
Rosemary (Rosmarinus officinalis)	• Rosmarinic acid • Essential oils (cineole)	• Antioxidant • Cognitive enhancer • Antimicrobial	• Rosmarinic acid provides unique cognitive-enhancing properties. • Rosemary is particularly used for memory improvement, unlike garlic or chamomile.

Table 3: Herbal compounds studied for preventing diseases.

S. No	Herbs/Natural Plants	Extract/Compound	Effective Dose	Animal Model	Mechanisms
1	Cinnamon	Cinnamomum verum	47.8 mg/kg	Acute alcohol-fed S.D. rats	Improved insulin sensitivity, increased glucose uptake, antioxidant effects
2	Fenugreek	Trigonella foenum-graecum	25mg/kg	Acute alcohol-fed S.D. rats	Enhanced insulin action, improved glucose utilization, decreased gluconeogenesis
3	Bitter Melon	Momordica charantia	200mg/kg, 400mg/kg, and 600mg/kg	alloxan-induced diabetic rats	Increased insulin secretion, improved glucose uptake, reduced insulin resistance
4	Ginseng	Panax ginseng	0.1-, 0.5-, 1.0-mL	**Sprague-Dawley rats**	Enhanced insulin sensitivity, improved glucose metabolism
5	Aloe Vera	Aloe vera	200mg/kg and 400mg/kg	streptozotocin induced diabetic rats	Increased insulin sensitivity, potential regeneration of pancreatic beta cells
6	Turmeric	Curcuma longa (Curcumin)	95.6 mg/kg	Acute alcohol-fed S.D. rats	Anti-inflammatory, antioxidant, improved insulin sensitivity, beta-cell protection
7	Gymnema	Gymnema sylvestre	350 mg/kg	Acute alcohol-fed S.D. rats	Inhibition of glucose absorption, increased insulin secretion

8	Berberine	Various plants (e.g., Berberis vulgaris)	5 mg · kg	high-fat–fed rats.	Improved insulin sensitivity, AMPK activation, anti-inflammatory effects
9	Bilberry	Vaccinium myrtillus	5 mg/kg	streptozotocin and high-fat–fed rats.	Antioxidant effects, improved vascular function
10	Ginger	Zingiber officinale	200 mg/kg	Chronic alcohol-fed S.D. rats	Improved insulin sensitivity, anti-inflammatory effects
11	Neem	Azadirachta indica	200 mg/kg	Chronic alcohol-fed Wistar rats	Improved insulin sensitivity, anti-inflammatory effects
12	Okra	Abelmoschus esculentus	200 and 400 mg/kg	Chronic alcohol-fed Wistar rats	Improved insulin sensitivity, reduced oxidative stress
13	Holy Basil	Ocimum sanctum	200 mg/kg	Chronic alcohol-fed S.D. rats	Improved insulin sensitivity, antioxidant effects
14	Mango Leaves	Mangifera indica	200 mg/kg	Chronic alcohol-fed S.D. rats	Improved insulin sensitivity, potential beta-cell protection
15	Rosemary	Rosmarinus officinalis	200 mg/kg	streptozotocin and high-fat–fed rats.	Antioxidant effects, anti-inflammatory properties
16	Salacia	Salacia oblonga	200mg/kg and 400mg/kg	streptozotocin-induced diabetic rats	Inhibition of carbohydrate absorption, improved insulin sensitivity
18	Chromium	Various plants (e.g., Broccoli, Green Beans)	200 mg/kg	Chronic alcohol-fed S.D. rats	Improved insulin sensitivity, enhanced glucose metabolism
19	Quercetin	Various plants (e.g., onions, apples)	200 mg/kg	Chronic alcohol-fed S.D. rats	Anti-inflammatory effects, potential insulin-sensitizing effects
20	Green Tea	Camellia sinensis	21.1 mg/kg	streptozotocin-induced diabetic rats	Improved insulin sensitivity, antioxidant effects
21	Olive Leaf	Olea europaea	200 mg/kg	Chronic alcohol-fed S.D. rats	Improved insulin sensitivity, potential anti-inflammatory effects

22	Garlic	Allium sativum	200 mg/kg	Chronic alcohol-fed S.D. rats	Improved insulin sensitivity, potential lipid-lowering effects
23	Black Seed	Nigella sativa	45 mg/kg	Chronic alcohol-fed S.D. rats	Antioxidant effects, potential insulin-sensitizing properties
24	Artichoke	Cynara scolymus	Not provided	Chronic alcohol-fed Wistar rats	Improved lipid metabolism, potential anti-inflammatory effects
25	Cactus Pear	Opuntia ficus-indica	3 g/kg	Chronic alcohol-fed Wistar rats	Improved glucose metabolism, potential antioxidant effects
26	Mulberry	Morus alba	50 mg/kg	Chronic alcohol-fed S.D. rats	Inhibition of carbohydrate absorption, potential insulin-sensitizing effects
27	Juniper Berries	Juniperus communis	3327 mg/kg	Chronic alcohol-fed Wistar rats	Potential insulin-sensitizing effects, antioxidant properties
28	Licorice Root	Glycyrrhiza glabra	Not provided	Acute alcohol-fed C57BL/6 mice	Potential anti-inflammatory effects, improved insulin sensitivity
29	Dandelion	Taraxacum officinale	50 mg/kg	Chronic alcohol-fed S.D. rats	Potential insulin-sensitizing effects, antioxidant properties
30	Astragalus	Astragalus membranaceus	250 mg/kg	Chronic alcohol-fed Wistar rats	Potential immunomodulatory effects, improved insulin sensitivity

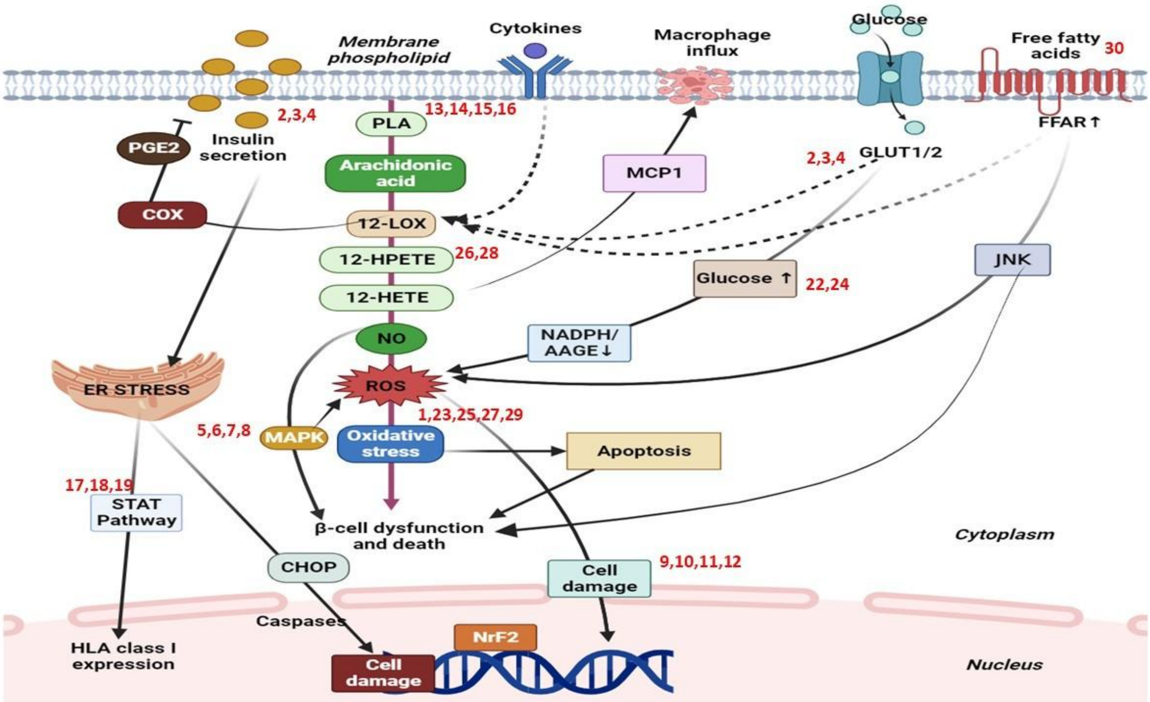

Figure 1: Schematic diagram of significant pathways of diabetes and potential molecular targets of herbal medicine for the management of diabetes. The number indicates potentially targeted extracts or single compounds from herbal drugs, as in Table 2. Abbreviations: Abbreviations: AMPK, AMP-activated protein kinase; COX-2, cyclo-oxygenase; FFAR, Free fatty acid receptor; 12 LOX, 12-lipoxygenase; 12-HPETE, hydroperoxyeicosatetraenoic acid; 12-HETE, Hydroxyeicosatetraenoic Acid; MCP, monocyte chemoattractant protein-1; GLUT1, Glucose transporter 1; PGE2, Prostaglandin E2; PLA, Phospholipase A2; PPARA, peroxisome proliferator-activated receptor alpha; PGC-1, Peroxisome proliferator-activated receptor gamma coactivator 1-alpha; ROS, reactive oxygen species; STAT3, Signal transducer and activator of transcription 3.

Discussion and Conclusion

This review has explored the extensive phytochemistry and pharmacology of medicinal plants, highlighting their therapeutic potential in modern medicine. The primary strength of current research includes detailed identification and analysis of bioactive compounds such as alkaloids, flavonoids, and terpenoids, which exhibit a wide range of pharmacological activities. For instance, compounds like curcumin, ginsenoside, and silymarin have shown significant anti-inflammatory, antioxidant, and hepatoprotective properties respectively. However, there are notable limitations. Many studies are confined to in vitro and animal models, which may not accurately reflect human physiology. Additionally, bioavailability and metabolism of these compounds in human are often poor, limiting their therapeutic efficacy. Standardization and quality control of herbal extracts remain challenging due to variations in plant sources and extraction methods. Furthermore, the safety profile of these compounds needs thorough investigation to prevent potential adverse effects. Future research addresses these gaps by focusing on clinical trials to validate preclinical findings and improve our understanding of pharmacokinetics and pharmacodynamics in humans. Developing advanced drug delivery systems to enhance bioavailability and conducting comprehensive safety assessments are crucial. Investigating the synergistic effects of combined phytochemicals and integrating traditional knowledge with modern scientific techniques could also offer new insight and therapeutic avenues. By bridging the gap between traditional medicine and modern pharmacology, we can better harness and health benefits of medicinal plants, potentially leading to more effective and safer therapeutic options.

Conflict of Interest

We declare that we have no conflict of interest.

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