



Medicinal Plants with Psychoactive Properties: A Comprehensive Review

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Abstract: Medicinal plants have been used in traditional medicine to alleviate a range of neurological and psychological disorders. Numerous plant-derived phytochemicals are known to modulate central nervous system activity by interacting with neurotransmitters, receptors, and neurochemical pathways. This review provides a comprehensive overview of medicinal plants with psychoactive properties, their major bioactive constituents, mechanisms of action, therapeutic potential, toxicity concerns, and regulatory considerations. Literature was collected from scientific databases, including PubMed, Scopus, ScienceDirect, Web of Science, and Google Scholar, using relevant keywords on psychoactive medicinal plants and neuropharmacological activities. Twenty medicinal plants commonly associated with anxiolytic, antidepressant, sedative, hallucinogenic, or cognition-enhancing effects were reviewed. Major phytochemical classes identified included alkaloids, flavonoids, terpenoids, phenolic compounds, cannabinoids, and saponins. Several plants, such as *Withania somnifera*, *Cannabis sativa*, *Valeriana officinalis*, *Psilocybe cubensis*, and *Passiflora incarnata*, have been reported to exhibit neuropharmacological activities in preclinical and limited clinical studies, through modulation of serotonergic, dopaminergic, GABAergic, and endocannabinoid systems. In addition to psychoactive effects, many reviewed plants exhibited antioxidant, anti-inflammatory, neuroprotective, and adaptogenic properties. However, despite promising pharmacological findings, most available evidence remains preclinical, with limited clinical validation regarding efficacy, safety, standardization, and long-term use. This review highlights the therapeutic prospects and current limitations of psychoactive medicinal plants and emphasizes the need for further experimental and clinical investigations for safe and evidence-based therapeutic applications.

Introduction

Mental health represents a fundamental aspect of overall human well-being and significantly influences emotional stability, cognition, behavior, decision-making, and the ability to cope with daily stress. Being an integral part of our health, mental health condition significantly affects one's quality of life. It helps us to understand our potential, to work efficiently and to ensure social contributions (1, 2). Mental disorders are generally characterized by abnormalities in emotional regulation, cognitive processes, or behavior that interfere with normal psychological functioning and daily activities (3). Among the most frequently reported psychiatric conditions are depression, anxiety disorders, schizophrenia, bipolar disorder, obsessive-compulsive disorder (OCD), and post-traumatic stress disorder (PTSD) (4). Recent reports from

the National Institutes of Health (NIH) indicate that mental illnesses affect a substantial proportion of the adult population in the United States, emphasizing the increasing global burden of neuropsychiatric disorders (5). Psychoactive medications are substances capable of modifying mood, perception, consciousness, cognition, and behavior through their effects on the central nervous system (6, 7). Conventional psychoactive medications, including antidepressants, anxiolytics, antipsychotics, and mood stabilizers, are widely prescribed for the treatment of psychiatric illnesses (8). Despite their therapeutic importance, many synthetic psychoactive drugs are associated with undesirable effects such as dizziness, sedation, agitation, cognitive impairment, metabolic disturbances, and dependency-related complications (9). Moreover, inconsistent therapeutic responses and concerns regarding long-term safety continue to limit their

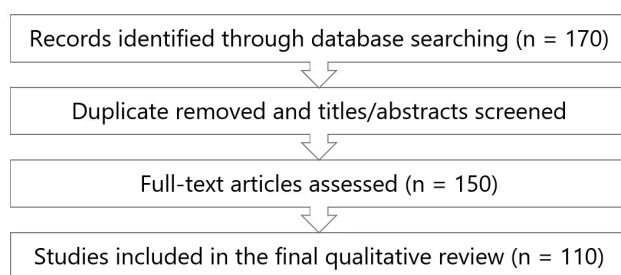


Figure 1. Simplified literature identification and screening process.

clinical utility in some patients.

Medicinal plants have long been incorporated into traditional healthcare practices for the management of neurological and psychological disorders. Several plant species used in traditional systems such as Ayurveda have been reported to possess calming, cognition-enhancing, anxiolytic, antidepressant, and neuroprotective properties. For example, medicinal plants such as Brahmi and Ashwagandha have been reported to exhibit scientific attention because of their potential neuropharmacological effects (10). Various plant parts, including leaves, roots, bark, seeds, and fruits, contain bioactive phytochemicals such as alkaloids, flavonoids, phenolic compounds, terpenoids, saponins, and volatile oils that may influence brain function and neurotransmitter activity (11, 12). Several plant-derived psychoactive compounds have been reported to exert multiple neuropharmacological effects, including anxiolytic, antidepressant, sedative, stimulant, hallucinogenic, and cognition-enhancing activities. These effects are believed to occur through interactions with neurotransmitter systems and signaling pathways involving serotonin, dopamine, gamma-aminobutyric acid (GABA), glutamate, and acetylcholine (13, 14).

Although some medicinal plants have demonstrated relatively favorable tolerability in experimental and limited clinical investigations, their pharmacological efficacy and safety may vary depending on dosage, phytochemical composition, duration of use, and individual biological response. In addition, important concerns related to toxicity, pharmacokinetics, standardization, abuse potential, and regulatory control remain inadequately explored for many psychoactive medicinal plants. Although previous review articles have discussed certain medicinal plants or isolated psychoactive constituents, a comprehensive and balanced overview integrating therapeutic potential, mechanisms of action, safety considerations, toxicity profiles, and regulatory perspectives remains limited. Therefore, the present review aims to critically summarize medicinal plants reported to possess psychoactive properties, with emphasis on their major phytochemical constituents, neuropharmacological activities, therapeutic significance, safety concerns, and future research prospects in the field of neuropharmacology and mental health research.

Methodology

This study was designed as a comprehensive narrative review rather than a formal systematic review or meta-analysis. To enhance methodological transparency, selected principles of the PRISMA 2020 guidelines were considered during the literature search, screening, and study selection process. Relevant scientific publications

were collected from October 2024 to July 2025 using electronic databases, including PubMed, Scopus, ScienceDirect, and Web of Science. Google Scholar was also explored as an additional source to identify relevant publications that might not have been indexed in the major databases.

The literature search strategies were developed using combinations of keywords and Boolean operators related to psychoactive medicinal plants and neuropharmacological activities. The main search query included terms such as ("medicinal plant" OR "herbal plant" OR phytomedicine) AND ("psychoactive" OR "psychotropic" OR hallucinogenic OR anxiolytic OR antidepressant) AND ("phytochemicals" OR "bioactive compounds" OR "traditional medicine"). Additional keywords including "sedative," "neuroprotective," "cognitive enhancement," and "central nervous system" were incorporated when necessary to broaden the search coverage.

Research articles published from 2015 to 2025 were primarily prioritized to ensure inclusion of recent scientific evidence, while a few earlier studies were retained to provide historical and conceptual background. Only peer-reviewed English-language publications describing psychoactive, anxiolytic, antidepressant, sedative, hallucinogenic, or cognition-enhancing properties of medicinal plants or their active phytochemicals were considered suitable for inclusion. Studies were excluded if they were duplicates, non-English articles, conference abstracts, editorials, dissertations, unreliable online materials, or studies relying exclusively on molecular docking without pharmacological or experimental support. Screening was initially performed through assessment of titles and abstracts, followed by full-text assessment of potentially relevant articles. The final selection of literature was assessed by the authors to ensure scientific relevance and consistency with the objectives of the review.

The literature screening procedure was carried out in two stages. Initially, the titles and abstracts of the retrieved studies were examined to assess their relevance to the scope of the review. Articles were then selected based on their scientific relevance, methodological reliability, and alignment with the objectives of the study. The preliminary database search identified approximately 170 records. After removal of duplicate entries and initial screening, 150 articles remained eligible for full-text evaluation, of which 110 studies were ultimately included in the final qualitative review.

The collected information was analyzed through a qualitative approach and organized based on plant origin, major phytochemical compounds, mechanisms underlying psychoactive activity, therapeutic potential, toxicity profiles, and regulatory aspects. Due to considerable differences in study design, experimental procedures, and reported outcomes across the selected literature, conducting a quantitative meta-analysis was not considered feasible. A formal risk-of-bias assessment was not conducted because the included literature comprised diverse types of evidence, including narrative reviews, ethnopharmacological reports, *in vitro* studies, animal-based experiments, and limited clinical studies, which were not appropriate for standard bias assessment methods. A simplified overview of the literature identification and screening procedure used in this comprehensive review is presented in **Figure 1**.

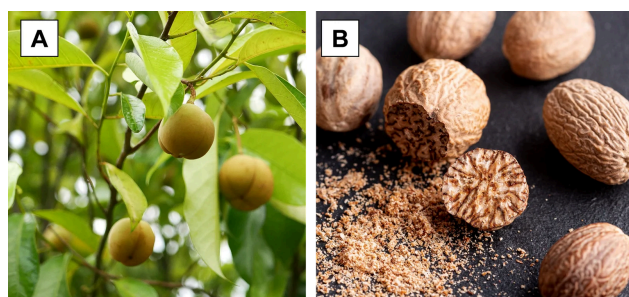


Figure 2. (A) *Myristica fragrans* (Nutmeg) tree, (B) Nutmeg fruit. Used with permission from (23).

Medicinal Plants with Psychoactive Properties

The three main categories of naturally occurring psychoactive substances are hallucinogens, cannabinoids, and opioids (15). Hallucinogens have the potential to cause the most profound psychological changes like changes in mood, awareness, and perception, which can lead to synesthesia, vivid visual hallucinations, and a distorted perspective of space and time (16). *Psilocybe* genus "magic mushrooms", nutmeg and ergot are well-known natural sources of hallucinogens (17). On the other hand, cannabinoids are a complex group of molecules that comprise phytocannabinoids, endocannabinoids, and synthetic cannabinoids. Cannabinoids are phytochemicals that act on cannabinoid receptors (CB1 and CB2) and play an important role in the central nervous system (CNS) and immune system. The main psychoactive compounds are Δ 9-tetrahydrocannabinol (Δ 9-THC) and cannabidiol (CBD), which may produce opposite effects on human brain function. Cannabinoids are derived from the *Cannabis sativa* (marijuana) have shown therapeutic potential in the management of disorders such as schizophrenia, Parkinson's disease, Alzheimer's disease, epilepsy, depression, and anxiety disorders (15, 18, 19). Finally, opioids are those compounds derived from the poppy plant (*Papaver somniferum*) as well as semisynthetic and synthetic substances with comparable characteristics that have the ability to interact with opioid receptors in the brain. Drugs like morphine, codeine, and fentanyl are frequently used to treat pain because of the analgesic and sedative properties of opioids (20).

From the above discussion, we can summarize psychoactive substances into three categories found in various plants, their possible psychoactive effects as summarized in Table 1.

Common Medicinal Plants with Psychoactive Properties in nature:

In this review twenty (20) renowned medicinal plants are studied which possess phytochemicals with psychoactive activities. Most of them are often used in our cuisine as spices or as medicine for different therapeutic purposes.

***Myristica fragrans*:** *Myristica fragrans* (Houtt.) is known to as nutmeg locally and belongs to Myristicaceae family (Figure 2). It is an evergreen tree indigenous to the Maluku Islands in Indonesia, and has been widely used in Indian traditional medicine to cure a variety of diseases (22).

Nutmeg seeds have shown psychoactive action and are known for their sedative, hallucinogenic, antidepressant and anxiolytic properties. Approximately 5-7 g of ground nutmeg seeds may produce these psychogenic effects (23). Nutmeg seed contains 20-40% of essential oil, with myristicin (11.17%), myristic acid (39.93%), and elemicin (22.16%) identified as the major constituents (24). Nutmeg seed extract may stimulate serotonin release and promote relaxation and drowsiness through interaction with the brain's endocannabinoid system. Therefore, it may have potential benefits in managing insomnia, anxiety, and behavioral agitation (25). Besides their psychogenic effects, nutmeg seeds have also shown antioxidant, anti-inflammatory, antidiabetic, antimicrobial, and anticancer activities (24).

***Valeriana officinalis*:** *Valeriana officinalis* is a perennial herb of Caprifoliaceae family and has been used as traditional Chinese medicine for years (26). It is locally known as sugandhabala, mushkbal, valerian root and widely found in Europe, Asia and North America (27, 28). The roots and rhizomes of *V. officinalis* are aromatic with slightly bitter taste and reported to be used in the treatment of insomnia, depression, anxiety and nervous system disorders (Figure 3). *V. officinalis* is approved by USFDA to be used as dietary supplement in order to improve sleep quality (29). Studies have reported that the essential oil of *V. officinalis* increases the release of interleukin-1 β [IL-1 β] and tumor necrosis factor- α [TNF- α], which relaxes the cerebral cortex and has a calming effect.

Table 1. Classification of plant derived psychoactive compounds with their sources.

Type of psychoactive compounds	Source	Major Chemical constituents	Psychoactive Effects	References
Hallucinogen	Ayahuasca, Psilocybe genus, Ergot Etc.	N, N-dimethyltryptamine, psilocybin, dimethyl tryptamine	Synesthesia, Vivid Visual Hallucinations, Distorted Time Perception, Altered awareness	(21)
Cannabinoid	<i>Cannabis sativa</i> (marijuana)	Δ 9-tetrahydrocannabinol (Δ 9-THC) and cannabidiol (CBD), phytocannabinoids, endocannabinoids	Antidepressant. Anxiolytic. Used in schizophrenia, Parkinson's disease, Alzheimer's disease, Epilepsy.	(15, 18, 19)
Opioid	<i>Papaver somniferum</i> (poppy plant)	Morphine, codeine, and fentanyl	Sedation	(20)

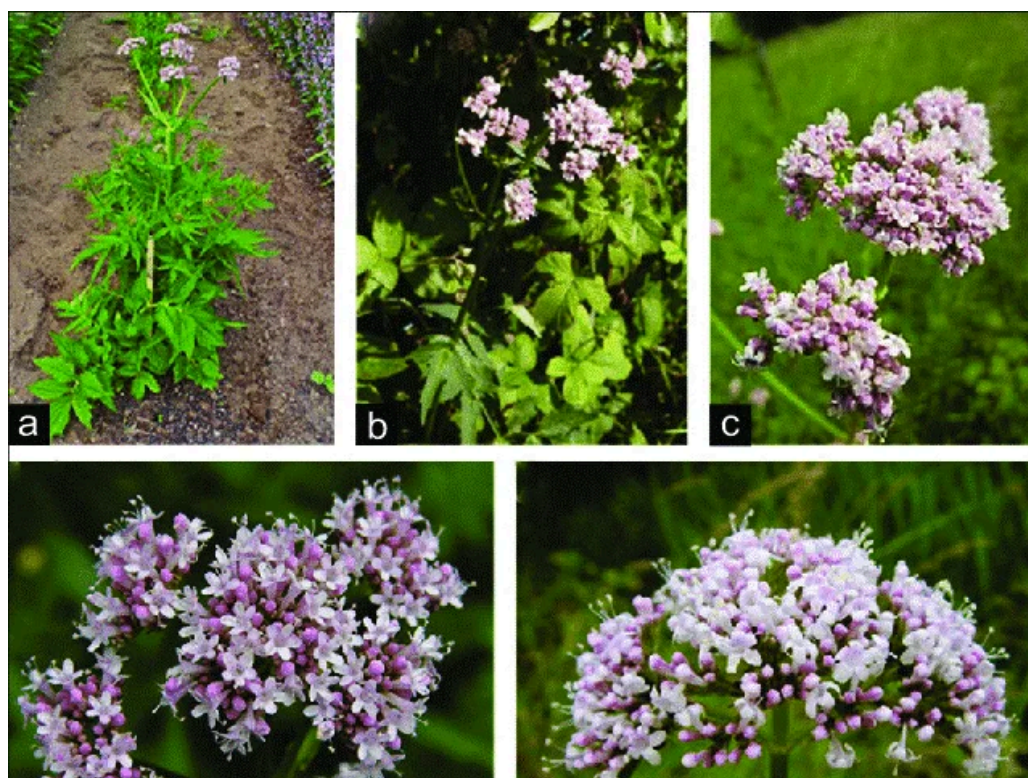


Figure 3. Morphology of *Valeriana officinalis* (a) whole plant, (b) aerial parts with flower, (c) flower at an early stage. Used with permission from (30).

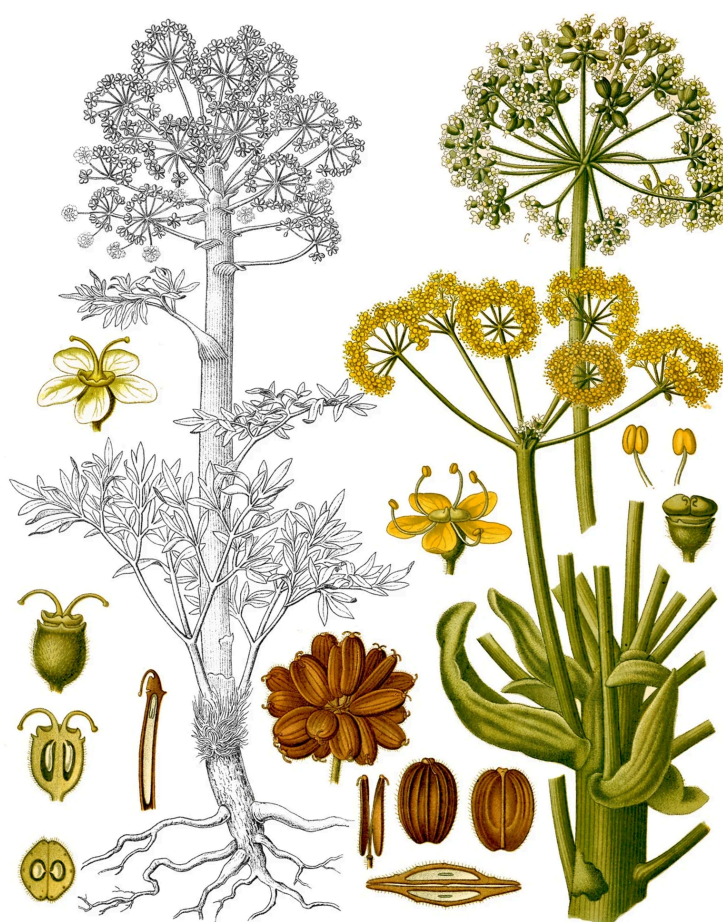


Figure 4. Asafoetida plants part. Used with permission from (35).



Figure 5. *Cannabis sativa* L. leaves. Used with permission from (41).



Figure 6. *Panax ginseng*. Used with permission from (49).



Figure 7. Opium poppy (*Papaver somniferum*) with (A) mature fruit and (B) seed. Used with permission from (53).

Additionally, other phytochemicals that cause sleep by activating GABA receptors include flavonoids, valerianone, and valerenic acid (26).

Animal study also revealed that *V. officinalis* improves behavioral activities in mice by proliferating 5-HT level, hippocampal neurons, and expression of phosphorylated cAMP responsive element binding protein. Hence, their use as anxiolytic and antidepressant has become widespread, with valerenic acid serving as the primary constituent for these effects (31).

***Ferula asafoetida*:** *Ferula asafoetida* is a herbaceous plant belonging to the Umbelliferae family and is known for its diverse biological and therapeutic properties (Figure 4) (32). It is commonly known as hing, stinging gum, Devil's drug, ferula, God's food in local market and generally used in curries, sauces and pickles (33). Traditionally, asafoetida, an oleo-gum-resin derived from

the root exudates of *Ferula asafoetida*, has been used to treat intestinal parasites, gastrointestinal disorders, and asthma. Typically, asafoetida is prepared from *Ferula* species native to the southern and eastern regions of Iran (34). The major constituents of *F. asafetida* include ferulic acid, monoterpenes, coumarins, sesquiterpene, sulfur-containing compounds, and polyphenols which are considered responsible for its psychoactive properties. (32).

It possesses antidepressant and neuroprotective activities, along with this antispasmodic, antimicrobial, antiviral, antifungal, cancer chemopreventive, anti-diabetic, anti-hypertensive, anticarcinogenic, antimicrobial, and relaxant properties (36–38). *In vivo* studies have suggested that *Ferula* exert their pharmacological effect by increasing the levels of serotonin, noradrenaline, and dopamine. These findings suggest that *Ferula* species have potential as an anxiolytic and sedative agent and may serve as a potential alternative to diazepam. However, further preclinical and clinical studies are required to confirm its efficacy and safety (39, 40).

***Cannabis sativa*:** *Cannabis sativa* is one species in the genus Cannabinaceae. There are numerous common names for this plant species, and many people call it as hemp or marijuana (Figure 5). Although this plant is native to Central Asia, it has spread throughout the world due to its ability to adapt to several environments.

Numerous bioactive substances are often extracted from cannabis. These substances are classified as alkaloids, carotenoid, flavonoid, lignanamide, terpenoid, stilbenoid, and cannabinoid. The primary component of cannabis, Δ-9-tetrahydrocannabinol (THC), is mainly responsible for its psychoactive effects (41). In addition, cannabidiol (CBD) has been reported to exhibit therapeutic potential in the management of schizophrenia, depression, anxiety, and other neurological disorders (42). THC stimulate the cannabinoid receptors (CB1, CB2) of the brain, increase dopamine release, followed by psychoactive effect. In contrast, CBD interacts with serotonin (5-HT1A) receptors and mediate anxiolytic, antidepressant and panicolytic effect by increasing serotonin release (43). Cannabinoids can be beneficial for a variety of additional diseases, such as Tourette syndrome, PTSD, and sleep issues. It has also anti-inflammatory, anti-cancer, neuroprotective, antifungal, anticoagulant, antibacterial, anti-aflatoxigenic, insecticidal, antioxidant and dermocosmetic properties. Cannabis seeds are used as an analgesic, anxiolytic, antiepileptic, antiemetic, and to treat neurological discomfort (41, 44, 45).

***Panax ginseng*:** *Panax ginseng* or ginseng, is one of the most significant herbal medicines in Asia belongs to the Araliaceae family of plants. Ginseng roots are widely used in oriental and traditional medicine from ancient days due to its numerous health benefits (Figure 6). It contains a variety of bioactive monomers, including triterpene saponins, fatty acids, polysaccharides, and mineral oils. The triterpene saponins, also referred to as ginsenosides, are the main component responsible for the psychoactive property of ginseng (46–48).

Studies have reported that ginsenoside increases the expression and activity of brain-derived neurotrophic factor (BDNF) and phosphorylates extracellular signal-related kinases (ERK) to produce an antidepressant effect. Additionally, ginseng saponin acts on the serotonin



Figure 8. Leaves of *Glycyrrhiza glabra*. Used with permission from (56).



Figure 9. *Humulus lupulus* cone. Used with permission from (61).

receptor (5-HT_{2A}) to boost serotonin production, which improves depression-like behavior (50). *Panax ginseng* also possesses anti-inflammatory, antioxidant, and anti-apoptotic properties which contribute to their neuroprotective effects on the central nervous system (51).

***Papaver somniferum*:** Opium poppy is one of the world's oldest medicinal plants (Figure 7). One species that is well known for its variety of alkaloids is *Papaver somniferum* L. (Family: Papaveraceae). It is typically found in America, Asia, North Africa, and Europe. Since ancient times, it has been used as a strong analgesic and antitussive to treat mild to severe pain (52).

Opioids, the primary component of opium, modify the brain's molecular and neurological pathways, which in turn affects the brain's reward system. Opioid use causes neurological responses and can alter the brain's affective

and pain systems, increasing the likelihood of compulsive drug-seeking behavior and causing hypersensitivity. Chronic opioid consumption changes the brain's composition and capabilities, particularly in regions linked to reward, motivation, and judgment. These alterations may have an impact on neurotransmitter systems and neural circuitry, which may impair cognition and raise the danger to one's mental health conditions like depression and anxiety. Moreover, it may have important psychological implications including altered mood and behavior (52, 54).

***Glycyrrhiza glabra*:** The plant *Glycyrrhiza glabra*, commonly known as licorice, is a member of the Leguminosae family and abundant in the Middle East, Asia, and Europe (Figure 8) (55).

This plant contains more than 400 phytochemical elements including triterpenoid saponins, flavonoids, coumarin, phenolic compounds, pterocarpin etc. Among all the bioactive constituents, licorice total flavonoids (LF) and liquiritine are the prime components with antidepressant activity. Licorice has been shown in studies to have psychoactive properties through a variety of ways. LF and liquiritine reduce serum corticosterone levels and also increase BDNF expression, which causes autophosphorylation of tyrosine kinase B (TrkB) and has an antidepressant effect (57, 58). Additionally, licorice has other therapeutic advantages like sedative, anticoagulant, anti-inflammatory, anti-microbial, anti-asthmatic, anti-cancer, anti-atherogenic, and antispasmodic properties. (55, 59).

***Humulus lupulus*:** *Humulus lupulus* L., also known as Hops is a climbing herbaceous perennial from the Cannabaceae family, and extensively used worldwide for fermentation (Figure 9). Although *H. lupulus* originated in central Europe, it is now widely grown industrially in the North's temperate zones (60).

Phytochemical screening results showed that *H. lupulus* extract contains 1% volatile oil, 15-25% resins, 2-4% tannins, flavonoids, xanthohumol, ferulic acid, polyphenols, glycosides etc. The oils and resins together is known as lupulin which is responsible for several pharmacological activities (62). Beside several therapeutic effects, recent studies have found the efficacy of hops extract in anxiety, sleep disturbances, depression, ADHD and restlessness. The suggestive mechanism is interaction of lupulin with serotonin receptor (5-HT₆) leading to anxiolytic and antidepressant activity. *In vivo* study also confirmed the sedative and hypnotic effect of hops as they increase the level of γ -aminobutyric acid (GABA) neurotransmitter and relaxes CNS stimulation. Hence, hops are used for the treatment of insomnia alone or in combination with other herbs like valerian (60, 62-65).

***Tabernanthe iboga*:** *Tabernanthe iboga*, a plant native to West Africa, contains ibogaine, an indole alkaloid with hallucinogenic properties found in its root bark (Figure 10). This species belongs to the Apocynaceae family, was first classified about 140 years ago (66). The root bark contains about 6% indole alkaloids, including ibogaine, ibogaline, ibogamine, and tabernanthine. Among these, ibogaine makes up roughly 80%, ibogaline 15%, and ibogamine 5%. Ibogaine is a type of tryptamine (67, 68). Its effects are complex, as it influences multiple neurotransmitter systems simultaneously. It shows significant binding to NMDA, kappa-opioid, sigma, and



Figure 10. The *Tabernanthe iboga* shrub. Used with permission from (71).



Figure 11. *Psilocybe cubensis*. Used with permission from (75).



Figure 12. *Banisteriopsis caapi* leaves. Used with permission from (84).

nicotinic receptors. Its interaction with the kappa-opioid receptor likely plays a role in its psychoactive properties (69). Ibogaine's hallucinogenic properties may be due to its modest agonist effect on the serotonin 5HT_{2A} receptor. In addition to reducing dopamine levels, ibogaine accelerates dopamine breakdown (70). It may also reverse opioid-induced changes in gene expression, helping restore normal receptor function and bringing the brain back to a pre-addiction state. Moreover, it appears to interrupt and reset addiction-related brain circuits (66).

Ibogaine induces vivid, fast-paced visual hallucinations, especially in the dark, along with symptoms like drowsiness, sound sensitivity, insomnia, and physical effects such as dry mouth, sweating, dilated pupils, and tremors. It frequently improves memory recall and self-reflection, allowing individuals to critically examine their thoughts and life experiences. Heroin addicts treated with ibogaine claimed relief from withdrawal and acquired insight into the psychological causes of their addiction, allowing them to build a stronger sense of self (72).

***Psilocybe cubensis*:** For millennia, humans have recognized and intentionally utilized the hallucinogenic properties of certain plants and fungi, among which mushrooms being a primary source for such effect. The magic mushroom, or *Psilocybe cubensis*, contain psilocybin, a hallucinogenic substance that has long been used in religious and spiritual rites as well as the treatment of neuropsychiatric illnesses (Figure 11) (73, 74).

Major phytochemical constituents of magic mushroom are hydroxylated derivatives of tryptamine, which include psilocybin, psilocin, baeocystin, and norbaeocystin. These days, psilocybin's therapeutic uses are transforming mental health care and providing fresh hope for illnesses including depression, PTSD, and terminal anxiety. The two main active ingredients that provide the psychoactive effects are psilocybin (O-phosphoryl-4-hydroxy-N, N-dimethyltryptamine) and psilocin (4-hydroxy-N, N-dimethyltryptamine) (73, 74, 76–79). It is suggested that psilocybin affects serotonergic system (5-HT) as a non-selective agonist of 5-HT_{2A} followed by therapeutic efficacy against several neuropsychiatric disorders like anxiety, depression, OCD, addiction etc. (80).

***Banisteriopsis caapi*:** *Banisteriopsis caapi* is a psychoactive plant vine of the Malpighiaceae family, native to Amazon rainforest (Figure 12). It is also known as cappi, yage, soul vine and found as the core ingredient of psychoactive decoction, Ayahuasca (81). The antidepressant activity of cappi has been reported in both animal studies and clinical trials. *B. caapi* mainly contains β -carboline indole alkaloids namely harmine, tetrahydroharmine, and harmaline along with some polyphenols. Alkaloids present in cappi reversibly inhibit monoamine oxidase A (MAO-A) enzyme followed by reduced degradation of serotonin, noradrenaline and dopamine and results in psychoactive effect. Similarly, tetrahydroharmine also inhibits the reuptake of serotonin by 5-HT_{2A} and ensures the anxiolytic and antidepressant effect. Moreover, β -carboline alkaloids stimulate neurogenesis by increasing the BDNF in hippocampal region that also helps in improvement of depressive behaviors (82, 83).

***Psychotria viridis*:** *Psychotria viridis*, locally known as chacrona, rainha, belongs to the coffee family Rubiaceae, is a perennial shrubby flowering plant (Figure 13). It has



Figure 13. *Psychotria viridis* plant. Used with permission from (85).



Figure 14. Common sage (*Salvia officinalis*) in bloom. Used with permission from (92).

been used in a common version of Ayahuasca tea with *Banisteriopsis cippi* (84). *P. viridis* leaves contain serotonin

like alkaloid, N, N-Dimethyltryptamine (DMT) which is responsible for the psychoactive effect revealed by the activation of 5-HT_{2A} receptors.

Additionally, DMT also interacts with sigma-1 intracellular receptors which plays important role in producing antidepressant and antipsychotic effects (86). Beside the psychoactive properties, *P. viridis* also possesses other pharmacological benefits like anti-inflammatory, antibacterial, antioxidant, analgesic properties (87-89).

***Salvia officinalis*:** The plant *Salvia officinalis*, also known as Sage, belongs to the Labiatae/Lamiaceae family. It is an evergreen, perennial subshrub with woody stem and grayish leaves (Figure 14). Although it originated in the Middle East and the Mediterranean, it has now spread around the world. This aromatic plant is frequently used in tea along with its use in Asian and Latin American traditional medicine to treat a variety of conditions such as seizures, ulcers, gout, rheumatism, inflammation, disorientation, tremor, paralysis, diarrhea, and hyperglycemia. *S. officinalis* has been used in European traditional medicine to treat age related cognitive problems, excessive perspiration, mild dyspepsia (including heartburn and bloating), and skin and throat inflammations (90, 91).

Numerous terpenes and phenolics present in sage (*Salvia*) plants interact with brain function-related processes, improving certain aspects of cognitive performance. The principal ingredients are alkaloids, phenolic chemicals (e. g., coumarine), flavonoids (e. g., chlorogenic acid, rosmarinic acid, caffeic acid), carbohydrates (e. g., arabinose, galactose, mannose), terpenoids, steroids, and so on. The volatile oil derived from sage are rich in flavonoids such as borneol, camphor, linalool, cineole, humulene, thujone, pinene, limonene (91). Animal studies support the anxiolytic and antidepressant effects of sage leaf extracts, as well as the improvement of cognitive behavior. According to research, sage, which is rich in flavonoids and essential oils, may operate as a psychoactive agent in the treatment of anxiety, depression, and behavioral problems (93).

***Apocynum venetum* :** *Apocynum venetum* is a perennial herbaceous shrub from the family Apocynaceae (Figure 15). It is referred to as "Luobuma" in Chinese and "Rafuma" in Japanese and has been used as food supplement for its numerous medicinal values (94). The primary constituents of the shrub include flavonoids (apocynins A–D, quercetin, hyperin, lupeol, scopoletin isofraxidin, and kaempferol), phenols, and beta-sitosterol. The presence of several flavonols, flavanols, and glycosides

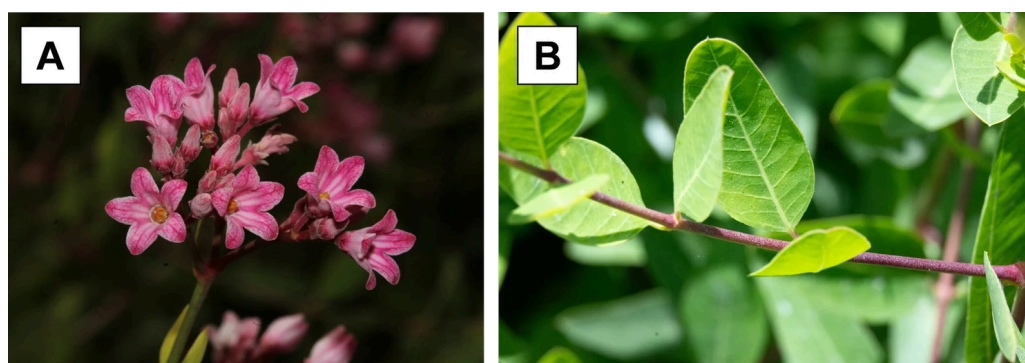


Figure 15. *Apocynum venetum* (A) flower (B) leaves. Used with permission from (97).



Figure 16. *Hypericum perforatum*. Used with permission from (99).

in this plant can account for a range of pharmacological activities, such as antihypertensive, hepatoprotective, hypnotic, depressive, anxiolytic, and antioxidant properties (95).

In addition, it can be used to treat major depression with efficacy comparable to tricyclic antidepressants. *In vivo* experiments showed that *A. venetum* extracts relieve the symptoms of major depressive disorder (MDD), including persistent melancholy, disinterest, loss of enjoyment, low self-esteem, difficulty concentrating, feelings of guilt or exhaustion, and irregular eating or sleeping patterns (94-97).

***Hypericum perforatum*:** *Hypericum perforatum* (Family: Hypericaceae), known as Saint John's wort (SJW), is a perennial herb indigenous to northern Africa, western Asia, and Europe (Figure 16). It was originally applied in a variety of traditional medicinal systems, such as, Islamic, Greek, and Chinese medicine. St. John's Wort is used as an over-the-counter anxiolytic or antidepressant (98).

It is a xenobiotic made up of at least 10 groups of physiologically active, identifiable chemicals, including flavonoids, campferol, rutin, hyperoside, and quercetin and five different types of hypericin. According to reports, St. John's Wort functions as a reuptake inhibitor of serotonin, dopamine, and norepinephrine, which is one of the primary processes utilized in healthcare. This reduces the uptake of dopamine, norepinephrine, and serotonin at neural synapses. Increased neurotransmitter levels are thought to be beneficial in the treatment of depression. Besides, the ability to bind to GABA receptors and reduce GABA binding, which lowers CNS depression (99, 100).

Additionally, this plant has a variety of therapeutic applications, including as antibacterial, antidepressant, neuroprotective, anxiolytic. St. John's wort has also been used to treat psoriasis, obsessive-compulsive disorder, behavioral problems, and menopausal somatic symptoms (98, 99, 101).

***Passiflora incarnata*:** *Passiflora incarnata*, often known as Passion flower, is a member of the Passifloraceae family (Figure 17). The species is indigenous to Australia, South East Asia, and South America. Since ancient times, Passiflora-based herbal remedies have been used extensively to treat anxiety (102).

The plant's fruits, flowers, and aerial portions are all utilized medicinally. *Passiflora incarnata* contains flavonoids, cyanogenic glycosides, alkaloids, and phenolic compounds. The primary phytochemicals found in passionflower are flavonoids (kaempferol, quercetin, luteolin, and apigenin), alkaloids (hamaline, harmalol, harmine, harmol), coumarine, phytosterols and glycosides (vitexin, isovixetin, orientin) (104, 105). On the other hand, passion fruits are rich in phenols, carotenoids, flavonoids and tannins while the leaves contain flavonoids and tanins mainly with slight amount of alkaloids (106, 107). Owing to the rich content of flavonoids, *P. incarnata* is widely used as herbal supplement for the ailment of anxiety, insomnia,



Figure 17. *Passiflora incarnata* L. (A) Leaves, and (B) Flower. Used with permission from (103).



Figure 18. *Withania somnifera* plant. (A) Leaves (B) Roots (C) Fruits. Used with permission from (112-114).



Figure 19. *Camellia sinensis* plant. Leaves and Flower. Used with permission from (116).

seizures, hysteria etc. It has also been reported to exhibit therapeutic potential in the management of morphine dependence, insomnia, neurotic disorders, and attention-deficit/hyperactivity disorder (ADHD) (104, 108). Usually, pharmacological actions of *P. incarnate* are mediated via GABA system regulation, which includes GABA_A and GABA_B receptor affinity as well as effects on GABA absorption. Consequently, GABA_A system involvement has anxiolytic effects (104, 109, 110).

***Withania somnifera*:** *Withania somnifera*, also known as Ashwagandha is a plant of Solanaceae family which is highly renowned for its medicinal values (Figure 18). Ashwagandha has long been used as an adaptogen in ancient Ayurvedic and Unani medical systems. Herbs known as adaptogens enhance the body's reactions to stress and aid in adaptation by restoring physiological functions during periods of elevated stress. Adaptogens exert their stress-protective effect by regulating homeostasis via several mechanisms of action associated with the hypothalamic pituitary adrenal (HPA) axis (111).

Ashwagandha contains acylsterylglucosides and sitoindosides, which have anti-stress properties. It has been shown that ashwagandha's active compounds, such as sitoindosides VII-X and Withaferin-A, have potent anti-stress effects. As a result, Ashwagandha can be used to treat Huntington's disease, Parkinson's disease,

Alzheimer's disease, and other neurological disorders at any stage of their progression. Ibotenic acid-induced cognitive deficits in Alzheimer's disease were significantly reversed by glycowithanolides containing aferin-A and sitoindosides VII-X isolated from ashwagandha roots. Furthermore, biologically active chemical components of *W. somnifera* include alkaloids (Anahygrine, cuseohygrine, anaferine, isopelletierine, and so on), steroidal lactones (withanolides, withaferins), and saponins. Apparently being a multifunctional herb, ashwagandha has anti-inflammatory, neuroprotective, adaptogenic, hematopoietic, memory-enhancing, sleep-inducing, anxiolytic, and antidepressant characteristics (111, 115).

***Camellia sinensis*:** *Camellia sinensis* belongs to the family Theaceae and known as tea throughout the world (Figure 19). The main growing environments for this tree are tropical and subtropical areas. Teas can be classified depending on the degree of fermentation as green tea (unfermented tea), white tea and yellow tea (lightly fermented), oolong tea (semi-fermented tea), black tea (fermented tea), and pu-erh tea (post-fermented tea). Throughout human history, green tea has been one of the most popular drinks drunk worldwide.

The principal bioactive substances found in *Camellia sinensis* leaves are caffeine, flavonols namely catechin, epigallocatechin gallate (EGCG); glycosyl derivatives including apigenin, myricetin, quercetin; and rutin, teaflavins, and thearubigins. Green tea has long been used to promote relaxation, physical stimulation, mental clarity, and cognitive function. Caffeine, L-theanine, and EGCG have been found to improve mood and cognitive function on numerous occasions. Green tea contains L-theanine, a non-proteinic amino acid that has effects on brain. Regular and frequent tea consumption has been linked to improvements in mood, health, and cognitive function. It has been proven that L-theanine and caffeine improve task performance and attention span. Additionally, L-theanine is believed to boost mood by causing the brain's α -waves to be stimulated. In a brief amount of time, this substance is usually linked to increased energy, motivation, focus, and performance. Hence, it is the most often used as psychoactive stimulant globally (117, 118).

***Rhodiola rosea*:** *Rhodiola rosea* L., commonly referred to as "arctic root," "roseroot," or "golden root," is a



Figure 20. *Rhodiola rosea* L. plant. Flowers (left) and rhizomes (right). Used with permission from (120).

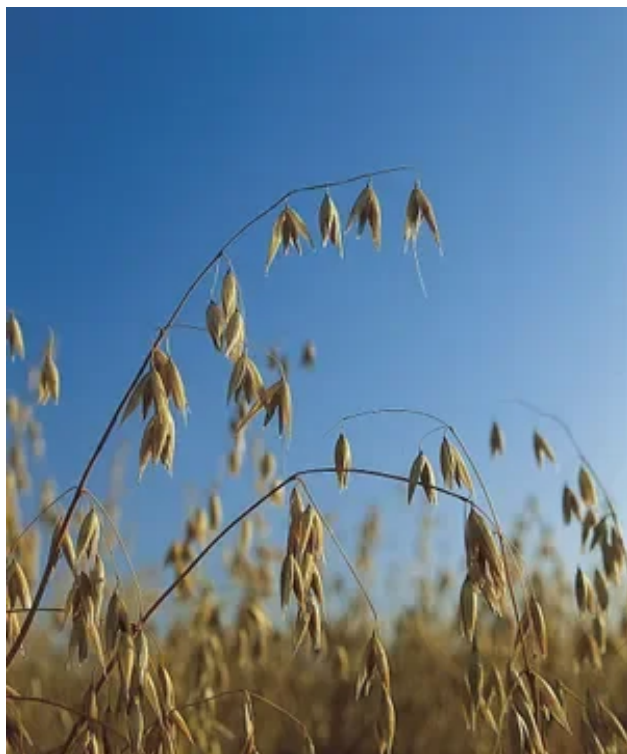


Figure 21. *Avena sativa* L. Used with permission from (126).

member of the Crassulaceae family (Figure 20). It is well recognized to strengthen memory and learning, protect

the brain, and promote cognitive performance (119).

From *R. rosea*'s roots and rhizome, about 140 compounds have been identified, including proanthocyanidins, flavonoids, flavonolignans, cyanogenic glycosides, aryl glycosides, phenylethanoids, phenylpropanoids, and their glycosides, as well as monoterpene alcohols and their glycosides (121). *R. rosea* has antidepressant effects through altering defense mechanism proteins (e. g., heat shock proteins Hsp 70 and FoxO/DAF-16), nitric oxide, and protein kinases p-JNK in addition to its interaction with the HPA-system (cortisol-reducing). Certain components of *R. rosea* raise the levels of 5-HT and noradrenaline in the frontal, prefrontal, and cerebral cortex resulting in improved depression symptoms. It has long been used in traditional medicine to strengthen the nervous system, alleviate depression and stress-induced fatigue, increase longevity, physical performance, and resistance to high altitude sickness, as well as to treat anemia and fatigue. Cardioprotective, antifatigue, anxiolytic, nootropic, life-extending, and central nervous system stimulating effects are some additional medicinal use of *R. rosea* (122-124).

Avena sativa: *Avena sativa* is a domesticated cereal grass from the family Poaceae and grown primarily for its edible grains (Figure 21). It is usually known as 'oats', 'green oats' or 'common oat'. The higher aerial parts of *Avena sativa* plants are used to make immature or "green" oat extracts and tinctures, which have a long history of medical use and cover a variety of psychoactive indications, such as anxiety and sleeplessness (125).

A variety of possibly beneficial secondary metabolite

Table 2. Summary of the major psychoactive constituents of the discussed plants.

No.	Name of the plant	Major psychoactive constituent	Reference
1.	<i>Myristica fragrans</i>	Myristicin, Myristic acid, Elemicin	(24)
2.	<i>Valeriana officinalis</i>	Valerenic acid, Valerenal, Valerianone	(26)
3.	<i>Ferula asafoetida</i>	Ferulic acid, Coumarine, Monoterpenes, Sesquiterpene, Sulphide compounds	(32)
4.	<i>Cannabis sativa</i>	Δ -9-Tetrahydrocannabinol, Terpenoid, Cannabinoid.	(42)
5.	<i>Panax ginseng</i>	Ginsenoside, saponin, fatty acid.	(46)
6.	<i>Papaver somniferum</i>	Opioids, morphin	(54)
7.	<i>Glycyrrhiza glabra</i>	Glycyrrhizin, Glycyrrhetic acid, Liquiritin, Isoliquiritin,	(58)
8.	<i>Humulus lupulus</i>	Lupulin, Triterpenes, Flavonols, Tannins, Ferulic acid	(128)
9.	<i>Atropa belladonna</i>	Scopolamine, Hyoscyamine, Atropine	(129)
10.	<i>Psilocybe cubensis</i>	5-methylpsilocybin, Psilocin	(77)
11.	<i>Banisteriopsis caapi</i>	Harmine, Tetrahydroharmine, Harmaline	(82)
12.	<i>Psychotria viridis</i>	N, N-dimethyltryptamine	(87)
13.	<i>Salvia officinalis</i>	α -thujone, 1, 8-cineole, Camphor, Rosamarinic acid	(91)
14.	<i>Apocynum venetum</i>	Quercetin, Apocynins, Phenols, β -sitosterol	(97)
15.	<i>Hypericum perforatum</i>	Hyperforin, Hypericin, Quercetin	(101)
16.	<i>Passiflora incarnata</i>	Harmalol, Kaempferol, Lutionin, Coumarine	(104)
17.	<i>Withania somnifera</i>	Withaferins, sitoindosides	(111)
18.	<i>Camellia sinensis</i>	L-theanine, Caffeine, epigallocatechin gallate	(117)
19.	<i>Rhodiola rosea</i>	Flavanoids, Monoterpenes, Rosiridol	(123)
20.	<i>Avena sativa</i>	Avenacins, Flavonoids, Terpenes	(126)

compounds and multiple categories of potentially psychoactive phytochemicals are often found in green oat (*Avena sativa*) preparations. These invariably comprise a variety of terpenes, including species-specific triterpene saponins known as "avenacins," a wide range of phenolic acids and polyphenols, some of which include flavonoids and avenanthramides (125). The green oat extracts inhibit the monoamine oxidase B (MAO-B) and phosphodiesterase 4 (PDE-4) enzymes that increase the dopaminergic availability. As dopamine plays a cardinal role in mood improvement, oat extracts could alleviate anxiety, depression and cognition (127). A summary of the major psychoactive constituents of the discussed plants is presented in **Table 2**.

The above discussion reveals the emerging scope of using medicinal plants in psychological disorders like anxiety, depression, insomnia, stress, ADHD, PTSD etc. Review data indicate that a number of plants in our surroundings could act as psychoactive agents. Asafoetida, ashwagandha, ginseng, and other medicinal herbs have chemical components that significantly alter mental health conditions. These plants contain bioactive compounds that may serve as potential candidates for future neuropharmacological research. The phytochemical constituents obtained either from the leaves, stem, roots, flowers of the above mentioned plants are particularly flavonoids, alkaloids, phenolic components, resins, terpenes which act on the neurotransmitters. They lead to increased level of serotonin, dopamine, noradrenaline in the brain along with reduced serotonin and dopamine reuptake. Besides, some of the psychoactive agents are able to increase neurogenesis by elevated expression of BDNF in hippocampal region of brain. Preclinical and limited clinical findings suggest that some of these plants may contribute to improvement of depressive symptoms, anxiety, restlessness, sleep quality, cognitive behaviors and mood.

The psychoactive effects of the medicinal plants discussed in this review are mainly associated with diverse phytochemical groups, including alkaloids, flavonoids, terpenoids, cannabinoids, phenolic compounds, and saponins. Several well-known bioactive compounds, such as psilocybin, psilocin, Δ^9 -tetrahydrocannabinol (THC), cannabidiol (CBD), valerenic acid, ginsenosides, harmine, harmaline, and myristicin, have been reported to interact with neurotransmitter systems involved in central nervous system regulation. These phytochemicals may exert neuropharmacological effects by modulating serotonergic, dopaminergic, GABAergic, monoaminergic, and endocannabinoid signalling pathways. In addition, certain

structural features of these compounds, including indole alkaloid structures, phenolic moieties, and lipophilic terpene constituents, may also contribute to their receptor-binding ability and psychoactive activity. However, detailed structure-activity relationship studies and advanced phytochemical characterisation remain limited for many medicinal plants. Summative information on some psychoactive chemicals with possible mechanism of action is presented in **Table 3**.

Toxicity and Safety Concerns

Although many psychoactive medicinal plants demonstrate significant neuropharmacological potential, their inappropriate or excessive use may lead to adverse reactions, toxicity, drug interactions, or dependence (130) (see **Supplemental Table 1**). Safety concerns remain particularly relevant for plants containing potent hallucinogenic or opioid-like compounds because of their strong psychoactive effects and potential for misuse. *Papaver somniferum* may cause respiratory suppression, tolerance development, and opioid dependence due to the presence of morphine-derived alkaloids. *Atropa belladonna* contains tropane alkaloids that may cause lethargy, coma, and potentially fatal outcomes.

Excessive consumption of *Cannabis sativa* has been linked to impaired cognition, anxiety, dependency, and neurochemical imbalance, temporary reduction in motor activity in susceptible individuals. Similarly, uncontrolled use of *Psilocybe cubensis* or plants used in ayahuasca preparations may trigger intense psychological disturbances, altered perception, and unfavorable psychiatric effects. In addition, some medicinal plants can interfere with conventional medications by affecting hepatic enzyme activity or neurotransmitter systems (131). The regulatory status and toxic effects of plants listed in highlight the need for cautious use, as several of these species are associated with significant safety concerns. Consequently, proper dose standardization, toxicological assessment, and professional medical guidance are critical to ensure their safe therapeutic application.

Pharmacokinetics and Dosage Considerations

The pharmacokinetic properties, bioavailability, metabolic pathways, and dose-dependent effects of numerous plant-derived psychoactive compounds have not yet been adequately investigated (132). Differences in geographical origin, cultivation conditions, extraction techniques, preparation processes, and phytochemical composition

Table 3. Representative phytochemicals of selected psychoactive medicinal plants and their neuropharmacological targets.

Plant	Major phytochemicals	Proposed neuropharmacological target/mechanism
<i>Cannabis sativa</i>	Δ^9 -THC, CBD	CB1/CB2 receptor modulation; serotonergic activity
<i>Psilocybe cubensis</i>	Psilocybin, psilocin	5-HT2A receptor agonistic activity
<i>Valeriana officinalis</i>	Valerenic acid, flavonoids	GABAergic modulation
<i>Banisteriopsis caapi</i>	Harmine, harmaline	MAO-A inhibition; serotonergic modulation
<i>Panax ginseng</i>	Ginsenosides	BDNF regulation; serotonergic signaling
<i>Myristica fragrans</i>	Myristicin, elemicin	CNS stimulation and possible serotonergic interaction

can substantially affect both therapeutic effectiveness and safety profiles. Moreover, variability in dosage practices and the scarcity of long-term toxicity studies make it difficult to establish reliable and standardized clinical applications (133).

Some psychoactive medicinal plants may also interact with conventional pharmaceutical agents through alterations in neurotransmitter signalling pathways or hepatic enzyme activity, potentially increasing the likelihood of adverse effects, contraindications, and drug interactions. Consequently, further pharmacokinetic, toxicological, and well-designed clinical investigations are necessary to support the safe, effective, and reproducible therapeutic use of these plant-derived compounds.

Evidence Level and Clinical Translation

The strength of scientific evidence varied substantially among the medicinal plants included in this review. Some plants, such as *Cannabis sativa*, *Psilocybe cubensis*, and *Withania somnifera*, have relatively stronger experimental support along with limited clinical evidence demonstrating their neuropharmacological potential (134). In contrast, many other plants are still supported mainly by ethnopharmacological knowledge, traditional therapeutic practices, and preliminary *in vitro* or animal-based investigations. Although a wide range of phytochemicals exhibited promising psychoactive and neuroactive mechanisms, the translation of preclinical outcomes into validated clinical efficacy remains restricted. This limitation is largely associated with the scarcity of well-controlled human studies, absence of standardized formulations, and significant variability in dosage, extraction methods, and phytochemical composition. Consequently, interpretation of therapeutic effectiveness should be approached cautiously until further more rigorous and well-designed clinical evidence becomes available.

Ethical and Regulatory Considerations

The therapeutic use of psychoactive medicinal plants involves important ethical and regulatory issues. Many of the plants discussed in this review are controlled or restricted in various countries due to their psychoactive properties, potential for misuse, and risk of dependence. Regulations related to medicinal *Cannabis sativa*, psilocybin-containing fungi such as *Psilocybe cubensis*, opioid-bearing plants, and ayahuasca preparations differ widely across different legal and healthcare frameworks (135). Ethical challenges, including recreational misuse, self-medication without supervision, dependence, and non-medical consumption, remain key concerns in both research and clinical contexts. Therefore, future advancement of psychoactive medicinal plants in therapeutic settings requires strict regulatory control, standardized pharmaceutical formulations, precise dose regulation, and well-designed clinical trials to ensure safety, efficacy, and responsible application in healthcare.

Future Prospects of Medicinal Plants Use in Mental Health Disorders

Medicinal plants continue to attract considerable scientific interest as potential sources of novel neuropharmacological agents for the management of mental and neurological disorders. Increasing evidence suggests that plant-derived phytochemicals may provide

therapeutic benefits through modulation of neurotransmitter systems, neuroinflammatory pathways, oxidative stress, and neurogenesis. Advances in phytochemistry, molecular pharmacology, and biotechnology may facilitate the isolation, characterization, and development of safer and more effective plant-derived psychoactive compounds for future therapeutic applications. Ancient civilizations, including those in India, China, South America, and Egypt, continue to rely on plant-based remedies for these conditions (72). The World Health Organization (WHO) reports that 60% of the global population uses medicinal plants, with 80% of people in developing countries depending on them for primary healthcare (136). Phytochemicals and their chemical analogs have led to the development of clinically useful drugs for treating both chronic and acute diseases. For centuries, medicinal plants have been widely practiced as treatments, particularly for common ailments like colds, allergies, upset stomachs, and toothaches. Despite a decline in their use within conventional medical practices in the mid-20th century, the interest in natural remedies continues to grow. Throughout history, various medicinal and psychoactive plants have played significant roles in healing, spirituality, and cultural rituals (137-139). The opium poppy has been widely used as a narcotic analgesic for pain relief. Cannabis, also known as marijuana, was commonly utilized by shamans for its mild hallucinogenic effects, often revealing subconscious thoughts and triggering memories. Wormwood, an ancient hallucinogenic herb, was a key ingredient in absinthe, a drink that was later banned in the 20th century due to its psychoactive properties. The peyote cactus, containing mescaline, has been used in indigenous rituals for its powerful visual and mystical hallucinations. In Africa, the Bwiti cult consumed iboga, a hallucinogen believed to facilitate communication with ancestral spirits. Meanwhile, in the Amazon, indigenous tribes in Peru, Bolivia, and Brazil prepared ayahuasca, a potent psychoactive brew containing DMT and MAO inhibitors, which was central to religious and spiritual enlightenment ceremonies. These plants have long been intertwined with medicine, mysticism, and cultural traditions, shaping human history through their profound effects on consciousness (72). However, in recent years, the WHO has emphasized the importance of documenting the use of medicinal plants by these traditional practitioners. This has led to efforts in developing countries to record ethnomedical knowledge about plants, making it easier to scientifically validate their pharmacological properties. Once these local plant preparations are properly evaluated and disseminated, people will be more informed and confident in using effective treatments, which may contribute to improved healthcare understanding and future therapeutic research (136). Future investigations involving advanced phytochemical characterization, metabolomic profiling, and structure-activity relationship studies may further improve clearer understanding of the neuroactive properties of medicinal plant constituents.

Limitations of the Review

Several limitations need to be acknowledged when interpreting the results of this review. A large proportion of the existing evidence on psychoactive medicinal plants is derived from preclinical experiments, *in vitro* studies, or

ethnopharmacological reports, while rigorously designed clinical trials remain scarce. In addition, marked variability is observed across studies in terms of experimental design, extraction procedures, phytochemical profiles, administered doses, and measured outcomes, which complicates meaningful comparison of results. Differences in plant source, processing techniques, and concentrations of active constituents may further contribute to inconsistencies in both pharmacological effects and safety outcomes. Moreover, legal restrictions and ethical constraints surrounding certain psychoactive species also hinder extensive clinical research. In addition, the broad narrative approach of this review and the diversity of the available evidence may limit direct comparisons between studies and make it difficult to draw definitive conclusions regarding clinical efficacy and safety. Accordingly, there is a strong need for future studies employing standardized methodologies and well-controlled clinical designs to better establish efficacy, safety, optimal dosing, and long-term therapeutic potential.

Conclusion

Medicinal plants are a valuable source of biologically active compounds that may exert psychoactive and neuropharmacological effects. The plants discussed in this review contain a wide range of phytochemical classes, including alkaloids, flavonoids, cannabinoids, terpenoids, phenolic compounds, and saponins, which can modulate central nervous system activity through different neurochemical mechanisms. A number of these plants have shown anxiolytic, antidepressant, sedative, hallucinogenic, cognitive-enhancing, and neuroprotective properties in preclinical research, with only limited support from clinical studies. Despite promising therapeutic potential, current evidence remains insufficient to establish these medicinal plants as direct alternatives to conventional psychoactive medications. Major limitations include the lack of standardized formulations, inconsistency in phytochemical content, limited human clinical trials, potential toxic effects, and inadequate long-term safety data. As a result, future research should prioritize on well-standardized pharmacological investigations, rigorous clinical trials, comprehensive toxicity assessments, and clear regulatory frameworks to support the safe and evidence-based therapeutic applications of psychoactive medicinal plants.

Declaration

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Conflict of Interest

The authors declare no conflicting interest.

Data Availability

The data generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Statement

Ethical approval was not required for this study.

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Supplementary Material

Supplemental Table 1 is available as supplementary material at the journal's website ([link](#)).

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Additional Information

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