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Phytochemical Constituents and Antidiabetic Potential of Swertia Chirayita: A Review of Pharmacological and Therapeutic Applications

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ABSTRACT

Artificial intelligence (AI) is revolutionizing pharmaceutical sciences and healthcare by enabling predictive analytics, automation, precision therapeutics, and real-time clinical decision support. The integration of machine learning (ML), deep learning (DL), natural language processing (NLP), and generative AI across drug discovery, pharmaceutical manufacturing, clinical practice, pharmacovigilance, and regulatory science has transformed traditional workflows. AI-driven molecular modelling accelerates target identification and de novo drug design, while advanced analytics optimize clinical trials and manufacturing processes. In clinical settings, AI enhances diagnostic accuracy, patient risk stratification, and medication safety monitoring. However, challenges including algorithmic bias, data privacy concerns, regulatory uncertainty, and explainability remain significant barriers to widespread adoption. This review provides a comprehensive overview of AI applications in pharmaceutical sciences and healthcare (2020–2025), discusses regulatory and ethical frameworks, and outlines future directions including explainable AI, federated learning, and digital twins. Responsible integration of AI technologies holds transformative potential for improving healthcare efficiency, therapeutic precision, and patient outcomes globally.

Keywords: Artificial Intelligence; Drug Discovery; Machine Learning; Precision Medicine; Pharmacovigilance; Clinical Decision Support; Regulatory Science.

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INTRODUCTION:

Overview Diabetes mellitus, which affects 25% of the global population with morbidity and mortality, is thought to be the most common endocrine metabolic illness. Based on insulin, diabetes is divided into two categories. reliance. About 10% of people have the illness overall, and type 2 is thought to account for 90% of cases.(1)

The absence of production or reaction to the crucial regulatory hormone, insulin, throughout the human body's metabolism is typically what distinguishes diabetes in the first category. Because it makes it easier for carbs, like sugar and starch, to be converted into energy, this hormone is thought to be the most significant hormone. The elevated blood glucose level is caused by a lack of hormone synthesis. Increased vulnerability to heart attacks, cardiovascular conditions including atherosclerosis, renal failure, and other illnesses like retinopathy, neuropathy, and nephropathy are commonly linked to this severe endocrine problem.(2)

The WHO predicts that the number of people with diabetes will increase to 300 million or more by the end of 2025 (3). Insulin and other oral antibiotics such sulfonylureas, biguanides, glinides, etc. are the most widely used treatments and medications now on the market for the treatment of the illness; nevertheless, the majority of these have some drawbacks and side effects (4). One of the most important issues driving research into herbal medicine with improved hypoglycemic action is the rising expense of conventional medications in underdeveloped nations. The mechanism of action of indigenous medicinal herbs with such therapeutic potentials is well known [5].

Many chemical substances that are utilized as medicine in the profession of medicine come from medicinal plants. The majority of the world's population uses medicinal plants as their main source of medicines. In affluent nations, herbal remedies are becoming more and more popular for medical purposes [6,7].

In the field of pharmacology, the genus Swertia holds great significance. Specifically, Swertia chirayita (Roxb. ex Fleming) H. Karst. is utilized in traditional medicine to treat and cure a variety of illnesses, including chronic fever, malaria, anemia, bronchial asthma, liver disorders, hepatitis, epilepsy, ulcers, hypertension, mental disorders, diabetes, and blood purifiers [8-13]. The other Swertia species are rare in the commerce of S. chirayita due to the rigorous standards in the field of pharmacology.

Swertia densifolia, Swertia lawii, and Swertia minor are species from the Western Ghats that are utilized as adulterants[14,15] and/or substitutes[16]. Erroneous replacements and adulterants of medicinal plants utilized in the international market are a serious issue. They are utilized because they are less expensive or because species with similar physical traits are mistakenly identified.

Morphological traits and keys, which serve as the primary foundation for taxonomy, are used to authenticate biological species [17]. One crucial stage in quality assurance is the genuine identification and authentication of the plants utilized in production. On the other hand, medicinal plant replacement might happen accidentally or on purpose [18, 19]. The genus Swertia belongs to the Gentianaceae family, which includes a wide variety of annual and perennial herbs. The family has about 135 species. It has been discovered that one of the key components of herbal remedies is Swertia species. Based on its therapeutic qualities, Swertia chirayita is considered the most significant of the 40 species of Swertia that have been identified in India[20]. Roxburgh originally identified S. chirayita as Gentiana chyrayta in 1814 [21]. Because of its anti-hyperglycemic qualities, Swertia chirayita is the most widely used and well-known species of herbal plants. There are about 135 species in the genus Swertia of the Gentianaceae family that have therapeutic qualities.[22]

DIABETES AND ITS EFFECTS:

Diabetes Mellitus (DM) is a polygenic condition characterised by insufficient insulin delivery and/or abnormalities in insulin function, which ultimately result in elevated blood sugar levels. The prevalence of diabetes would rise from 4% in 1995 to 5.4% in 2025.[23]

It is estimated that over 33 million adults in India have diabetes, and by the end of 2025, that figure is predicted to rise to 57.2 million.[23]

The main features of diabetes include hyperglycemia, which affects how fats, carbs, and proteins are metabolized, and the body's propensity to be impacted by major long-term health issues like cardiovascular diseases [24].

Prolonged hyperglycemia might lead to severe complications that could impact patients' medications and bodily systems [24].

Diabetes that is left untreated causes significant tissue and vascular damage, which ultimately results in major health issues like ulceration, neuropathy, retinopathy, and cardiovascular difficulties[25-28]. Type 1 diabetes, one of the two most common forms of the disease, is insulin-dependent and results from insufficient or malfunctioning insulin. This type of diabetes is mostly caused by restrictions on beta cell activation. Contrarily, type 2 diabetics are thought to be insulin-independent[29]. and their therapy mostly consists of dietary modifications, exercise, and medication.People who are fat are more likely to get this type of diabetes. Hypertension, dyslipidemia, odd thrust, urine, severe hunger accompanied by vomiting, weight change,blurred vision ,excessive weakness,nausea,mood swings[23].

MEDICINAL USES:

Many indigenous population groups use S. chirayita, an indigenous traditional Ayurvedic medicinal herb, for a variety of therapeutic purposes. Locals frequently use the entire plant to cure digestive system issues, hepatitis, and inflammation[30]. Chronic fever, malaria, anemia, bronchial asthma, hepatotoxic disorders, liver disorders, hepatitis, gastritis, constipation, dyspepsia, skin conditions, worms, epilepsy, ulcers, scanty urine, hypertension, melancholia, mental disorders, bile secretion, blood purification, and diabetes are among the many medical conditions for which S. chirayita is used[8,9,31,13,32]. Extracts of S. chirayita have recently been found to have anti-hepatitis B virus (anti-HBV) action[33].

This species' decoction has historically been used to treat anthelmintic, hepatoprotective, hypoglycemic, antimalarial, antifungal, antibacterial, cardiostimulant, antifatigue, anti-inflammatory, antiaging, antidiarrheal, and cardioprotective properties as well as to lower blood pressure and blood sugar[34]. Herbal remedies like Melicon V ointment, Ayush-64, Diabecon, and Mensturyl syrup[35].

Due to the plant's widespread use in traditional medicines, a great deal of scientific research has been done on the plant and the active chemical components that give it its therapeutic qualities. Additionally, the herb is utilized as a tincture and infusion in American and British pharmacopeias[14]. Although the root has been found to have the highest bioactivity, the entire plant has been utilized in traditional medicine[36]. Concurrently, the pharmacological characteristics of S. chirayita have been evaluated using a wide range of test systems. The aqueous, alcoholic, and methanolic extracts of S. chirayita contain several interesting pharmacological activities, according to evidence-based test research. There have been reports of using the entire S. chirayita plant to treat antifungal and antibacterial properties[37-39].

MEDICINAL PLANTS WITH ANTI-DIABETIC POTENTIAL:

Potential Anti-Diabetic Medicinal Plants Since medicinal herbs are thought to be excellent sources of therapeutically important phytochemicals, they have historically demonstrated a key role in the management of a variety of ailments. Many medications have been obtained from plants in the form of various extracts, and plants have been traditionally utilised all over the world to treat a variety of illnesses. Numerous studies have demonstrated the use of medicinal plants to treat a variety of illnesses in particular bodily systems, such as the nervous system, cardiovascular system, respiratory system, digestive system, and various body organs, while the cultural and geographical characteristics of the plants have demonstrated the treatment of a variety of illnesses in the form of crude extracts, whole plants,plant pastes,infustion,etc[(40).] Herbal plant species that are significant for nutrition are being used for both therapeutic and nutritional purposes[(41).] The herb's leaves, bark, seeds, fruits, stems, flowers, and occasionally the entire plant have all been used to treat diabetes. Recent studies show that 30,000 plant species have been used medicinally worldwide, with 800 of those species having anti-diabetic qualities[(2).] In affluent nations where the cost of regular medications is not entirely beyond the reach of the general public, herbal remedies are already utilized to treat polygenic disorders. Human cell lines and animal models have been used to confirm the hypoglycemic effect of several medicinal plant extracts against the second type of diabetes. Such extracts have been shown to include chemical substances having antidiabetic effects, including polysaccharides, peptidoglycans, hypoglycans, glycosides, guanidine, steroids, carbohydrates, glycopeptides, terpenoids, and alkaloids[(5).]

SWERTIA CHIRAYITA AND ITS VALUABLE CONSTITUENTS:

Swertia chirayita and Its Usefulness Constituents Since 1839, Europeans have become familiar with the ancient herbal plant Swertia chirayita. The plant has become well-known due to its many names, including Nidrari, Haima, Ramasen-ka, Kairata (Sanskrit), Chiravata (Urdu), Chireta (Bengali), and Qasabuzzarirah (Arabic and Farsi)[(42).]

The plant primarily reaches maturity at high elevations, or sub-temperature regions, particularly the Himalayan slopes, or shaded areas, which are typical of the areas between 1200 and 1500 meters, or from Bhutan to Kashmir[(22,43).] The Khasi hills, Meghalaya, and the middle region of India are the locations where the plant is also grown. Twenty of these species were used to treat choleric, inflammatory, and hepatic conditions. The genus of the plant is well known for its usage in Chinese traditional medicine[(44).]

India is home to forty Swertia chirayita endangered species. The majority of these herbs are either annual or biennial[(45,36).] The maximum growth of this therapeutic herb is between 0.5 and 1.5 meters. Such a plant has lanceolate, cordate-based leaves that are nearly 4 cm long, have five to seven nerves, and point in nearly the opposite direction[(46).] The fowers of this therapeutic herb are small, many, tetramerous, and green-yellowish in color, while the root is simple, yellowish, somewhat inclined, and about 7-8 cm long[(14).]

The plant contains a number of important phytochemicals, i.e., xanthones, ursolic acid, favonoids, terpenoids, iridoids, amarogentin, glycosides, secoiridoids, and swertiamarin. Ophelic acid ($C_{13}H_{48}O_{15}$) and chirantin ($C_{26}H_{48}O_{15}$) are two of the important compounds present in the plant, and they are reasonable for the development of bitter test. On the basis of nature, ophelic acid is yellowish, non-crystalline, and hygroscopic, and it can dissolve in water, ether, and alcohol. Chirantin or amarogentin combines with tannic acid and produces an insoluble compound. This compound is pale yellow, soluble in alcohol, ether, and especially soluble in warm water. This compound splits into ophelic acid, water, and chiratogenin ($C_{13}H_{24}O_3$) when boiled with hydrochloric acid[(47).]

The extract from S. chirayita has been shown to contain transparent monoterpene alkaloids like geneticine. The chemical has been added to the group of known compounds that are polycyclic aromatic compounds having a pyran ring connected to a pyridine ring, or pyranopyridines. Gentianine is naturally soluble in aqueous solutions and possesses anti-inflammatory, anesthetic, antihistamine, and anticonvulsant qualities[(48).] Other therapeutic qualities of the substance include hypotension, antimalarial, antiamoebic, and antipsychoties,and antibacterial [(49).]

Gentianine is a possible biomarker for consuming the food product containing the molecule because of characteristics like bitter taste. Derived from the same plant extract as gentianine, swertiamarin is thought to be a secoiridoid glycoside and is well-known for its analgesic properties. The substance has been effectively utilized to treat conditions like diabetes, atherosclerosis, arthritis, malaria, hypertension, and stomach ulcers[(50).]

In rats given high cholesterol, it was demonstrated that this possible secoiridoid glycoside effectively reduced elevated serum total cholesterol and triglycerides. One of the xanthone member classes, swerchirin, is separated from Swertia species. Similar therapeutic qualities, including hypoglycemic, antimalarial, and antihepatotoxic effects, have also been demonstrated. Similar to Swerchirin, Swertia species were likewise found to contain nine tetraoxygenated xanthones. The existence of such xanthones in the plant extract was evident from preliminary pharmacological screening, which primarily indicates its medicinal potential. Another possible bioactive substance found in Chirayita species is mangiferin, which is well-known for its antioxidant qualities and numerous medicinal applications[(51).]

It has been demonstrated that the substance has an inhibitory action against a number of human malignancies. The compound's low solubility, permeability, and bioavailability are primarily to blame for its development as the most effective clinical therapeutic agent; physicochemical modification is necessary to increase its applicability.Another kind of fiber-associated polyphenolic molecule that typically comes from the same plant is lignan. The substance, which has hepatoprotective properties, is typically found in a wide range of food items related to plants, including grains, seeds, nuts, fruits, vegetables, legumes, and beverages like wine, tea, or coffee. Research is needed to support the specific role of lignans, however current studies in this field indicate that food products high in lignans are beneficial for health and can treat illnesses.Along with such compound ,chirayita also contain verities of triterpenoids including pichierenol, swertanone[(42).]

The anticancer, anti-proliferative, and pro-apoptotic activities of several triterpenoids found in the same plant species have already been demonstrated using a variety of experimental animal models. Scholars such as Basnet et al[(52).]

found that Swertia chirata's roots and aerial parts contained nine tetraoxygenated xanthones, among which 1,5,8-Trihydroxy-3-methoxyxanthone was found to have the capacity to reduce blood sugar. The same plant species were found to have the anti-inflammatory xanthone derivative 1,5-dihydroxy-3,8-dimethoxyxanthone, and the degree of the compound's efficacy was evaluated using sub-acute and chronic male albino rat models[9].

Significant pharmaceutical effects In Ayurveda, S. chtrayita is used as an antipyretic, anthelminthic, antiperiodic, cathartic, and for asthma and leucorrhea. It is also harsh, analeptic, stomachic, reduces inflammation, calms the uterus during pregnancy, and never ends[36].

Ulcers, gastrointestinal, skin, liver, kidney, neurological, and urinogenital tract illnesses are all treated with it. It also purifies breast milk, acts as a laxative, and acts as a carminative[53,54].

Numerous pharmacological studies have been started as a result of S. chirayita's numerous ethnobotanical applications. According to literature on earlier studies, S. chirayita extracts have a wide range of biological activities, including antidiabetic and antioxidant properties as well as antibacterial, antifungal, antiviral, anticancer, and anti-inflammatory properties[55,37,56,57,38].

MACHANISM OF ACTION

Action Mechanism Depending on the bioactive substances in the extract, S. chirayita has a variety of modes of action that contribute to its therapeutic qualities. For instance, antioxidants and anti-inflammatory substances like xanthones and secoiridoid glycosides that stop oxidative stress and inflammation in the liver are responsible for the hepatoprotective action[58].The presence of xanthones, such as swerchirin, modulates insulin sensitivity and improves glucose metabolism, which results in hypoglycemic action[59].

When it comes to their anti-inflammatory qualities, flavonoids and xanthones prevent the production of pro-inflammatory cytokines like TNF-α and IL-6. In addition, the plant's antioxidant qualities scavenge ROS and other reactive oxygen species[60]. These characteristics demonstrate the plant's effectiveness in treating inflammatory conditions and suggest that it may be used to stop the development of chronic illnesses including diabetes and cardiovascular diseases.

Phytochemical Composition

Composition of Phytochemicals Swertia chirayita's rich phytochemical makeup is responsible for its potency and therapeutic qualities. several bioactive substances, including xanthones, flavonoids, alkaloids, secoiridoid glycosides, and several secondary metabolites, are present in the plant. The pharmacological activity of S. chirayita, including its hepatoprotective, anti-inflammatory, antidiabetic, and antimalarial properties, is attributed to all of these bioactive substances. The main bioactive substances found in S. chirayita, along with their structural formula and pharmacological action, will be the main topics of discussion in this section [60].

Xanthones

One of the most important phytochemicals found in Swertia chirayita, xanthones are what give it its therapeutic qualities. These polyphenolic substances are known to have hepatoprotective, anti-inflammatory, and antioxidant qualities [14]. Swerchirin, mangiferin, and amarogentin are some of the important xanthones found in Swertia chirayita. Swerchirin: Swerchirin is known for its strong hepatoprotective, hypoglycemic, and antimalarial effects. Its capacity to control blood sugar levels and prevent the growth of Plasmodium falciparum, the parasite that causes malaria, has been thoroughly investigated(61). Another important xanthone with anti-inflammatory and antioxidant qualities is mangiferin. It reduces oxidative stress, which is crucial for preventing chronic diseases like diabetes and cardiovascular disorders [59].

One of the bitterest natural compounds, amarogentin has antileishmanial and anticancer properties. Because of its intense bitterness, this xanthone is utilized as a digestive aid. The medicinal benefit of S. chirayita, which includes the treatment of inflammation, malaria, and liver issues, is mostly due to the diverse biological actions of xanthones [58].

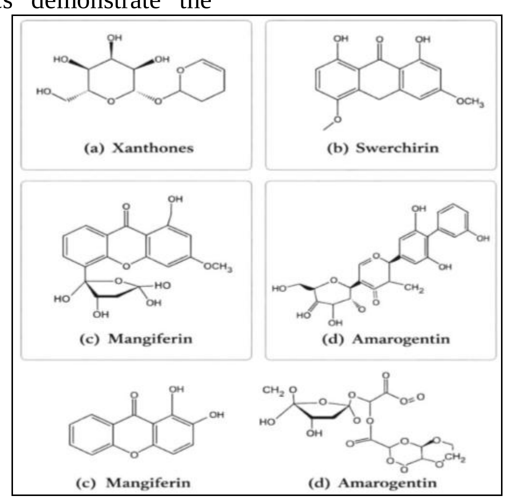

Figure 1: Chemical Structure of major Xanthones in Swertia chirayita

Another important family of phytochemicals in S. chirayita that greatly influences its pharmacological actions are securidoid glycosides. These substances are well-known for their gastroprotective, hepatoprotective, and anti-inflammatory qualities[14]. Swertiamarin, amaroswerin, and gentianine are the three primary secoiridoid glycosides found in S. chirayita.

Swertiamarin's gastrointestinal tract-protective properties have been thoroughly investigated. By lowering gastrointestinal lesions and shielding the stomach lining from harm brought on by stress, alcohol, and other factors, swertiamarin has been shown to have significant gastroprotective effect (60). It has been discovered that amaroswerin is a powerful anti-inflammatory and hepatoprotective drug. It has been discovered that this substance shields the liver against oxidative stress, alcohol, and poisons. As a result, liver problems can be treated with it [14].Gentianine has several biological functions and is a versatile chemical. It has been discovered that gentianine has antipsychotic, antihypertensive, and anti-inflammatory properties. Furthermore, gentianine has been shown to lower oxidative stress and modify immunological responses (61).

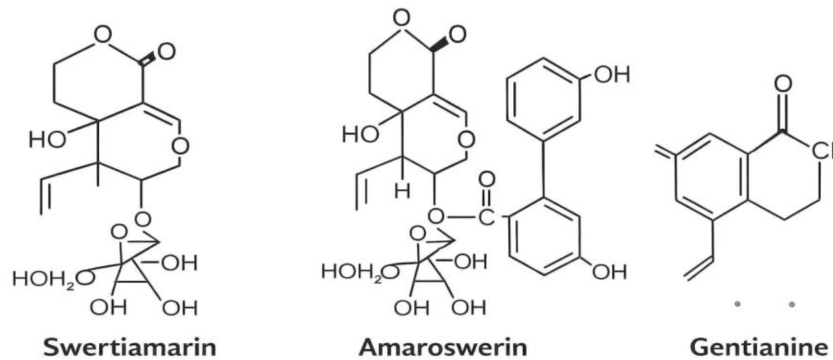

Figure 2: Chemical Structure of Secoiridoid Glycosides in Swertia chirayita

FLAVONOIDS

Polyphenolic substances with anti-inflammatory and antioxidant qualities are called flavonoids. The primary flavonoids found in S. chirayita are isoorientin and isovitexin, which provide the plant its anti-inflammatory and free radical scavenging properties Isoorientin is an antioxidant with anti-inflammatory and anti-tumor qualities that helps shield cells from oxidative stress by scavenging reactive oxygen species (ROS) [59].

Another flavonoid with strong antioxidant properties is isovitexin. It plays a role in preventing oxidative stress-related cell damage. Isovitexin has demonstrated potential in preventing long-term illnesses such cancer and heart problems[63]. S. chirayita's flavonoids enhance the plant's therapeutic value in preventing illnesses linked to oxidative stress.

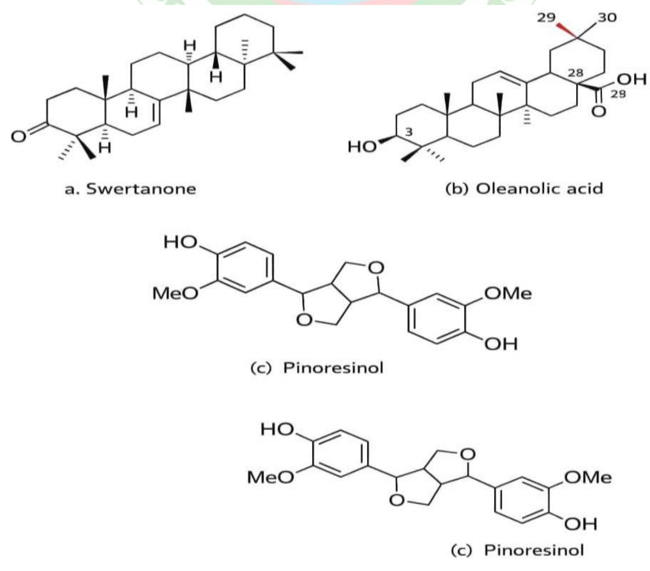

Figure 3: Chemical Structure of Flavonoids in Swertia Chirayita

Triterpenoids and Ligands:

Two more biochemically important substances found in Swertia chirayita are triterpenoids and lignans. Strong anti-inflammatory, hepatoprotective, and anticancer properties have been demonstrated by both lignans and triterpenoids [60].

Triterpenoids with anti-inflammatory, hepatoprotective, and anti-cancer effects include oleanolic acid and swertanone [14]. The Plants hepatoprotective and antioxidant qualities are attributed to liganda such pioresinol the compound reduce oxidative stress and prevent liver damage caused by toxins

(62). The plant's hepatoprotective and antioxidant qualities are attributed to lignans such pinoresinol.

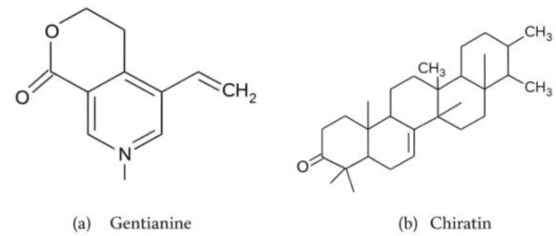

Figure 4: Chemical Structure of Triterpenoids and Lignans in Swertia chirayita

Alkaloids

These lignans are known to lessen oxidative stress and shield the liver from toxic damage. S. chirayita contains alkaloids such gentianine and chiratin, which give it its pharmacological characteristics. Alkaloids are well-known for their pharmacological characteristics, which include analgesic, antibacterial, and antimalarial effects[58].

Gentianine has been shown to exhibit hypotensive, antipsychotic, and anti-inflammatory properties. Additionally, by controlling blood pressure and enhancing insulin sensitivity, it can manage metabolic diseases [14]. Chiratin is essential to S. chirayita's analgesic and antimalarial properties. As a result, it can be used to relieve pain and fever[61].

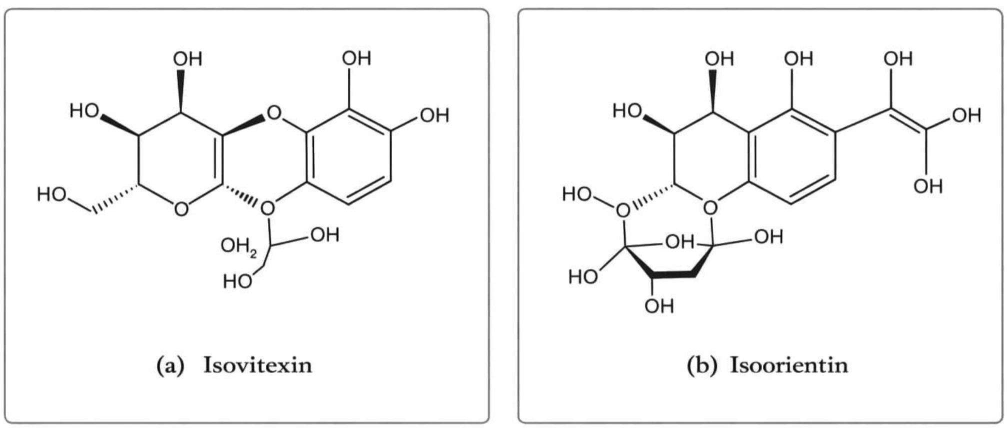

Figure 5: Chemical Structure of Alkaloids in Swertia chirayita

CONCLUSION:

Medicinal plants continue to play an important role in the management of various chronic diseases, including diabetes mellitus. Swertia chirayita is one of the most valuable medicinal plants known for its wide range of therapeutic properties. The presence of bioactive compounds such as xanthones, flavonoids, alkaloids, and secoiridoid glycosides contributes significantly to its pharmacological activities, particularly its antidiabetic effect. Scientific studies have demonstrated that these phytochemicals help regulate blood glucose levels, improve insulin sensitivity, and reduce oxidative stress, which are key factors in diabetes management. In addition to its hypoglycemic activity, Swertia chirayita also exhibits antioxidant, anti-inflammatory, hepatoprotective, and antimicrobial properties, making it a versatile medicinal plant. Although traditional and experimental studies support its therapeutic potential, further clinical research and standardization are required to ensure its safety, efficacy, and quality. Overall, Swertia chirayita holds great promise as a natural source for the development of effective herbal formulations for diabetes and other related metabolic disorders.

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