



Therapeutic Potential of Sky Fruit Seeds and its Utilization in Functional Foods and Nutraceutical: A Review

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10.18805/ajdfr.DR-2267

ABSTRACT

The prevalence of NCDs (non-communicable diseases), which include diabetes, cardiovascular diseases and chronic inflammatory conditions has been rising globally, posing significant challenges to public health systems. Remedies from natural ingredients and functional foods have gained attention these days for their potential to prevent and manage these conditions. Local communities in Southeast Asian countries have been using sky fruit seeds for centuries as a traditional medicine because of their unique characteristics and therapeutic potential. Sky fruit seeds rich in phytochemical compounds such as phenolic acids, flavonoids, limonoids, saponins, tannins, etc., which show antioxidant, antihyperglycemic, antihypertensive, anti-inflammatory and antimicrobial properties. These phytochemicals also play a crucial role in inhibiting the production of ROS (reactive oxygen species) through the activation of antioxidant enzymes. A literature review of 25 relevant scientific articles that were published in the last 10 years from PubMed and Google Scholar was conducted, using the search terms "*Swietenia macrophylla* and *Swietenia mahogany*" to identify articles related to the botanical species. This review provides a comprehensive understanding of current knowledge on the phytochemical composition, biological activities and health benefits of sky fruit seeds, as well as their potential applications in the development of nutraceuticals and functional food products.

Key words: Antidiabetic, Antimicrobial, Ant-inflammatory, Antioxidant, Mahogany seeds, *Swietenia macrophylla*.

In Southeast Asia, especially in Indonesia and Malaysia, the sky fruit is a tropical tree scientifically known as *Swietenia macrophylla* that belongs to the Meliaceae family. The term "macrophylla" comes from the Greek words "macro" which means large and "phylon" which means leaf (Telrandhe *et al.*, 2022). Due to its distinctive characteristics and therapeutic potential, its seeds, commonly known as sky fruit seeds, have recently attracted considerable attention in the scientific community. These seeds are elongated, fat and enriched by a papery wing that helps the wind blow around. These seeds are red, brown or light brown in color and are produced in large woody capsules on the tree [Indian Mahogany (*Swietenia Mahagoni*), Species of Indian Mahogany, Propagation of Mahogany/ : Eco India, n.d.]. For centuries, the seeds, bark and leaves of this sky fruit tree have been used by local communities. There's a long history with this tree, which is rooted in ancient medicine. Traditional healers and herbalists have been valuing the sky fruit seeds for their medicinal value ever since. They have been given to treat a variety of diseases, e.g. hypertension, diabetes, inflammation and other metabolic disorders.

Swietenia macrophylla consists of many phytochemical constituents, which have a wide range of pharmacological effects on human health, which give rise to its healing potential. Several research studies have demonstrated the antioxidant activity of sky fruit seeds, which help in reducing oxidative stress and mitigate its effect on cell damage resulting from free radicals (P. C. Pal *et al.*, 2024). In addition, sky fruit seeds also have anti-inflammatory properties, antihypertensive properties, antihyperglycemic

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How to cite this article: Bajaj, P. and Sharma, M. (2025). Therapeutic Potential of Sky Fruit Seeds and its Utilization in Functional Foods and Nutraceutical: A Review. Asian Journal of Dairy and Food Research. 1-9. doi: 10.18805/ajdfr.DR-2267.

Submitted: 14-08-2024 **Accepted:** 17-12-2024 **Online:** 10-02-2025

properties, hepatoprotective effects and immunomodulatory properties, offering a holistic approach to health and wellbeing (Telrandhe *et al.*, 2022).

The nutraceutical value of sky fruit is enhanced by its wide variety of pharmacologically active components, which have been linked to immunological, metabolic and cardiovascular health advantages. Swietenine and swietenolide, two bitter limonoids found in abundance in the seeds, have been demonstrated to have potential for decreasing cholesterol and promoting cardiovascular health. Sky fruit has potential for people at risk of cardiovascular disease since it may lower blood pressure and enhance heart health by improving blood circulation and avoiding plaque accumulation (Moghadamtousi *et al.*, 2013). Furthermore, the high saponin content has anti-

inflammatory properties that may help alleviate chronic inflammatory diseases like arthritis and aids in cholesterol metabolism (Moghadamtousi *et al.*, 2013).

Its ability to promote liver health and detoxification is another aspect of its functional significance. The antioxidants in the plant help the liver eliminate toxins and lower the risk of liver-related illnesses in addition to fighting free radicals. Furthermore, because of its high nutrient content and health-promoting phytonutrients, sky fruit is widely recognized for its ability to improve endurance and general vitality. The fiber content promotes gut health and digestion, which may help people with digestive disorders and enhance nutrient absorption. Sky Fruit is a powerful functional food with a wide range of bioactivities that provide comprehensive advantages that are consistent with both conventional medical applications and current scientific knowledge of nutraceuticals.

Sky fruit seed can be incorporated into a wide variety of functional food formulations such as snacks, beverages, cereals or supplements. These days, a wide range of health products contain sky fruit seeds because of their remarkable bioactive component profile. Because of their alleged advantages in controlling blood sugar, boosting immunity and supporting cardiovascular health, these seeds are frequently processed into capsules, powders and teas. This review aims to provide an overview on a therapeutic potential of sky fruit seeds or mahogany seeds and their utilization into nutraceuticals and functional food products. The review mainly focuses on phytochemical constituents, their biological activity and pharmacological properties of sky fruit seeds.

A qualitative review was conducted using the PubMed databases to explore the therapeutic potential of sky fruit seeds (*Swietenia macrophylla*) and their utilization in functional foods and nutraceutical products. Some of the research studies were accessed from google scholar. The database was accessed at Manav Rachna International Institute of Research and Studies on May 7, 2024, to retrieve relevant articles published between 2014 and 2024. The preliminary search keywords used were "*Swietenia macrophylla* and *Swietenia mohogany*" to identify articles related to the botanical species.

Data collection

A total of 71 articles were initially identified using the search terms "*Swietenia macrophylla* and *Swietenia mohogany*". These articles were then further screened based on the following criteria (Fig 1): 1) free to access (n=34): articles that were freely accessible were included in the review to ensure comprehensive coverage and accessibility to readers. 2) Out of 34 papers (n=25) articles was selected, which were relevant and focused on the studies that investigated different biological activities and conducted phytochemical analysis of sky fruit seeds. 3) Out of 25 papers (n=12) were selected from PubMed and (n=13) were selected from Google Scholar.

The selected articles were carefully analyzed to extract relevant information regarding the therapeutic potential of sky fruit seeds, including their nutritional composition, phytochemical profile, pharmacological activities and utilization in functional foods and nutraceutical products.

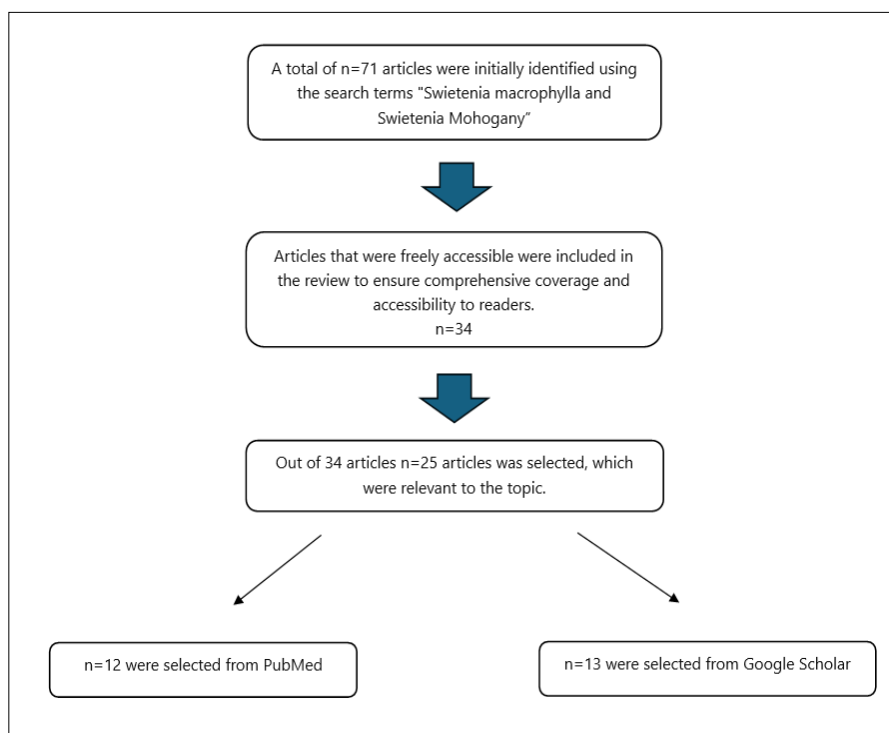


Fig 1: Flowchart of methodology.

Data extraction was performed systematically to ensure accuracy and consistency in reporting the findings.

A total of 25 research papers were studies and abridged in this section presenting a thorough synthesis of findings from the pool of studies on the sky fruit seeds (*Swietenia macrophylla*). Focusing on the therapeutic potential and its application in functional foods and nutraceuticals. The results highlighted the presence of phytochemicals or bioactive compounds such as flavonoids, terpenoids, saponins, alkaloids, limonoids, phenolic acids and tannins. Also, emphasized on their mechanism of action in disease prevention and health promotion. Additionally, this section has also provided insights of current trends and future prospects for the integration of sky fruit seeds into nutraceutical and functional food products.

Botanical classification

Kingdom: Plantae

Family: Meliaceae

Genus: Swietenia

Species: Macrophylla

Swietenia macrophylla is characterized with its enormous height and is a large deciduous tree. It usually reaches the height ranges from 98 to 131 feet (approximately 30 to 40 meters), but if the conditions are favorable it can grow even higher. The tree has a straight, cylindrical trunk that is between 3.3 and 6.6 feet (or 1 to 2 meters) in diameter. *Swietenia macrophylla* has smooth, grayish-brown bark that occasionally has little fissures or furrows in it (*Agroforestry Species Profile*, n.d.).

During the flowering season, *Swietenia macrophylla* bears small, sweet-smelling flowers in clusters at the end of its branches. The flowers typically consist of five petals and come in shades ranging from white to light yellow. *Swietenia macrophylla* produces unusual fruit capsules known as mahogany pods or fruits after pollination. These elongated capsules have a woody texture and brown color and they contain numerous winged seeds. Sometimes referred to as sky fruit seeds or mahogany seeds, the oval shaped pods of *Swietenia macrophylla* are notable for their appearance (*Agroforestry Species Profile*, n.d.).

Phytochemical composition and pharmacological properties of sky fruit seeds

Sky fruit seeds contain a variety of bioactive compounds that are a part of their phytochemical makeup and all contribute to the plant's potential for therapeutic applications. These seeds are abundant in phenolic acids, flavonoids, saponins, alkaloids, terpenoids and tannins as tabulated in Table 1. The pharmacological properties of these substances include antibacterial, antidiabetic, immunomodulatory, antioxidant and hepatoprotective effects (Table 1).

Mechanism of various bioactive compounds present in sky fruit

These bioactive compounds, such as flavonoids, phenolic acids, alkaloids, terpenoids and tannins, work through various mechanisms to help in maintaining health and avoiding a range of disorders. Table 2 includes the phytochemical compounds in sky fruit seeds.

Flavonoids

The total flavonoid content in *Swietenia macrophylla* or sky fruit seed is 41.75 ± 3.42 mg QE/g extract, where QE stands for quercetin equivalents. This figure indicates a significant amount of flavonoids, a class of potent antioxidants that are well-known for their capacity to fight oxidative stress and promote a number of health outcomes, such as the health of the immune and cardiovascular systems (Kurnijasanti *et al.*, 2023).

Anti-inflammatory effects

flavonoids such as quercetin and kaempferol inhibit pro-inflammatory enzymes like lipoxygenase (LOX) and cyclooxygenase (COX). They also decrease the production of pro-inflammatory cytokines such as TNF- α and IL-6, which in turn reduces chronic inflammation associated with conditions like inflammatory bowel disease and arthritis (Ginwala *et al.*, 2019).

Antioxidant activity

Flavonoids such as rutin, kaempferol and quercetin neutralize reactive oxygen species (ROS) and reduce oxidative stress by providing hydrogen atoms or electrons to free radicals.

Table 1: Phytochemical composition and pharmacological properties of sky fruit seeds.

Phytochemical constituents	Pharmacological properties
Flavonoids	Antioxidant activity and anti-inflammatory effects (Mak <i>et al.</i> , 2023).
Terpenoids	Anti-cancer activity and hepatoprotective effects (Mak <i>et al.</i> , 2023).
Phenolic acids	Antioxidant activity; antimicrobial action and anti-inflammatory effects (Divakar <i>et al.</i> , 2023).
Saponins	Antitumor activity, Cholesterol lowering properties and Immunomodulatory properties (Duan <i>et al.</i> , 2021).
Limonoids	Insulin sensitizing, inhibition of α -amylase (Duan <i>et al.</i> , 2021).
Alkaloids	Antidiabetic activity (Shiming <i>et al.</i> , 2021).
Tannins	Antimicrobial activity, Astringent properties and Antioxidant effects (Assaduzzaman <i>et al.</i> , 2020).

This helps in reducing cell damage and protecting against chronic diseases like cancer and cardiovascular issues (Aiello *et al.*, 2021; Micek *et al.*, 2021; Singh *et al.*, 2023).

Terpenoids

The amount of terpenoids in *Swietenia macrophylla* varies depending on the part of plant extracted. A study conducted by Mohammed *et al.* (2014) reported that TLC profile of seed extracts demonstrated two and seven spots for alkaloids and terpenoids (Mohammed *et al.*, 2014).

Anti-cancer activity

Terpenoids such as swietenine and swietenolide by activating the caspase pathway and causing mitochondrial dysfunction, these substances cause cancer cells to go into Apoptosis. They also prevent angiogenesis, which is

the growth and metastasis of malignancies through the production of new blood vessels (Wang *et al.*, 2022).

Hepatoprotective effects

Terpenoids like triterpenes and limonoids enhance the function of antioxidant enzymes (e.g. catalase, superoxide dismutase) to boost liver's ability to detoxify. In addition, they protect liver cells, known as hepatocytes, from oxidative stress and harmful effects of toxins. The protective effect on the liver is crucial in preventing conditions like hepatitis and cirrhosis (Mak *et al.*, 2023).

Phenolic acids

The total phenolic content of sky fruit seeds, or *Swietenia macrophylla* seeds, has been reported to be around 59.23±2.41 mg GAE/g extract. This figure illustrates the

Table 2: Phytochemical composition of sky fruit seeds.

Compounds	Class	Reference
Swietenolide	Limonoid	(Moghadamtousi <i>et al.</i> , 2013)
Swietenine		
Swietenine acetate		
8,30-epoxyswietenine acetate		
Swietenolidetiglate		
Augustineolide		
Swietenolidediacetate		
3β,6-dihydroxydihydrocarapin		
Andirobin		
7-deacetoxy-7-oxogedunin		
Proceranolide		
6-O-acetylswietenolide		
Khayasin T		
3,6-O,O-diacetylswietenolide		
Swietemahonin E		
Swietemahonin F		
Swietemahonin G		
2-hydroxyswietenine		
Methyl 3β-tigloyloxy-2,6-dihydroxy-1-oxo-meliac-8(30)-enate		
Methyl 3β-tigloyloxy-2-hydroxy-1-oxo-meliac-8(30)-enate		
Methyl 3β-tigloyloxy-2-hydroxy-8α,30α-epoxy-1-oxo-meliacate		
Methyl 3β-acetoxy-2,6-dihydroxy-8α,30α-epoxy-1-oxo-meliacate		
Methyl 3β-isobutyryloxy-2,6-dihydroxy-8α,30α-epoxy-1-oxo-meliacate		
6-deoxyswietenine (febrifugin)		
6-O-acetyl-32 -demethylswietephragmin E		
3-O-tigloylswietenolide		
3-O-tigloyl-6-O-acetylswietenolide		
6-O-acetylswietemahonin G		
Scopoletin	Coumarin	
Stearic acid methyl ester	Fatty acid ester	
β-sitostenone	Steroid	
3β-hydroxystigmast-5-en-7-one		
β-sitosterol		
stigmasterol		

abundance of phenolic components in the seed extract and is given as milligrams of gallic acid equivalents per gram of extract (mg GAE/g) (Kurnijasanti *et al.*, 2023).

Anti-inflammatory activity

The expression of inflammatory mediators is dependent on the nuclear factor-kappa B (NF-κB) pathway, which is inhibited by gallic acid. gallic acid also reduces the inflammation and protect against inflammatory illnesses by obstructing this pathway (Naik *et al.*, 2014; Singh and Khare, 2022).

Antioxidant activity

By scavenging free radicals through electron transfer or hydrogen donation, phenolic acids like ferulic acid, gallic acid and caffeic acid stabilize the radicals and stop oxidative damage to cells and tissues (Kumar and Goel, 2019).

Antimicrobial action

The development and multiplication of bacteria and fungus can be inhibited by phenolic acids especially gallic acid, which also have the ability to damage microbial cell walls and membranes, inhibit microbial enzymes and interfere with microbial protein synthesis (Balamuniappan *et al.*, 2016).

Limonoids

About 100 limonoids have been identified from *S. macrophylla* to date, including well-known ones that have been found in different plant parts, like evodulon, gedunin, azadirone andirobin, mexicanolide and phragmalin. Phragmalin-type limonoids are mostly found in the stem and leaves, whereas Mexicanolides are mostly concentrated in the fruits and seeds (Reis *et al.*, 2023).

Inhibiting α-amylase and α-glucosidase

Limonoids also inhibits key enzyme involved in carbohydrate digestion, such as α-amylase and α-glucosidase. Limonoids reduce the rate at which complex carbs are broken down into glucose by blocking these enzymes, which lowers blood glucose levels after meals (Lam *et al.*, 2024).

Enhancing insulin release

Limonoids have been shown to stimulate insulin secretion from pancreatic beta-cells. This is through the modulation of calcium ion channels. By increasing intracellular Ca²⁺, limonoids improve the exocytosis of insulin-containing vesicles, thus enhancing insulin release and improving uptake by tissues (Duan *et al.*, 2021).

Alkaloids

The alkaloid content of the seed extract of *Swietenia macrophylla* (skyfruit) is 22.61±1.97 mg CoE/g extract, where CoE stands for colchicine equivalents. Alkaloids are bioactive substances that are well known for their pharmacological characteristics, which include analgesic, antibacterial and anti-inflammatory actions. The skyfruit seed extract's high concentration of alkaloids points to

possible medicinal advantages because these substances can help lower inflammation, alter the immune system and ward against infections (Kurnijasanti *et al.*, 2023).

Anti-diabetic activity

Mahoganine and swietemahonine are two examples of alkaloids that can be discovered in mahogany seeds. Alkaloids also blocks the enzymes involved in the metabolism of carbohydrates like α-glucosidase and α-amylase, it lowers postprandial glucose levels and enhance glycemic control (Mursiti *et al.*, 2016).

Tannins

According to a study on *Swietenia macrophylla*, the plant's tannin content varies depending on its sections. About 11.5 mg of tannins per gram (GAE/g) are present in the seed's methanolic extract. A tannin concentration of 4.0 mg GAE/g is also visible along the middle fruit axis. These results demonstrate that tannins, which are mostly found in the seed and leaf, may be involved in the plant's medicinal properties, such as its antibacterial and antioxidant properties (Durai *et al.*, 2016).

Antimicrobial activity

Tannins inhibit the growth and survival of pathogenic organisms by disrupting the integrity of microbial cell walls and membranes, by producing microbial proteins and by inhibiting microbial enzymes (Borah *et al.*, 2022).

Antioxidant effects

In order to protect cells from oxidative damage and reduce the risk of developing diseases, tannins scavenge free radicals and chelate metal ions which are catalysts for oxidation reactions (Borah *et al.*, 2023).

Sky fruit and metabolic disorder

There are very few studies on impact of sky fruit seeds on metabolic disorders. Existing studies consist of *in vitro* and *in vivo* investigations. Most studies involves the investigation through animal models and very few studies have been conducted on human subjects. These studies summarizes the impact of sky fruit seeds on metabolic disorders.

The *in vitro* mechanism of vasorelaxation and the *in vivo* antihypertensive effects of a 50% ethanolic SM (*Swietenia macrophylla*) seed extract (SM50) and its fingerprint created using tri-step Fourier transform infrared (FTIR) spectroscopy have been investigated in a study by Ch'ng *et al.* (2018). In the presence of antagonists, the vasorelaxant activity of SM50 was assessed on thoracic aortic rings isolated from Sprague-Dawley rats. Three different doses of SM50 (1000, 500 and 250 mg/kg/day) were administered orally to spontaneously hypertensive rats (SHRs) for four weeks in order to examine the therapeutic effect of SM50. The tailcuff method was used to measure the SBP and DBP of the rats once a week. SM50's tri-step FTIR macro-fingerprint revealed that it contains esters, limonoids and flavonoids, all of which may be involved in its vasorelaxant properties. The result

Table 3: Bioactive compounds, health benefits and recommended intake of functional foods.

Functional food category	Bioactive compounds	Health benefits	Common food sources	Recommended intake	References
Fruits	Vitamin C, flavonoids, anthocyanins, polyphenols, fiber, beta-carotene	Boost immune system, antioxidant effects, support digestion, improve gut health	Oranges, lemon, berries, mango, papaya, peaches, plum, apple, pear, watermelon	100-150 g/day	(Dietary Guidelines for Indians Dietary Guidelines for Indians ICMR-National Institute of Nutrition Hyderabad-500 007, Telangana, n.d.)
Group A Vegetables (green leafy, colored and cruciferous vegetables)	Vitamin (A,C,K), folate, iron,calcium, beta-carotene, glucosinolates	Support eye health, boost immunity, reduce cancer risk, anti-inflammatory properties	Spinach, fenugreek, amaranth, carrot, pumpkin, red bell pepper, cabbage, broccoli	100g-200 g/day	(Dietary Guidelines for Indians Dietary Guidelines for Indians ICMR- National Institute of Nutrition Hyderabad-500 007, Telangana, n.d.)
Group B Vegetables (root vegetables and other vegetables)	Fiber, potassium, folate, vitamin C	Improve digestive health, regulate blood pressure	Potatoes, beetroot, cucumbers, tomatoes, zucchini	100-200 g/day	(Dietary Guidelines for Indians Dietary Guidelines for Indians ICMR-National Institute of Nutrition Hyderabad-500 007,Telangana, n.d.)
Probiotics	Lactobacillus, Bifidobacterium	Improve gut microbiota balance, enhance digestion, boost immunity	Yogurt, kefir, kimchi	1-2 servings/ day (100-200 g)	(Prebiotics - International Scientific Association Probiotics and for Prebiotics (ISAPP), n.d.)
Prebiotics	Inulin, Oligofructose	Promote the growth of beneficial gut bacteria, enhance digestion	Garlic, onion, asparagus	4-5g/day of prebiotics	(Prebiotics - International Scientific Association for Probiotics and Prebiotics (ISAPP), n.d.)
Herbs and spices	Curcumin, capsaicin, gingerol	Anti-inflammatory, antioxidant, promote gut health	Turmeric, Ginger, Turmeric, Ginger, xGarlic	10 g/day (eg: Curcumin: ~500-1000mg/day)	(Dietary Guidelines for Indians Dietary Guidelines for Indians ICMR-National Institute of Nutrition Hyderabad-500 007,Telangana, n.d.)
Plant-based Proteins	Isoflavones, phytosterols health, provide	Lower cholesterol, improve gut Chia Seeds day of total protein, satiety	Soy, Legumes, Quinoa,	0.83 g/kg of body weight/ (Eg: 50-60 g/day ~20-30 g from plant proteins)	(Dietary Guidelines for Indians Dietary Guidelines for Indians ICMR-National Institute of Nutrition Hyderabad-500 007, Telangana, n.d.)
Functional dairy products	CLA (Conjugated Linoleic Acid), Probiotics	Support immune function, promote bone health, improve gut microbiota	Fortified Milk, Cheese, Yogurt	2-3 servings/day (~400 ml milk/day or equivalent)	(Dietary Guidelines for Indians Dietary Guidelines for Indians ICMR- National Institute of Nutrition Hyderabad-500 007,Telangana, n.d.)

showed that treatment of SM50 significantly decreased the SBP and DBP SHRS (Ch'ng *et al.*, 2018).

Shiming *et al.* (2021) conducted a study assessing the antihyperglycemic and antioxidant effects of swietenine, both alone and in combination with Metformin, in streptozotocin-induced diabetic rats. The findings of the study indicated that Swietenine, at doses of 20 and 40 mg/kg, significantly reduced serum glucose, cholesterol, triglyceride and LDL levels while increasing HDL levels, demonstrating a dose-dependent effect. In addition, swietenine enhanced kidney and liver functions by lowering elevated levels of urea and creatinine. The combination of swietenine and metformin exhibited a synergic effect, normalizing serum biochemical parameters and improving pancreatic histology by increasing islet size and number (Shiming *et al.*, 2021).

A study conducted by Borah *et al.* (2022) on the bark extract of *Swietenia macrophylla*, sometimes referred to as mahogany, showed a strong antibacterial effect against gram-positive bacteria like *Staphylococcus aureus* and *Bacillus* sp. The study recorded areas of inhibition (AOI) of 181.4 mm² and 113.1 mm² respectively, which indicates the strong antimicrobial activity due to the presence of tannins and other phenolic compounds (Borah *et al.*, 2022).

In 2019, Leaf F. Quinto *et al.* administered oral swietenine (25 and 50 mg/kg body weight) to newborn streptozotocin-induced type 2 diabetic rats, which resulted in a significant reduction in their increased levels of triglycerides and cholesterol. Following five days of swietenine treatment (25 mg/kg body weight), there was a reduction in both the level of triglycerides and cholesterol of 29.12 mg/dL and 17.25 mg/dL, respectively. This decrease rose to 24.35 mg/dL and 31.58 mg/dL for 50 mg/kg of swietenine, respectively (Leah F. Quinto *et al.*, 2019).

Utilization of sky fruit seeds in functional foods and nutraceutical

Functional foods are nutrient-dense foods that offer health advantages beyond basic nutrition, supporting general health and preventing or treating illnesses. These foods are rich in bioactive substances that support body functioning and lower the risk of chronic diseases like cancer, diabetes and heart disease. These include antioxidants, vitamins, minerals, fiber and probiotics (as shown in Table 3). In addition to being fortified, such as calcium-enriched orange juice for bone health, functional foods can also be found naturally, such as oats with heart-healthy beta-glucan fiber. Berries are high in antioxidants that strengthen the brain, while yogurt has probiotics that improve immunity and aid in digestion (de Castro and Castillo-Peinado, 2016; Pal *et al.*, 2024).

Sky fruit seeds or Mahogany seeds, derived from the mahogany tree (*Swietenia* genus), have gained attention in recent years for their potential utilization in functional foods and nutraceutical due to their rich nutritional profile and bioactive compounds including as antioxidants, anti-inflammatory agents and substances with hypoglycemic

qualities, have made it a promising nutraceutical agent. It is frequently used as a nutraceutical to help control long-term conditions like diabetes, high cholesterol and heart disease. Significant amounts of limonoids, especially swietenine and swietenolide, which have been shown to have the ability to reduce blood sugar and enhance insulin sensitivity, are present in the seeds. The current trends and future prospects for the use of sky fruit seeds as a form of functional foods are as follows.

Current trends

The utilization of natural ingredients, such as sky fruit seeds, in functional food and nutraceuticals has been increased over the last few years. Sky fruit seeds are rich source of various nutrients, including proteins, dietary fiber, fats vitamins and minerals. In addition, these seeds consists of bioactive compounds, such as flavonoids, phenolic acids, saponins, alkaloids, etc., which work through various mechanisms to help in maintaining health and avoiding a range of disorders (Kamaraj *et al.*, 2021). One of the current trends in utilizing sky fruit seeds in the extraction method *i.e.* extraction of sky fruit seed oil. Sky fruit seeds oil is rich in unsaturated fatty acids, particularly oleic acid and linoleic acid, which are beneficial for cardiovascular health and have a potential for application in functional foods as a healthy cooking oil or as an ingredient in lipid-based formulations (Mursiti *et al.*, 2019). Another trend is the incorporation of sky fruit seed powder or extract into various food products to enhance their nutritional value. Sky fruit seeds can be ground into a fine powder and added to beverages, snacks, baked goods and supplements to boost their protein and fiber content. In addition, the phytochemical compounds present in sky fruit seeds can also provide health benefits.

Future prospects

The utilization of sky fruit seeds in functional foods and nutraceuticals is expected for the further growth and innovation in the future. One area of potential research is the development of new food formulations and product applications deriving from sky fruit seed ingredients is a potential area for research. Researchers can explore different processing techniques to optimize the bioavailability of bioactive compounds and nutrients in sky fruit seeds, thus maximizing their health promoting properties. In addition, there is a potential for exploring the synergic effects of combining sky fruit seeds with other natural ingredients or functional compounds for the development of multifunctional food product with enhanced health benefits. For example, the development of symbiotic products promoting gut health could result from the combination of sky fruit seed extract with probiotics or prebiotics. Finally, the potential for innovation and development of products is presented when sky fruit seeds are used to make functional foods or nutraceuticals. Food scientists and manufacturers can develop a wide range of value-added products to meet the increasing demand for healthy and nutritious food options, making use of sky fruit seeds' nutrition and its bioactive properties.

CONCLUSION

In conclusion, sky fruit seeds (*Swietenia macrophylla*) hold a significant potential as a natural source of bioactive compounds with a variety of therapeutic properties. The extensive phytochemical composition of these seeds, including phenolic acids, flavonoids, saponins, alkaloids, terpenoids and tannins highlights their potential to combat oxidative stress, inflammation, hyperglycemia and other metabolic disorders. In addition to offering a holistic approach to disease prevention and management, the antidiabetic, antioxidant, anti-inflammatory and antimicrobial activities of these phytochemicals are well aligned with the growing consumer demand for the natural and functional health products. The integration of sky fruit seeds into nutraceuticals and functional foods provides a novel and effective strategy for enhancing nutritional profiles and delivering therapeutic benefits in convenient and consumable forms. The potential applications are vast and varied, from fortified drinks to baked goods or dietary supplements as well as health bars. In order to sustainable health claims and regulatory approvals, future research and development should focus on optimizing extraction methods, ensuring standardization and quality control and conducting rigorous clinical studies. Overall, sky fruit seeds are considered to be an excellent addition to the arsenal of nature's ingredient that seek to improve people's health and well-being in terms of their therapeutic potential.

ACKNOWLEDGEMENT

We would like to acknowledge Department of Nutrition and Dietetics, SAHS, Manav Rachna International Institute of Research and Studies for their unwavering support and guidance throughout the development of this review paper.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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