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SACRED LOTUS: A COMPREHENSIVE REVIEW OF ITS FUNCTIONAL USES

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ABSTRACT

The sacred lotus (*Nelumbo nucifera* Gaertn.), India's national flower, symbolizes purity, beauty, wisdom and immortality. The lotus, a perennial rhizomatous aquatic plant renowned for its large floating leaves and vibrant flowers, is distributed globally and cultivated for over 3,000 years. It holds a prominent position in history and cultural traditions, particularly in Hinduism and Buddhism. The sacred lotus is more than just a symbol, it offers wide range of ecological, economic, and nutraceutical benefits. Almost all parts of the lotus have both edible and medicinal uses, highlighting its deep cultural and religious significance. Beyond its nutritional and medicinal benefits, the lotus plant's stem produces fine fibers known as "Lotus Silk," which creates eco-friendly fabrics with antibacterial, self-cleaning, and super-hydrophobic qualities. These characteristics collectively emphasize the lotus's diverse contributions to horticulture and its sustainable use contributes significantly to human welfare through its harmonious relationship with nature. This review explores the functional uses of lotus plant, emphasizing its role in promoting environmental sustainability, cultural heritage, horticultural significance and innovative applications in various industries.

***Keywords* :** Sacred lotus, Diversity, Commercial uses, Cultivation practices

Introduction

The Sacred lotus, *Nelumbo nucifera* Gaertn. holds the esteemed status of being India's national flower and is well-known as a stunning addition to aquatic gardens. The lotus, deeply ingrained in Indian cultural traditions, has been revered for millennia. Originating 135 million years ago in Northern Hemisphere, its cultivation in the Far East spans over 5,000 years. Beyond its culinary and medicinal uses, the lotus holds immense spiritual significance, especially in Buddhism where it symbolizes purity and enlightenment. In Sanskrit, it's known by various names like Padma, Kamal, and Pankaja, each carrying profound meaning. Padma evokes the lotus's diurnal bloom and fragrant offering to the rising sun. Kamal signifies its life-giving presence in water bodies. And Pankaja, meaning "born in mud," symbolizes the lotus's ability to rise above adversity, emerging pristine and beautiful.

Diversity, distribution and botanical marvels of the sacred lotus

Lotus is a perennial aquatic plant belonging to the family Nelumbonaceae. The genus Nelumbo is commonly found in tropical and subtropical regions of Asia, with two species *viz.*, *Nelumbo nucifera* (Asiatic lotus) and *Nelumbo lutea* (American lotus). The Asian lotus, typically referred to simply as lotus or sacred lotus, is predominantly found in the old world *i.e.* subtropical and tropical regions of Southern Asia and distribution ranging through Philippines, Indonesia, Myanmar, Korea, Japan, China, Taiwan, India, Thailand, Srilanka and Austarlia . In contrast, the American lotus is native to the new world *i.e.* North and South America (Misra and Misra, 2017). Due to the vast expanse of the Pacific Ocean between them, these two species exhibit distinct differences in their external features, including petal color and shape, leaf morphology, and overall plant size (Shen-Miller, 2002). The Asian lotus is characterized by its large bluish-green leaves with frilled edges, adorned with a prickly stem, and its fragrant pink or white flowers. American lotus features round, bluish-green leaves and delicate sulphur yellow flower with dark yellow stamen (Brickell, 2001). Hybridization between these two species has led to the creation of novel hybrids, thereby enriching the lotus germplasm worldwide. To date, approximately 4,500 lotus cultivars have been documented globally (Liu *et al.,* 2019).

In India, sacred lotus occurs throughout the country exhibiting enormous morphological and genetic diversity with a large number of variants in different shapes, sizes and shades of pink and white, suitable for various commercial and landscape uses. Cultivated lotus is typically classified into three categories based on usage *viz.,* rhizome lotus, seed lotus, and flower lotus (Guo, 2009). Moreover, flower lotuses are again classified on the basis of number of petals per flower, which are categorized ranging from those without petals to those with various petal counts such as less than or equal to 20, more than 51, and between 21 to 50 petals. The maximum number of petals in *Nelumbo nucifera,* ranging from 116 to 160, was recorded in a pink double-flowered variety collected from Midnapur (West Bengal), described as *N. nucifera* 'Krishna'. Another exceptionally beautiful cultivar, 'Kamal Krishna', is notable for cut flowers, with a vase life of 4-5 days (CSIR-NBRI). 'Namoh 108' is a new lotus variety with 108 petals from CSIR-NBRI Lucknow. This improved lotus is hardier, blooms longer, and is the first of its kind to have its entire genetic makeup mapped. Originally from Manipur, it was further developed by scientists at CSIR-NBRI.

Some flower lotus cultivars, like Qianban, exhibits unique characteristics where carpels, stamen, pistil, and receptacle transform completely into petals. *Nelumbo nucifera* 'Zhizun Qianban' is notable cultivar from southern China and registered by the International Waterlily and Water Garden Society in 2010. It is a large-sized lotus with a double pink flower composed of up to 1650 petals (Tian, 2011). The flower lotus classification criterion again pertains to the variety of petal colors, flower diameter, plant height, and shape of both seeds and fruit. Flower colour is varies to red, white with a red edge, plain white, and white petals with a base in green and red at the top. Seed shapes range from ellipse to olivary to intermediate, while fruit shapes include reverse-coniform, bowl-shaped, umbrella-like, and trumpet-shaped. Guo H.B. (2009). Qichao *et al.* (1997) and Qichao and Zhang (1998) proposed similar classification systems that encompass these attributes.

Unique properties of lotus

Biologically, lotus possess common aquatic plant features. Besides this, it also have certain unique properties including prolonged seed longevity, leaf ultra-hydrophobicity and floral thermoregulation that distinguish it from other plant species. In addition to these distinct properties, lotus contributes to ecological significance through its phyto-remediation capabilities.

(a) Prolonged seed longevity: Lotus seeds, particularly sacred lotus are famous for their remarkable longevity and ability to remain viable for centuries. Studies have documented instances of lotus seeds germinating after being dormant for over a thousand years, illustrating their extraordinary capability for prolonged viability. This enduring vitality makes lotus seeds a subject of great interest in seed research, making lotus an outstanding genetic model for studying seed biology. This exceptional seed longevity is attributed to the unique structural and biochemical characteristics of the seeds, including a robust seed coat that protects the embryo from physical damage and microbial invasion, and the presence high levels of antioxidants that mitigate oxidative stress. The pericarp of seed tissue and the presence of heat-stable proteins with protective functions play a crucial role in ensuring this exceptional seed viability over centuries (Shen-Miller *et al.,* 2013). Shen-Miller *et al.* (2013) demonstrated the viability of lotus seeds var. China Antique up to 1,300 years and established by direct radiocarbon dating, with a germination rate of 84% from northeastern China.

In modern molecular research on seed longevity, Chen *et al.* (2016) identified and characterized the NnPER1 protein, a seed-specific protein from sacred lotus. NnPER1 protects DNA from ROS-induced cleavage, with its transcription and protein levels rising during seed desiccation, imbibition, and abiotic stress. Ectopic expression of NnPER1 in Arabidopsis enhanced seed germination after controlled deterioration treatment (CDT), indicating its role in improving seed longevity in transgenic plants. He *et al.* (2023) conducted a proteomic analysis on lotus plumule using controlled deterioration treatment (CDT). They quantified 4002 proteins, identifying 558 as differentially accumulated proteins (DAPs) crucial for maintaining seed vigor under CDT conditions. Specific proteins related to CDT resistance were found, with significant up-regulation in proteins involved in anti-oxidation, photosynthesis, RNA and DNA stability, starch and sucrose mobilization, and cell membrane and wall stability.

(b) Ultra-hydrophobicity : The leaf of *Nelumbo nucifera* have become an icon for superhydrophobicity, displays a quite remarkable water repellency by creating wider contact angle with water droplets which lead to the concept of 'lotus effect'. The reasons for these superior properties can be attributed to the hierarchical surface structure. Although many plant species having superhydrophobic surfaces with almost similar contact angles, the lotus shows better stability and perfection of its water repellency. It is because of the combination of optimized surface characteristics, robustness, and chemical composition of the epicuticular waxes. The morphology of the wax papillae, such as small tip radius, reduces the contact area to water droplets and robustness of the papillae ensures protection of wax crystals. The unique chemical composition of the epicuticular wax with the high content of nonacosanediols leads to dense coating of agglomerated wax tubules, creating a permanently hydrophobic surface (Ensikat *et al.,* 2011)**.** Yang *et al.* (2018) discovered two genes, NnCER2 and NnCER2-LIKE, in *Nelumbo nucifera* that are essential for the elongation of very-long-chain fatty acids, providing new insights into the specific roles of CER2 proteins in synthesizing fatty acyl-CoA precursors for cuticular wax production. Overexpression of these genes in Arabidopsis resulted in changes to the cuticle wax structure in inflorescence stems, with an increase in wax compounds of 30, 32, and 34 carbon lengths and their derivatives.

(c) Floral thermogenesis: Floral thermogenesis, particularly in the lotus flower (*Nelumbo nucifera*), is a fascinating area of plant physiology that involves unique metabolic pathways. Seymour and Schultze-Motel (1997) explored the phenomenon of floral thermogenesis in sacred lotus (*Nelumbo nucifera*) and gave a first scientific report on its physiological mechanisms and ecological advantages. During anthesis, lotus flowers can regulate floral temperature through metabolic heat production which helps to maintain stable internal temperature between 30 and 36 °C, even when external temperatures varies from 10 to 45 °C. The flowers generate heat using an alternative respiratory pathway involving the alternative oxidase (AOX) enzyme, which produces heat instead of ATP. Heat production independently occur in receptacle, stamens and petals (Seymour and Schultze-Motel, 1997; Grant *et al.,* 2010). This process is critical for maintaining elevated floral temperatures. The heat production plays a vital role in attracting pollinators, especially in cooler climates. Warm flowers can volatilize scents more effectively, drawing in pollinators such as endothermic beetles and bees, which prefer the warm microenvironment created by the thermogenic flowers.

To gain a deeper understanding of floral thermogenesis, numerous studies have explored various aspects, including mitochondrial dynamics, protein expressions, and physiological mechanisms that enable lotus flowers to regulate their temperature. During thermogenesis, mitochondrial biogenesis increases significantly in flowers. The mitochondria exhibit notable morphological changes, including long elliptical, rod-shaped, and dumbbell-shaped forms. Additionally, there is an increase in mitochondrial reactive oxygen species (ROS) levels in thermogenic (TM) cells. This process is accompanied by a higher expression of the alternative oxidase (AOX) enzyme, which plays a crucial role in heat production during thermogenesis. These changes facilitate efficient heat generation, enabling the lotus flowers to maintain stable temperatures for reproductive success (Li *et al.,* 2022).

Commercial uses of sacred lotus

Lotus plants are highly versatile, deeply revered culturally for their symbolic significance representing purity and spiritual growth, utilized in culinary dishes for their seeds, stems, and petals, in traditional medicine and in textiles for their durable fibers, while also being admired aesthetically in gardens and landscapes for their beauty and tranquility (Plate .1). Cultivated lotus is categorized based on its uses into rhizome lotus, seed lotus, and flower lotus, as described by Guo (2009). Rhizome and seed lotus varieties are mainly cultivated for their edible parts, whereas flower lotus varieties are primarily grown for ornamental purposes and phytoremediation.

Landscape design and aesthetic uses of lotus plants

Lotus flowers are notable for their large, showy blooms and lush green foliage and bring a sense of tranquility and natural beauty to any aquatic environment. In flower industry, apart from garlanding or worship, lotus flower buds and fully bloomed flowers are used in floral arrangements. Lotus dried seed pods are widely seen in dry flower decorations. Waterscaping with lotus also offers a unique opportunity to enhance outdoor spaces with their beauty and cultural significance, providing both aesthetic enjoyment and ecological benefits. Their ability to thrive in diverse climates and water conditions makes them good choices for both large-scale waterscaping projects and urban container gardens. Akhila, Pink Cloud, Ameri Camellia, Bucha, Green Apple, Amiri Peony, Ultimate Thousand Petal Lotus, and various hybrids have become aesthetic choices among gardeners of Kerala. Nurseries now offer a diverse selection of over hundreds of vibrant hybrids. Additionally, the emergence of miniature and micro lotus varieties capable of thriving in partial sunlight has spurred a growing trend in indoor gardening. These tiny lotus types, such as Liangli, Little Rain, and Almond Sunshine, are cultivated in small pots, ranging from small ice cream bowls to large teacups. Mondal *et al.* (2024) conducted an evaluation of six lotus varieties including Yellow Peony, Pastel Pink, Bucha, Rani Red, White Buddha, and Pink Cloud under the agro-climatic conditions of Prayagraj, Uttar Pradesh. The study found that Bucha excelled in both vegetative and floral parameters, demonstrating superior performance in various growth and economic aspects. This makes Bucha a highly promising variety for promotion and adoption by lotus growers in the region. The lotus hybrids 'Amiry Camelia', 'Amiry Peony', 'Almond Sunshine', 'White Peony', and 'Yellow Peony' demonstrated superior vegetative and floral characteristics. These hybrids are highly recommended for container aquatic gardening in landscaping and are well-suited for the conditions in Tamil Nadu (Gokul *et al.,* 2022).

(a) Nutritional profile and culinary uses of lotus

Sacred lotus is valued in Asian countries for its versatile culinary applications. Its seeds are a popular ingredient, enjoyed roasted, boiled, or ground into flour for both sweet treats and savory dishes. Indrayan *et al.* (2005) provided the nutritional composition of lotus seeds, indicating approximately 10.50% moisture, 4.50% ash, 72.17% carbohydrates, 10.60% protein, 0.1g fat, 2.70% crude fiber, and an energy content of 348.45 calories per 100 grams. Jirukkakul *et al.* (2019) investigated the physicochemical properties and potential of lotus seed flour as a substitute for wheat flour in noodles. They reported that incorporating 5% pre-gelatinized lotus seed flour in the noodle recipe lowered the fat content and improved the levels of fiber, ash, and phenolic compounds in the noodles.

Lotus rhizomes are sliced and incorporated into soups, stir-fries, and salads, offering a crunchy texture and mild flavor. Sruthi *et al.* (2019) analyzed the proximate composition of lotus rhizome and reported the following composition per 100 grams: 72.14% moisture, 10.05 grams of starch, 16.03 grams of carbohydrates, 2.6 grams of protein, 0.1 grams of fat, 3.2 grams of fiber, 38 mg of vitamin C, 40 mg of calcium, 1.07 mg of iron, 58 mg of phosphorus, and 450 mg of potassium. According to Sruthi *et al.* (2022), cookies containing lotus rhizome flour exhibit a lower glycemic index and reduced total fat content. This suggests that rhizomes of lotus can be effectively utilized in the biscuit industry. Saeed *et al.* (2020) also indicated that lotus rhizome flour has potential as a fat mimetic in biscuits, with benefits for enhancing antioxidant properties, physical characteristics, nutritional value, and sensory appeal.

Lotus leaves are utilized fresh as natural wrappers for steamed or baked foods, infusing dishes with a delicate herbal scent. Furthermore, dried lotus leaves are brewed into tea known for its digestive and detoxifying properties. Overall, sacred lotus enriches Asian cuisine with distinct flavors, textures, and nutritional benefits across a variety of culinary preparations. In Thailand, lotus flower petals are delicately used in salads for their subtle floral flavor and refreshing touch (Tuladhar, 2021).

(b) Bioactive constituents of lotus: Potential therapeutic applications

Lotus has a rich history in traditional medicine across various cultures, particularly in Asia. Modern scientific research continues to validate many of its traditional uses, revealing a wide range of pharmacological activities that support its therapeutic potential. As a result, *Nelumbo nucifera* remains an important plant in both traditional and contemporary medical practices. Recent research has extensively explored the various bioactive phytocompounds present in different parts of *Nelumbo nucifera* (Table.1). In the past few decades, intense scientific inquiry has focused on *Nelumbo nucifera* and its phytochemicals, particularly in the context of cancer research. Liensinine and nuciferine, primary active components found lotus, have demonstrated potential in inhibiting breast cancer cell-induced bone degradation, with liensinine exhibiting stronger anti-cancer and anti-bone resorption effects compared to nuciferine (Kang, *et al.,* 2017). Zhao *et al.* (2017) demonstrated that the ethanol crude extract from *Nelumbo nucifera* stamen (BLSEE) had significant suppression of proliferation in human colon carcinoma HCT-116 cells, highlighting its potential as a therapeutic candidate for colon cancer treatment. Neferine and isoliensinine derived from lotus have demonstrated efficacy as natural medicinal agents in targeting colorectal cancer cells (CRCs), underscoring their potential as potent anti-cancer agents against colon cancer (Manogaran *et al.,* 2019). All these findings advocate for further exploration of phytochemical constituents present in lotus and its therapeutic applications in oncology.

(c) Lotus-based ingredients in natural cosmetics

Lotus-based ingredients are becoming increasingly popular in natural cosmetics due to their beneficial properties for skin and hair care. Lotus alkaloids, encompassing aporphines, 1-benzylisoquinolines, and bisbenzylisoquinolines, offer versatile applications as ingredients in food, pharmaceuticals, and cosmetics (Wang, *et al*., 2023). A liquid chromatography-mass spectrometry (LC-MS) method was developed by Morikawa *et al.* (2016) to quantify the five aporphine (Nuciferine, Nornuciferine, N-methylasimilobine, Asimilobine and Pronuciferine) and five benzylisoquinoline alkaloids (Armepavine, Norarmepavine, N-methylcoclaurine, Coclaurine, and Norjuziphine) and its distributions in each flower parts, correlating with melanogenesis inhibition. These alkaloids, identified in different flower parts, correlate with melanogenesis inhibition, which has potential applications in developing skin-whitening and hyperpigmentation treatments in the drug industry.

This alkaloids also hold promise as ingredients in tea, other beverages, and healthcare products and can be incorporated into formulations such as facial masks, toothpastes, and shower gels, highlighting their versatile applications across food, pharmaceuticals, and cosmetics industries (Wang *et al*., 2023). Lotus flower extract and lotus seed extract, are known for their antioxidant, anti-inflammatory, and hydrating effects. These ingredients are often included in skincare products like moisturizers, serums, and masks to promote skin radiance, improve skin texture, and protect against environmental stressors. In hair care, lotus extracts are valued for their nourishing properties that help strengthen hair follicles and enhance hair vitality. Overall, lotus-based ingredients are celebrated in natural cosmetics for their holistic approach to beauty and wellness.

(d) Innovative uses of lotus fiber in fashion and textiles

Lotus fiber represents an innovative and sustainable approach in fashion and textiles. Derived from the stem of the lotus plant, is a natural fiber distinguished for its unique properties and eco-friendly production process. The production of lotus fiber involves a meticulous hand-harvesting process, where artisans carefully extract and weave the fine fibers and this sustainable method ensures minimal environmental impact, as it requires no chemicals or machinery. Research indicates that lotus fiber is among the finest natural fibers, with a delicate texture of 0.22 tex and a helical structure that ensures high quality. Chemical analysis reveals that lotus fiber contains cellulose and shares characteristics with cotton fibers, highlighting its remarkable potential (Pandey *et al.,* 2020). Lotus fibers were effectively dyed using chemical reactive dyes, indigo dyes, and natural Henna dyes. The superior color strength and color properties of lotus fibers, when compared to cotton fibers, are primarily attributed to their high moisture absorption and low crystallinity. Additionally, lotus fibers demonstrated greater elongation at break, making them more flexible and elastic than cotton fibers (Almas *et al.,* 2024).

In India, lotus silk production is mainly concentrated in the northeastern region, particularly in Assam and Manipur. In fashion, lotus fiber is increasingly used in high-end garments, including dresses, scarves, and shirts, due to its natural sheen and smooth drape. It offers excellent moisture-wicking properties, making it ideal for warm climates. Additionally, lotus fiber is hypoallergenic and possesses natural antibacterial qualities, enhancing its appeal in textiles. Overall, the innovative use of lotus fiber not only promotes sustainable fashion practices but also showcases the versatility and luxury of natural materials in the textile industry.

Cultivation practices of scared lotus

The lotus is mainly propagated through the division of rhizomes and seeds. Rhizomes with new sprouts are cut into small pieces, each containing at least three nodes. Three noded rhizome along with tip portion is the best propagule in lotus (Minimol, 2004). Seeds are scarified at both ends to encourage early germination. Mechanical scarification followed by leaching in water for 12-48 hours was found to be effective for enhanced lotus seeds germination (Minimol, 2004). Lotus are typically grown in damp soil, usually a combination of loam and clay. The plants require at least six hours of sunlight daily and should be sparingly fertilized during the first year. It is crucial to protect the lotus roots from freezing. Approximately 35,000 to 40,000 rhizomes are needed to plant one hectare of land (NBRI, Lucknow).

Conclusion

Sacred lotus (*Nelumbo nucifera*) renowned for its natural beauty and varied traits, has a rich historical significance and is cherished globally. Due to its versatile horticultural and medicinal applications, this divine beauty has recently drawn significant attention from the scientific community, positioning the lotus as a prominent focus of research. Exploring and utilizing the vast global lotus germplasm presents new opportunities for advancing crop improvement strategies and developing diverse lotus-based industries. Therefore, it is essential to focus on the conservation and effective management of the lotus, which holds significant potential for enhancing our country's economy. The lotus is emerging as a prominent choice among horticultural crops and offers valuable insights for studying unique plant characteristics.

Table 1: Pharmacological actions and clinical studies of phytochemical constituents in *Nelumbo nucifera*

Pharmacological Properties	Phytochemical constituents	Plant extracts	Clinical studies	Reference
Anti-cancerous	Neferine	$CHCl_3$ extract of the seed embryos	anti-colon cancer	Chaichompoo *et al.* (2018)
	Benzylisoquinoline alkaloids (lirinidine)	Ethanolic extract of *Nelumbo nucifera* petals	HeLa human cervical cancer	Maneenet, *et al.* (2021)
Anti-obesity	quercetin-3-*O*-*ß*-glucuronide	Leaf extract	Diabetes mellitus TYPE II	Liu *et al.* (2021)
Anti-Alzheimer and Antioxidant effects	Nuciferine and Norcoclaurine	Methanolic crude extracts of Nuciferine and Norcoclaurine	diabetes, Alzheimer's disease	Khan *et al.* (2022)
Anti-diabetic Activity	Saponnins, tannins, flavonoids	leaf extract	Diabetes mellitus	Maqbool, *et al.* (2021)
Antioxidant Effects	Phenolics and aporphine alkaloids	aqueous extract of the stamen	Alzheimer's disease	Temviriyanukul, *et al.* (2020)
Neuroprotective, anti-inflammatory, and antioxidant properties	Phenolics, Saponnins, tannins, flavonoids	Ethanolic extract of rhizome powder	Parkinson	Ansari *et al.* (2022)
Thrombolytic, anti-platelet aggregation activity	Flavanoids(chlorogenic, quercetin, benzoic acid, caffeic acid, ferulic acid, kaempferol, and gallic acid	Hydro alcoholic extracts of whole lotus plant	Thrombolysis	Sharma *et al.* (2019)

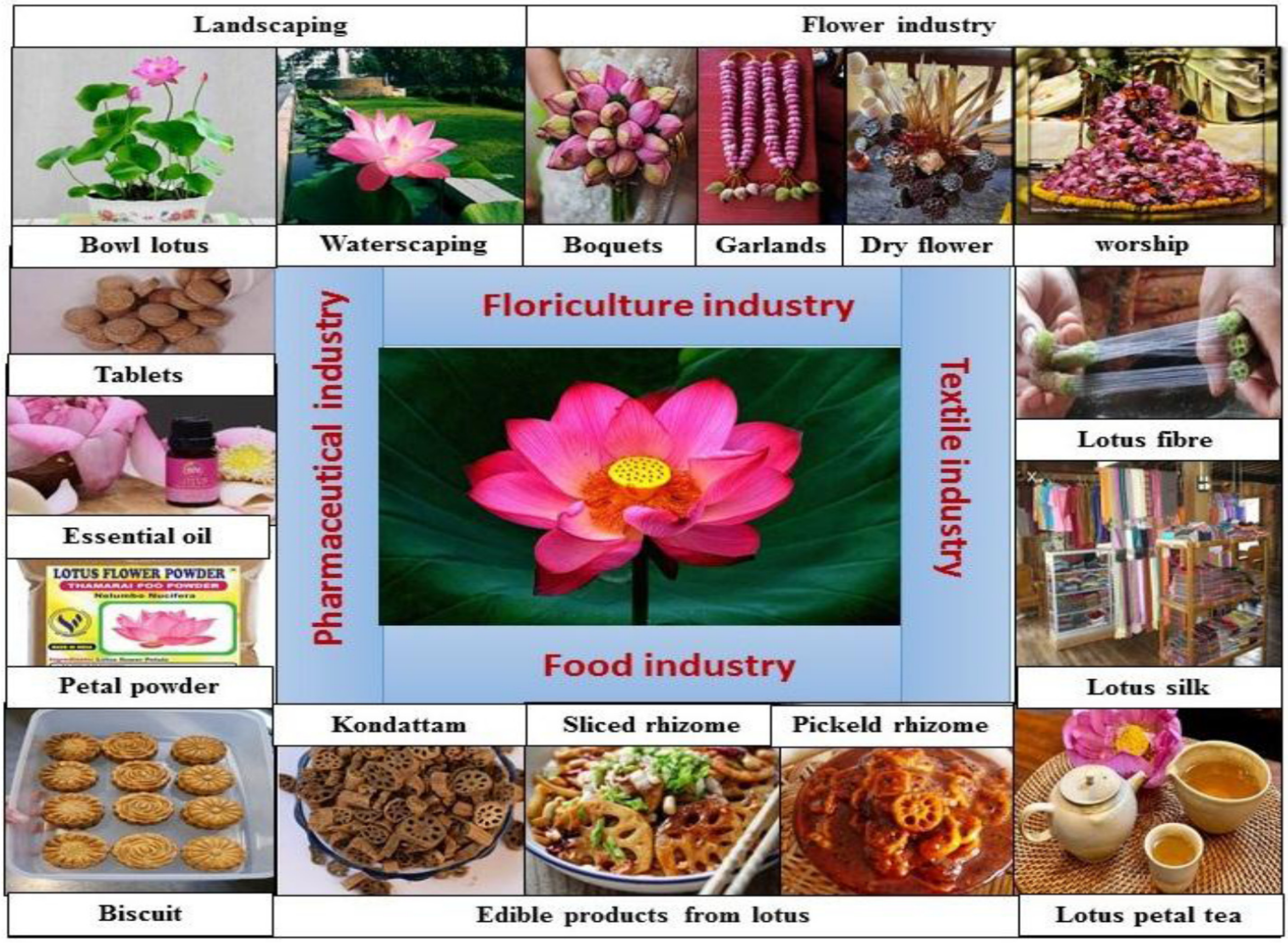

Plate 1: Commercial uses of sacred lotus in various industries

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