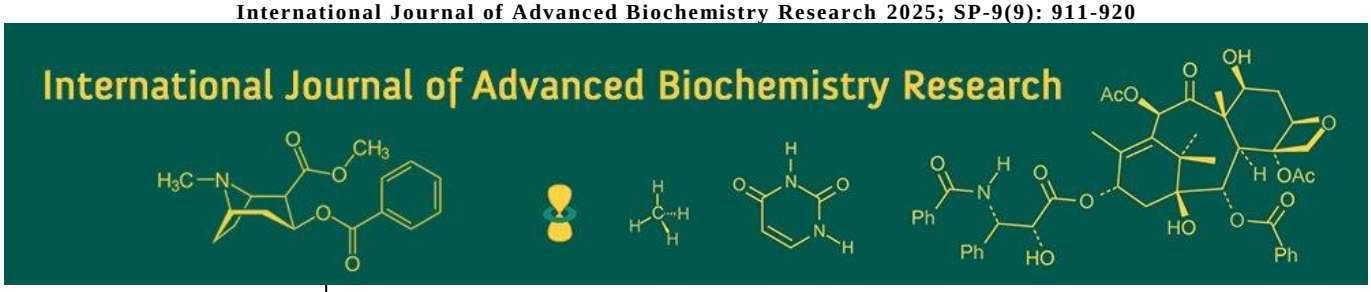

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The multifaceted Lotus: A review of its cultural, nutritional and medicinal significance with vast research potential

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Abstract
Nelumbo nucifera, one of the most ancient, perennial aquatic plant having versatile potential is drawing lot of attention in recent times for its ecological, nutritional, medicinal and cultural significance. Rich diversity of cultivars manifests its application in ornamental, vegetable, nutritional and medicinal sectors. The incredible features of lotus such as viability of the seed for long periods, ultra-hydrophobic nature of leaf also known as "lotus effect" and flower thermoregulation underscored its potentiality for scientific research. The increasing interests from scientific community has led to many cultivars with deep water tolerance, shade tolerant bowl lotus, thousand petalled types and cultivars with novel colours. The nutritional significance of its rhizomes and seeds in the food industry widened the scope for lotus cultivation in large scale. Rhizomes of *Nelumbo nucifera* are rich in starch (31.2%) characterized by a neutral taste and odour and their texture closely resembles that of raw potato. Comparative evaluations of the adhesive and disintegration characteristics of *Nelumbo*-derived starch against conventional starch sources such as maize and potato have demonstrated its superior efficacy as an excipient in tablet formulations. Furthermore, owing to the presence of nuciferine, neferine, and a spectrum of benzylisoquinoline alkaloids with pharmacological relevance, virtually all parts of the lotus plant have been traditionally and contemporarily employed in the management of conditions ranging from minor ailments to chronic diseases. Ecologically it is valued as good bio indicator of heavy metals and efficient aquatic species for waste water treatment. This comprehensive review with latest advancement of studies on lotus envisaged its versatile significances, breeding approaches, diversity in cultivars, cultivation aspects and preservation strategies.

Keywords: Lotus, species and cultivars, unique features, cultural, nutritional and medicinal significance, cultivation aspects

Introduction
Lotus (Nelumbo nucifera), recognized as the national flower of India, is a perennial aquatic plant thriving in freshwater habitats and belongs to the small family Nelumbonaceae. This family comprises a single genus, Nelumbo, which includes two species: Nelumbo nucifera Gaertn., widely known as the Asian lotus, which holds deep cultural, spiritual, and medicinal significance in Asia; and Nelumbo lutea Pers., commonly referred to as the American lotus, indigenous to North America. This remarkable aquatic flowering plant has been cultivated for millennia and is regarded as one of the oldest extant plant species on Earth (La-ongsri *et al*., 2009) [32]. The lotus (Nelumbo nucifera) is identified by various vernacular and common names across different cultures, such as Chinese arrowroot, lotus bean, sacred Indian lotus, Asian lotus, lily of the Nile, oriental lotus, bean of India, and sacred water lily. In India, it is known by several names, including Ambal, Thamarai, Padma, Ambuja, Pankaja, and Kamal, each carrying its own distinct meaning.

History
The genus Nelumbo is derived from the Sinhalese term "Nelum" meaning "blue," was classified into its own family, Nelumbonaceae, by Dumortier in 1829 [15]. Although it was traditionally considered part of the Nymphaeaceae family, it is now widely recognized as a separate monotypic family. This classification is supported by various studies, including those on morphology, anatomy, cytology, palynology, embryology, chemotaxonomy, molecular biology, and floral development (Li, 1955 [36]; Hu *et al*., 2003; Tian and Zhou, 2006) [76].

The name Nelumbo is linked to a location in Sri Lanka, south of India, which has led to the belief that India is the origin of Nelumbo nucifera. However, archaeological findings in China and Japan have revealed lotus seeds that are over a thousand years old, with some of which have remarkably retained ability to germinate (Shen-Miller *et al*., 1995) [66]. As a result, Japanese researchers consider China to be the lotus's place of origin. While the species is found from tropical East Africa to northeastern Australia, it is most extensively used in Southeast Asia.

Origin and Distribution

The Asian lotus, known scientifically as Nelumbo nucifera, is thought to have first appeared in eastern India before making its way to China and Egypt thousands of years ago. From China, it further expanded to other regions of Asia and northern Australia. Today, it is widely grown as a valuable crop in numerous Asian nations, such as China, Japan, India, Korea, Nepal, Thailand, Vietnam, Sri Lanka, the Philippines, and Indonesia. It was introduced early on to various tropical and subtropical areas and played a crucial role in ancient Egypt and other eastern Mediterranean cultures. In contrast to Nelumbo nucifera, which is native to Asia, the second species, Nelumbo lutea, or the American lotus, is found naturally in the eastern and central parts of North America. The American lotus is also present in southeastern Ontario, Canada, the West Indian Islands, and Brazil in South America, where it has native populations.

Species and Cultivars

Genetically, both Nelumbo nucifera Gaertn. and Nelumbo lutea Pear. are diploid species, each with a chromosome count of 2n = 16. Despite this genetic similarity, they display notable morphological differences in characteristics such as petal color and shape, leaf structure, and plant height (Shen-Miller, 2000) [65]. When these two species are crossbred, the resulting F1 offspring are entirely sterile. Although the Nelumbo genus consists of only two recognized species, there is a vast array of germplasm maintained worldwide, especially in Asia, showcasing significant genetic diversity and phenotypic variation. Huang *et al*. (1992) [23] were the pioneers in classifying Nelumbo lutea as a subspecies, specifically N. nucifera ssp. lutea, a classification later supported by molecular analysis of the rbcL gene (Les *et al*., 1991) [35] and further validated by other research (Borsch and Barthlott, 1994 [8]; Hayes *et al*., 2001 [19]; Hu *et al*., 2003) [22]. Recently, more researchers have embraced the classification of the genus into a single species with two subspecies: N. nucifera ssp. lutea (Willd.) Pers. and N. nucifera ssp. nucifera. The former, often known as American lotus, yellow lotus, water chinquapin, yonkapin, or yanquanpin, is found throughout eastern North America and extends south to Colombia. Conversely, N. nucifera ssp. nucifera is prevalent across Asia and Oceania, from Russia to Australia. Given the widespread distribution of wild N. nucifera and its diverse cultivars in China, the country is regarded as a natural distribution center for N. nucifera (Wang and Zhang, 2004) [75].

Globally a total of about 1500 cultivars of different types of lotuses are known at present. In China alone, more than 800 cultivars of lotus have been documented (Wang and Zhang, 2004 [75]; Qiu, 2005) [59], of which 120-200 are of rhizome-lotus cultivars (Ke *et al*., 2000) [27] and over 22 seed-lotus varieties (Zheng, 2004) [92]. In accordance with the database of the Lotus Society of Japan (2008), a total of 989 cultivars were reported in Japan, comprising 655 native Japanese cultivars and from China 328 cultivars were introduced.

In India nearly 60 cultivars of lotus were reported and were distributed throughout the country exhibiting wide morphological and genetic diversity with a large number of racial differences in shapes, sizes and shades of white and pink flowers having 16-160 petals. In India, the maximum petal number, ranging from 116 to 160, has been observed in a pink double-flowered race collected from a town Midnapur, West Bengal, which has been designated as *N. nucifera* 'Krishna'. Another excellent cultivar, *N. nucifera* 'Kamal Krishna', having commercial potential as cut flower is especially prized in the floriculture industry for its elegant beauty and suitability as a cut flower, with a vase life of 4-5 days. CSIR-National Botanical Research Institute (CSIR-NBRI), Lucknow has developed a lotus variety 'Namoh 108' having exceptional resilience to varying weather conditions with prolonged flowering period and to ensure its longevity and protection from potential extinction, its entire genome was sequenced.

Classification of Lotus cultivars

China is considered as one of the main centres of lotus cultivation and breeding, with a history extended over thousands of years of its cultivation (Wang and Zhang, 2005) [75]. Based on its agricultural usages and distinct morphological features, *N. nucifera* ssp. *nucifera* is generally categorized into three groups: rhizome lotus, seed lotus and flower lotus. Lotus rhizomes and seeds serve a dual purpose, used both as edible vegetables and as propagative materials, while flower lotus is solely cultivated for ornamental use and environmental enhancement. Although few cultivars may exhibit more than one agriculturally valuable character, but are typically classified according to their predominant characteristic seed lotus, flower lotus, or rhizome lotus (Guo, 2009). Rhizome cultivars generally produce very few flowers, whereas those selected for seed production typically develop insignificant rhizomes (Nguyen and Hicks, 2004) [51]. In certain cases, disbudding practices are usually employed to enhance rhizome yield (Tian, 2008) [71]. Seed lotus is characterized by prolific flowering, with high rate of fruit set and the production of high-quality large seeds. Flower lotus is characterized by the production of unusually large blossoms, but with no well-developed rhizomes and typically lives in deep water, often exceeding 1.5 meters, making it highly suitable for ecological restoration and wetland construction. The flowers shows wide variation in colour with pure white, pink, yellow, as well as bi-coloured forms, such as white petals with pink border. Based on lotus utilization, plant stature, flower type, form and size the Asian lotus has been categorized in various ways (Billing and Biles, 2007) [7]. Its extensive variation in floral colour and morphology has attributed to its popularity as one of the most widely cultivated and highly valued ornamental plants in Asia (Masuda *et al*., 2006) [44].

Classification Based on Plant Size

- **Miniature:** Plant stature with less than 16 cm (≤ 6″)
- **Small:** Plant stature between 18-46 cm (7-18″)
- **Medium:** Plant stature between 47-91 cm (19-36″)
- **Large:** Plant stature above 92 cm (> 36″)

Based on FLOWER TYPE (Chinese categories)

- **Single:** with less than 25 petals
- **Semi-double:** with 25-50 petals
- **Multi-petal:** with more than 50 petals
- **Thousand-petal:** Flowers having many petals, several hundred to thousands
- **Example: (**Nelumbo nucifera 'Zhizun Qianban'**)**

Based on Flower Shape

- **Plate:** Petals spread horizontally, forming a flat, plate-like structure.
- **Bowl:** Petals open widely around the receptacle, resembling a bowl.
- **Cup:** Petals curve upward, forming a cup-shaped form.
- **Ball:** Petals overlap tightly, forming a ball like structure.
- **Flying/Dancing:** Petals are arranged irregularly around the receptacle, giving a free-form appearance.

Uses: Lotus, a culturally and horticulturally significant plant, possesses a wide range of uses encompassing religious, ornamental, nutritional, and medicinal purposes.

Religious significance

Lotus has a pivotal role in Hindu mythology since the time of Rig Veda. Atharva veda compares human's spiritual heart to lotus. According to Hindu text, lotus is the symbol of creation. It is believed that Lord Brahma (the Creator), emerged from the navel of Lord Vishnu (the Protector), seated on a lotus. The sacred lotus played a religious significance in Hinduism and Buddhism, where the flower is represented as a symbol of beauty, purity and divinity (Shen-Miller, 2000) [65]. In Hinduism the sun is represented by sacred lotus, and is associated with mother goddesses as a symbol of fertility. The lotus serves as the seat of the Deity, signifying their purity and divinity and in yoga that asana is called padmasana or kamalasana. Thus N. nucifera is a symbol of Indian cultural heritage closely linked with Hindu mythology, philosophy, art, architecture, poetry and culture since the immemorial time (Sharma and Goel, 2000) [63].

Nutritional significance: In many Asian nations, notably China, Japan and India, lotus rhizomes are extensively consumed as a vegetable in different forms such as fresh, frozen, or canned forms. Culinary preparations often include frying, cooking in soups, pickling in vinegar or soaking in syrup (Tian *et al*., 2009). Japan is one of the top consumers, with lotus rhizomes comprising nearly 1% of the country's intake of overall vegetables. Although Japan has its own lotus, it continues to import approximately 18,000 tons of lotus rhizomes annually, with China alone supplying nearly 15,000 tons. Lotus rhizome is not only a food crop but also valued for its nutritional properties. It is rich in dietary fibre that helps in digestion, and serves as a good source of energy due to its high carbohydrate content. In addition, it contains essential micronutrients like manganese, zinc, iron, copper, vitamin B and C, potassium, and magnesium (Table 1). The starchy rhizomes of lotus can be processed into flour and are also used as adjuvant in tablet formulations (Mukherjee *et al*., 1996) [47]. In Sri Lanka, sliced lotus stem curry, locally known as *Nelum Ala*, is a popular traditional dish. Also, lotus seeds are versatile and highly nutritious, processed into a variety of products such as wine, ice cream, mooncakes, noodles, pastes, fermented milk, popcorn (*phool makhana*) etc. The Lotus seed tea is traditionally consumed in Korea, while lotus embryo tea is popular in Vietnam and China (Wu *et al*., 2013) [79]. In eastern and northern regions of India, the flower stalk is used to prepare a soup known as *Kamal gatte ki sabji* and a fried starter called *Kamal kakdi pakode*. In the southern states, lotus stems are sliced, salted, sun-dried and the slices are fried and served as a side dish. In Kerala and Tamil Nadu, this preparation is locally referred to as *Thamara Vathal*.

Table 1: Nutritional value of Lotus root per 100g (3.5oz)

Energy	**278KJ (66Kcal)**
Carbohydrates	16.02g
Sugars	0.50g
Dietary fibre	3.1g
Fat	0.07g
Protein	1.58g
Thiamine	0.127mg
Riboflavin(B2)	0.01mg
Niacin(B3)	0.3mg
Pantothenic acid(B5)	0.302mg
Vitamin B6	0.28mg
Folate(B9)	8 µg
Choline	25.4mg
Vitamin C	27.4mg
Calcium	26mg
Iron	0.9mg
Magnesium	22mg
Manganese	0.22mg
Phosphorus	78mg
Potassium	363mg
Sodium	45mg
Zinc	0.33mg
water	81.42g

Source: USDA Nutrient Database

Medicinal uses: In traditional Asian medicine, N. nucifera has a long history of its use with all parts of the plant being employed for therapeutic purposes. (Table 2).

The lotus embryo or plumule, extracted from ripe seeds is sun-dried and traditionally used in the treatment of insomnia, high fevers, nervous disorders accompanied by restlessness, and hypertension (Nguyen, 1999) [49]. The flower pods or receptacles, that contain carbohydrates, proteins and minute quantity of the alkaloid nelumbine, are employed to arrest bleeding and resolve blood stasis. The stamens are believed to support kidney function and are particularly utilized in managing male sexual disorders and female leucorrhoea.

In traditional Eastern medicine, fresh lotus seed wine is believed to possess spleen-strengthening, thirst-quenching and anti-diarrheal properties due to the presence of certain bioactive compounds. (Bhat *et al*., 2009 [4]; Wu *et al*.,2013) [79]. In Korea, a traditional liquor is prepared from lotus leaves and blossoms having antioxidant properties beneficial in lowering the risk of chronic diseases and reducing oxidative stress (Lee *et al*., 2005) [33]. The powdered rhizome is used as traditional medicine for the treatment of dyspepsia, piles, dysentery and is also applied as a paste for treating skin infections and ringworm (Chopra *et al*., 1986) [11]. Lotus honey, mostly noted in Ayurveda is often compared to *Amrita* (the nectar of immortality), is considered highly valuable for its ability to alleviate a wide range of common ailments (Bhattacharjee, 1995) [5].

Table 2: Medicinal properties of different parts of Lotus plant

Part of plant	Traditional uses	Active compounds	Other medicinal benefits	References
Seed	Exhibit Sedative, astringent, antidiarrheal properties	Alkaloids, flavonoids	Enhances cardiovascular health; used in the treatment of insomnia spleen tonic	Follett *et al*., 2003 [16], Chen *et al*., 2021b [9], Jiang *et al*., 2018 [26], Wu *et al*.,2013 [79], Yu *et al*. 2021.
Rhizome	Supports digestive health and is used in dermatological treatments	Polyphenols, alkaloids	Dermatological health, cure of gastrointestinal problems	Chopra *et al*., 1986 [11], Dhull *et al*., 2023 [14], Mukherjee *et al*. 1997 [47], Tsuruta *et al*., 2011 [72], Zhu *et al*., 2018 [94].
Leaf	Refrigerant, astringent and diuretic actions	Flavonoids, polyphenols, alkaloids	High fever, haemorrhoids and leprosy Encourages a sense of tranquillity and stress reduction, diarrhoea	Lee *et al*., 2005; Nguyen, 1999 [49], Sharma *et al*., 2006 [64], Song *et al*., 2019 [68], Wang *et al*., 2018, Wu *et al*., 2017, Zhou *et al*. 2021 [93].
Flower	Antioxidant, Astringent, Cardiovascular tonic, treatment of diarrhoea	Flavonoids, glycosides	Stress reduction, menstrual health concerns	Kim *et al*., 2011 [29], Kumarihamy *et al*., 2015 [31], Nakamura *et al*., 2013 [48].

Multidisciplinary uses

Nelumbo nucifera has shown high potential in wastewater treatment by removing the pollutants such as algal growth thereby improving the oxygen content in the lotus based aquatic systems (Zhang *et al*., 2015) [90] and also used for discharging the industrial effluents contributing to water purification (Rajeshwari Sahu and Chandravanshi, 2018) [60]. The lotus can efficiently remove heavy metals like copper, arsenic and cadmium through rhizofiltration (Thongchai and Udomphon 2004 [69], Anawar *et al*., 2008, Virendra, 2009 [1] [74]. It is also proved to be effective as phyto-remediator of nutrient run-off ($NH4^+$, NO3, P) and suspended solids from waste water from intense aquaculture systems (Obando, 2012) [56]. Beyond its environmental role, the dried lotus pod, which resemble the shower heads, are having great potential in international market for decorative purposes and for dried arrangements. In Asia, the petals are sometimes used for garnish and leaves are used as a wrapping material for steam cooked dishes in Southeast Asian cuisine. A unique fabric from the lotus plant is produced only at Inle lake, Myanmar and in Siem Reap, Cambodia. This thread is used for weaving special robes for Budha images called *kya thingahn* (lotus robe). Lotus fibre weaving is an art that originated in Myanmar (Burma) centuries ago. The process of growing, extracting, and weaving these fibres is extremely labour-intensive. It takes 32,000 lotus stems to make one meter or 1.09 yards of fabric.

Unique features

In addition to common aquatic plant features, biologically, lotus also has certain unique features that distinguish it from other plant species. These features include seed longevity, leaf ultrahydrophobicity and floral thermoregulation.

Extremely long seed viability: In the Northeast China it was discovered that lotus fruits laid underground over 1300 years were still able to germinate. (Shen-Miller, *et al*., 1995) [66]. Extremely long viability of seeds for several years may be attributed to high stability of SOD (superoxide dismutase) in radicles (Li *et al*. (2000) [39] and due to high contents of polysaccharides (galactose, mannose) and tannins in the lotus fruit wall (Van Bergen *et al*., 1997) [73]. Studies showed that small RNA might also be associated with the regulation of lotus seed longevity (Hu *et al*., 2016) [21]. Lotus seeds exhibited an extremely strong heat resistance with germination rate of 100% even after 24 hours of treatment in 100 ºC oven (Huang *et al*. 2003) [25].

Leaf Water repellence property: Scientific mystery of Lotus leaf being ever clean, floating over the dirty water is due to its super hydrophobic nature. This property is achieved by a specialized dense coating of waxy papillae on the leaf surface. (Zhang *et al*, 2012 [91]; Marmur 2004) [43]. Lotus leaves show two levels of structures, a microstructure layer (with size of microns or thousands of a millimeter) composed of surface lumps and a nanostructure layer (on the scale of nanometers or of the order of the millionth of a millimeter) formed by small hairs. Both layers are covered by a waxy coating and together makes the leaf surface highly repellent to water (super hydrophobic surfaces).
Furthermore, its water contact angle is greater than 150° and a water sliding angle is smaller than 10° (Bhushan *et al*., 2009) [6]. This unique character of lotus leaf forms a significant source of inspiration for many innovative technological applications. This ultra-hydrophobic nature of lotus leaf is also known as the “lotus effect” (Darmanin and Guittard, 2015) [13]. The biologists Neinhuis and Barthlott patented this idea under the name "Lotus-Effect". In recent years, the self-cleaning property of lotus has attracted much research attention worldwide, leading to development of many artificial surfaces on glass, metal, wood, plastic and stones as well as absorbents, textiles, etc. Notably in building sector, roofs and paints capable of self-cleaning are created exemplified by products such as Lotusan. (Liu *et al*., 2006 [41]; Cheng *et al*., 2006 [10]; Lee and Kwon, 2007; Guo and Liu, 2007 [34]; Kim *et al*., 2008) [28]. In textile industry it created revolution by manufacturing rain proof fabrics, less polluting clothes for the health sector, garments resistant to staining etc.

Table 3: Biomimetic materials and its applications created by Lotus (Yang *et al*, 2024)

Lotus parts acted as source of Inspiration	Biomimetic materials	Application	References
Lotus leaf	Lotus leaf-like gauze (Lotus@Gauze)	Wound dressing exhibits as excellent antiadhesive and antibacterial effects	Li *et al*. (2020a) [37]
Lotus leaf	PCL nanofibrous mats modified with HMDSO	Antiadhesive barrier having surface hydrophobicity	Klicova *et al*. (2022) [30]

Lotus leaf	PVA/CS composite film spray coated with beeswax and SiO_2 nanoparticles	Antibacterial adhesive packaging film with excellent physicochemical properties	Huang *et al*. (2022a) [24]
Lotus leaf	Superhydrophobic coating applied on the dielectric layer of a droplet-based electricity generator.	Raindrop energy, High electricity output, self-cleaning DEG for outdoor use and raindrop acidity alert	Yoo *et al*. (2022) [87]
Lotus leaf	Micro sized Spherulites	Ultra-hydrophobic coatings	Bai *et al*. (2018) [3]
Lotus rhizome	Kevlar aerogel	Photothermal conversion efficiency of 81.2%, Sewage treatment and fresh water production with high catalytic efficiency of 98.91% for pollutant degradation	Li *et al*. (2023a) [41]

Floral thermoregulation: Floral organ thermogenesis is another distinctive feature of the lotus, occurring independently in petals, receptacle and stamen (Li and Huang, 2009) [38]. The majority of heat is generated by the large, central receptacle before anthesis and ends with pollination and a fertilized ovary. This property has been attributed to the cyanide-resistant alternative oxidase pathway operated in the floral organs (Watling *et al*, 2006 [78]; Seymour *et al*., 1998 [62]; Grant, *et al*., 2010) [17]. Ecologically, this feature of thermogenesis is crucial for the sexual reproduction of the lotus by attracting insect pollinators (Wang and Zhang, 2013) [77].

Morphological description

The lotus is a perennial, aquatic herb with branched, slender, elongated, creeping stem containing nodal roots. The fibrous roots of the lotus plant ranging from 20 to 50 emerges from the nodes of the underground rhizomatous structure. The edible rhizome is a modified subterraneous stem that help the lotus to survive during severe winter with its bud dormancy and provide substrates and energy for its asexual propagation. The rhizomes vary in a length of 60-140 cm, diameter of 0.5 to 2.5 cm, smooth, longitudinally striated with brown patches and are yellowish white to yellowish brown in colour. It exudes mucilaginous juice and exhibits few large cavities when freshly cut. Usually, the plant completes its growth cycle in about 4 to 6 months for bud formation, leaf emergence, flowering, fruit development, rhizome formation and to reach a dormant period (Xueming, 1987) [83].

Leaves emerge directly from the rhizome and can either rise to 30 to 45 cms above the water or float on the water surface (Sayre, 2007) [61]. Both aerial and floating leaves are large, orbicular and measure about 20-90 cm in diameter. They are acute to form a short tip, entire, glaucous, petiolate, non-wettable and in case of aerial leaves they are strongly cupped whereas flat in case of floating ones. The fresh leaves are leathery and the leaf lamina is radiantly nerved. Leaves are waxy green in colour while, American lotus leaves are bluish green above and light yellowish on the lower surface at young stages. Flowers are solitary, large, 10-25 cm in diameter, white, pink or pinkish white, fragrant, hermaphroditic and peduncles are arising from the nodes of the rhizomes.

Leaves emerge directly from the rhizome and may either float on the water surface or extend 30-45 cm above it (Sayre, 2007) [61]. Both aerial and floating leaves are large, orbicular, and measure 20-90 cm in diameter. They are abruptly acute with a short tip, borne on long petioles, entire, glaucous, non-wettable, and leathery when fresh. Aerial leaves are strongly cupped, whereas floating leaves are flat. The lamina is radiantly nerved, with a waxy green surface; in contrast, American lotus leaves are bluish-green on the upper side and light yellowish beneath during their juvenile stages. The flowers are solitary, fragrant, hermaphroditic, large in size with a diameter of 10-25 cm, white, pink, or pinkish-white, and borne on peduncles that arise from the rhizome nodes. Flowers of Nelumbo lutea are pale yellow in colour, like a double tulip and are smaller than sacred lotus. The large green "showerhead-like" carpellary receptacle of a Lotus bloom bears numerous fruits, each of which contains one seed, a morphological specialisation for seed protection. Seeds, fill in the ripe carpel are black, hard and ovoid and are up to 1.5 inches (4 cm) in diameter. Fruits of *N. nucifera* have exceptional power of dormancy with greater longevity of its seeds surpassing that of any known species of flowering plant. The most significant factor contributing to the extended longevity of these seeds is water- and air-tight architecture of lotus pericarp chamber which makes it impervious to water.

Lotus research: Due to its remarkable significance in horticulture, medicinal applications, and plant phylogeny, the sacred lotus has attracted much attention from the scientific community. The studies on lotus breeding have been conducted by institutions, such as the China Lotus Research Center (CLRC), Vegetable Research Institute of Hunan Academy of Agriculture (HAA), Jiangxi Institute of White Lotus Research (JIWLR), Jingzhou Technical School in Hubei Province, Hangzhou West Lake, Beijing Botanical Garden (Chinese Academy of Sciences) and National Botanical Research Institute (NBRI), Lucknow, India. With advancement of science and technology, the breeders need to focus on production of novel and improved varieties of lotus through the more technical approaches (Qichao and Zhang, 2010) [58]. The Vegetable Research Institute of HAA developed a double-flower lotus, 'Dang Ding Yü E' with the treatment of Co-60 radiation from the few-petalled seed lotus. In China, the outer space breeding via Chinese satellite has launched and produced mutants 'Space Lotus 1', 'Space Lotus 2', 'Space Lotus 3' and 'Space Lotus 36' with improvement in both quality and yield (Wang and Zhang, 2004) [75]. The International Registration Authority for registration of novel cultivars of Nelumbo is International Waterlily and Water Gardening Society (IWGS)

Breeding aspects of Lotus

1. Cultivars with large-size and deep-water tolerance

Lotus usually grows favourably in shallow water with a depth of nearly 1.5 metre. Exceptionally in Puzhehei Natural Reserve a cultivar was reported that can tolerate 3.2 meters (10.5 feet) of water depth in the wild. Therefore, there is a need to develop lotus cultivars that can sustain in deep water

bodies with high ornamental values, so that scaling up of lotus cultivation in large areas is possible.

2. Micro cultivars with shade tolerance suitable for growing in bowls: Small-sized lotus cultivars having ornamental value that can be planted in a bowl refers to bowl lotus. Since the plant is not shade-tolerant, it rarely blooms on the balcony with less than six hours of daily direct sunlight. In the modern ornamental world, breeding of miniature, shade-tolerant bowl lotus holds a great potential in the market of house plants.

3. Long-blooming cultivars: The duration of a single lotus flower typically lasts for three to four days, whereas in ponds, the entire lotus flowering period may extend upto three months but less than two months in jars and only one month for bowl lotus grown in small containers. However, Sanshui Lotus World succeeded in breeding of cultivars that bloom from early May to late December *i.e* for nearly eight months. Hence there is a need to develop the cultivars with longer flowering duration in accordance with much demand in the market.

4. Cultivars with novel colors: In lotus only three basic colors are existing, namely reddish pink, white and light yellow. Unlike chrysanthemums and roses, due to the lack of a 'blue gene' in *Nelumbo* it is difficult obtain new lotus cultivars with more diverse, attractive and beautiful colors. Advanced breeding approaches such as cell fusion and gene transfer technology using non-*Nelumbo*naceae species with blue color gene source need to be considered to develop cultivars with novel colors.

5. More cultivars of thousand-petalled type: Thousand-petalled lotus is an extreme form of the double-flower cultivars in lotus. Qian Ban Lian, Yilian Qian Ban' and 'Zhi Zun Qian Ban' are the naturally discovered thousand petalled types resulted from a series of changes in chromosome and DNA structure. With novel breeding approaches such as radiation of Co-60 at a proper dose, space radiation, and ion implantation, development of thousand-petalled cultivars with novel colours may be possible.

6. Pest resistant cultivars: Lotus is not much affected by pests and diseases. However in recent times, chilli thrips have spread to cultivated lotus and became major pest in Lotus. Considering this, sustainable development of tropical lotus is possible only by breeding of chilli-thrips-resistant cultivars.

7. Cultivars that can serve dual purpose: Lotus has long been valued as an economic plant with medicinal values, edible and having ornamental importance. However, each variety is having specific value and are being classified based on their proper utilization. Currently, the most popular varieties are those that can produce large flowers, rhizomes and seeds. Thus, there is a good scope for dual-purpose cultivars.

Cultivation aspects

For vegetable production lotus is usually planted in a tilled pond or rice field. Based on the usage of plant it is also planted often in bowls, containers, small ponds and lakes for landscapes.

Soil

The rich and fertile loamy soil is good for lotus cultivation than sandy soil (Meyer, 1930) [45]. Large amounts of organic matter that are prevalent in lake or Pond bottoms are most suitable (Xueming, 1987) [83]. Specifically for rhizome lotus heavy clay soil is not suitable as roots cannot penetrate and harvesting is more difficult. Lotus can withstand a wide range of pH from 4.5 to 9.0 (Meyer, 1930) [45] and EC exceeding 1.0 $mS \cdot cm^{-1}$ even for large lotus plants is not favourable. (Tian, 2008) [71].

Climate

Lotus is classified as a long-day plant. Rhizome elongation and upright leaf production is promoted by long days, whereas short days accelerate rhizome enlargement and supress upright leaf production (Masuda *et al*, 2006) [44]. The climatic factors such as temperature, photoperiod and altitude influence the growth and performance of lotus (Wang and Zhang, 2004) [75]. Optimum temperature range for lotus growth is 22 to 32 ºC (Yang *et al*., 2006) [86]. However, *N. nucifera* can tolerate high temperature of 41 ºC and withstands continuous temperature exposure to above 35 ºC even for 20 days (Wang and Zhang, 2004) [75]. Water temperature must be at least 18º**C** during growing season. Lotus shows dormancy in regions with low light intensity in winter season. Plant performance is further influenced by container size, soil depth, and water level especially in container grown lotus.

Propagation

Lotus is propagated by seeds, enlarged rhizomes, running rhizomes (straps) and tissue culture. For breeding of new cultivars, seed propagation is primarily used but commercially not adopted as seeds are highly heterozygous. Lotus seeds must be treated physically or chemically before sowing to overcome the permeability barrier of the extremely rigid seed coat with high phenol content, to promote germination. Seed rate of 10- 12 kg is required for one hectare area. Scarified seeds germinate in 4-5 days if temperatures are more than 27 °C.

For commercial cultivation one year old enlarged rhizomes are used (Masuda *et al*., 2006) [44] and is considered as the best method to ensure a harvestable crop in one season. The rhizomes used for propagation must have at least two segments sealed at either end by an intact node. **T**he rhizomes should be planted in saturated media at an angle of 15º with the shoot meristem buried under 5 cm of media. About 35000-40000 rhizomes are required for planting in one hectare area.

In addition to traditional propagation methods, tissue culture offers a potential alternative for lotus propagation. In China, Japan and Thailand, studies on tissue culture of lotus have been reported. Among explants, for shoot induction terminal buds were found to be more efficient than axillary buds (Luo *et al*., 2004) [42]. Furthermore, through *in vitro* culture tetraploid lotus (4n = 32) was produced with colchicine treatment (Yamamoto and Matsumoto, 1990) [84].

Pond management

This is a critical step in commercial production because once pond is constructed, it is difficult to change. Site for a

pond needs to be relatively flat & close to a reliable source of a large volume of fresh water. As a rule of thumb, a lotus crop requires 60,000,000 L of water per ha (Hicks and Haigh, 2001) [20]. If the soil cannot retain water, the use of liners should be considered. In the black belt region, soils are rich in clay and can be compacted to form an impermeable barrier which allows the retention of water. Lotus is optimally grown in shallow ponds with a soil depth range of 20 to 30 cm to 1 meter (Nguyen and Hicks, 2004 [51]; Xueming, 1987) [83].

Container management

In recent horticultural industry, container-grown ornamental lotus has emerged as a potential crop (Creamer, 2008) [12]. Lotus production is more preferable in round containers as the tubers and runners tend to get obstructed in the corners of square planters (Slocum and Robinson, 1996) [67]. Containers should be filled at ¼ or ½ of their depth with wet pond soil. Planting can be done by filling the containers with water level of 4.5 cm (2 inches) above the surface of the soil and allow them to settle for two to three days and then rhizomes are planted so that they can firmly attached to the mud. Lotus rhizomes need 60-65 days to bloom under natural conditions. The range of flowering is from 50 days (early varieties) to 70-90 days (late bloomers). Plants should be lifted up once in every 2- 3 year and rhizome can be used for replanting.

Fertilization

Lotus is a heavy feeder, requiring tremendous amount of nutrients to support its growth and flower production (Billing and Biles, 2007) [7]. Earlier the lotus cultivation has been taken up organically without using any chemical fertilizers. Even today, it is still a major source of fertilizer however, especially for the production of vegetable lotus N-P-K fertilizers are widely used in some countries. In the less fertile soils it should be supplemented with various organic matters such as compost, biofertilizers, oil press cake or and green manure. For container lotus, frequent application of fertilizers should be done due to limited nutrition in container soil (Wang and Zhang, 2004) [75]. When the plant reaches the mature stage and the period of rhizome expansion, more potassium and less nitrogen fertilizer is required [Nguyen, 2001] [50].

Weed management

Weeds also influence the growth and performance of lotus. Water hyacinth, Water lettuce, Azolla, *Typha* and *Cyperus papyrus* are the major weeds observed in aquatic systems. Water hyacinth is troublesome weed, spreads rapidly from runners. Removal of aquatic weeds manually during cropping period and draining off water or use of herbicide during non-crop periods is the best management of weeds (Nguyen, 2001) [50].

Pests and Diseases

Aphids: Aphids (*Rhopalosiphum nymphaeae*) are the common pest that suck sap from the new young leaves, buds and stalks and reduces plant vigour. The leaves are disfigured and flowers are discoloured with this pest. They are easily controlled by a forceful clean water spray or in case of high infestation, by spraying dimethoate or Malathion @ 2 ml/ l of water at 10 days interval.

Tobacco cut worm: *Spodoptera litura*, a polyphagous pest causes severe damage to vegetative growth of lotus. Among 51 species preferred by *Spodoptera litura*, lotus is designated as the secondary favourite food. The caterpillars can be kept under control easily by hand picking at the early stage.

Beetle: Beetle (*Poppillia japonica*) causes damage to the lotus leaves and flowers. It can controlled by spraying Demecron @ 2 ml/ l of water at 10 days intervals.

In China and Japan diseases such as rhizome rot and leaf spot are observed in lotus cultivated on commercial scale as a major crop.

Rhizome rot: In cultivars planted in shallow ponds (Wang and Zhang, 2004) [75], rhizome rot caused by *Fusarium oxysporum* sp. *nelumbicolum* (Nishikado and Watanabe, 1952 [52]; Nishizawa, 1954a) [54] as well as possibly by *Pythium sp.* (Nishizawa, 1954b) [54] is causing major damage to lotus production.

Minor diseases include

Leaf spot: *Alternaria nelumbii* and *Cercospora nelumbonis.* Small reddish-brown spots appear on leaf which gradually increases in size. Control is by spraying Captan or Blitox at the rate of 2g/ l of water at 10 days interval.

Leaf dry spot: This disease is caused by *Phyllosticta hydrophylla sp*. generally seen on both floating and standing leaves. In the initial stages yellow spots occur on infected leaves and then enlarge into large brown patches (Wang and Zhang, 2004) [75].

Lotus leaf black spot: It is caused by *Gloeosporium nelumbii*. In the initial stages purple, brown to black spots appear on leaves that enlarges and spreads the entire leaf (Nishikado and Watanabe, 1955) [53].

Harvesting and Yield

Harvesting practices vary on the cultivar and the purpose for which the crop is cultivated. For ornamental purpose flowers are harvested 3-4 months after planting once in two days during summer and once in three days during winter. Lotus is generally harvested when flower bud is almost fully developed i.e 2- 3 days before opening so that they can be transported long distance and also have long vase life. The flowers should be harvested early in the morning with a long petiole and before sunrise it should be completed. From each plant 2- 5 flowers can be obtained. For vegetable purpose, harvesting of rhizomes is done during Oct-Nov when they get well matured and when the leaves dry up due to low temperature. Generally, in warm climate it takes 120 days after planting to harvest rhizomes, while in cool climate it takes 150-180 days. Mature crop may yield on an average of 3.0-3.5 tons of rhizomes/ ha. Each segment of fleshy rhizomes measuring about the length of 60-80 cm with 5-10 cm in diameter, weighing about 150 g to 1.2 kg are best for harvesting. Flesh varies in colour from white or greyish-white. Seeds are harvested as soon as seed heads turn brown.

Packaging and Postharvest Handling: After harvest, rhizomes are thoroughly cleaned and washed to remove soil and are trimmed followed by removal of lateral shoots. The

quality rhizomes are separated into pieces containing at least three nodes. Rhizomes are then graded into four categories including large, medium, small and second grade (Nguyen, 2001) [50]. The development stage of rhizomes can be classified as the stolon stage, initial swelling stage, middle swelling stage, and later swelling stage. Lotus rhizomes must be handled with care because they are easily bruised and physical damage results in an immediate purple discoloration. In Japan market, quality rhizomes have to meet specific color, size and flesh characteristics: skin color must be milky white, and 3 rhizome segments should have a diameter of more than 4 cm, and the quality of rhizome should be good with more flesh water content, soft and crunchy texture (Nguyen, 1999) [49].

Storage of rhizomes: The storage life of rhizomes is very less owing to continuous moisture loss, browning, shrinkage and decay (Zhan and He. 2006) [89]. In cold storage conditions at 6-8^{0}C with 95-100% RH rhizomes used as vegetables can be stored up to 150 days (Anonymous. 2004) [2], while at room temperature, rhizomes generally have a shelf life of only 2 weeks (Tian, 2008 [71]; Ong, 1996). At high temperatures (>15ºC), they are more prone to diseases caused by *Pseudomonas, Botrytis* and *Colletotrichum.* It also results in heavy weight loss, rhizome dormancy and carbohydrate degradation (Nguyen, 2001) [50]. In addition, flesh-browning (Xin *et al*., 2002) [81] and sugar degradation happens due to enzymatic activity (Xiong *et al*., 2002) [82].

Conclusion Lotus is one of the nature's greatest gifts to the world with opportunities awaiting people and money for exploring its vast potential. Fortunately, India is provided with extensive fallow wetlands, including reservoirs, lakes, ponds, canals and channels. Most of these are barely utilized or remain fallow due to weed infestation. In such situations, the lotus has vast potential for commercial cultivation and will ensure the livelihood for substantial number of farming communities since the demand for the lotus as a horticultural crop is booming in both national and international markets.

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