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A Review on Pharmacognosy, Phytochemistry and Pharmacological Properties of *Lychee chinensis*

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Abstract:
Tropical fruits like lychee (Litchi chinensis Sonn.) are prized for their distinct flavor and abundance of nutrients. The pharmacognosy, phytochemistry, and pharmacological characteristics of lychee are all thoroughly examined in this paper. Its taxonomy, classification, and morphological traits are covered in the botanical description, and its native locations and worldwide dissemination are highlighted in the geographical distribution and cultivation techniques. Traditional medical applications and culinary advantages are examples of ethnobotanical usage. A complex composition of primary and secondary metabolites, including important bioactive substances such phenolics, flavonoids, triterpenoids, and saponins, is revealed by the phytochemical study. To clarify these chemicals, advanced extraction and analytical techniques are given. The pharmacological properties of lychee are noteworthy, including effects on the heart, liver, immune system, cancer, inflammation, antioxidants, antimicrobials, antidiabetics, and neuroprotectors. With an emphasis on the necessity of more study to fully investigate lychee's medicinal potential, this article attempts to present a thorough grasp of the fruit's health advantages and its therapeutic uses.
Keywords: lychee; litchi chinensis; phytochemistry; pharmacological properties; antioxidant; anti-inflammatory; anticancer

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1. Introduction

Tropical and subtropical in nature, lychee (*Litchi chinensis*) is a highly valuable commercial fruit, especially in China, which is the world's largest grower. Lychee, also referred to as the "southern good fruit," is prized for its distinct flavor, vibrant look, and high nutritional value. But the fruit has problems since it deteriorates and browns quickly after harvest, which drastically reduces its transportability and shelf life (Qi et al., 2015). The transferability of simple sequence repeat (SSR) markers among these taxa indicates that lychee and other members of the Sapindaceae family, including pulasan (Nephelium ramboutan-ake) and longan (Dimocarpus longan), have a close genetic link. The family's reproduction and conservation efforts are impacted by this genetic proximity (Lora et al., 2018; Sim et al., 2005). Additionally, research on lychee microsatellites has shed light on the domestication and genetic diversity of Vietnamese lychee cultivars, aiding in the preservation of germplasm (Tran et al., 2019). The fruit known as Litchi chinensis has a rich cultural and economic history, but it's also a topic of scientific curiosity because of its genetic ties to the Sapindaceae family and the difficulties in preserving it after harvest. While knowledge of its reaction to pests through the emission of herbivore-induced plant volatiles (HIPVs) could influence agricultural practices, research into its genetic markers and variety promotes breeding and conservation initiatives (Ataide et al., 2023). Beyond its obvious economic worth, lychees are significant because they touch on more general topics in horticulture, genetics, and plant biology.

The tropical and subtropical fruit tree known as lychee (Litchi chinensis Sonn.) is highly valued both economically and culturally, especially in Southeast Asia where it is widely grown and prized for its fragrant and sweet flavor. Lychee comes from the Chinese regions of Guangdong and Fujian, and it has a long history of use as a food and medicine. It is now a well known fruit crop as production has expanded to various areas with favorable conditions, including South Africa, Vietnam, Thailand, and India (Sun et al., 2021). According to botanical classification, *Lychee chinensis* belongs to the Sapindaceae family, sometimes referred to as the soapberry family, which has over 2,000 species and 150 genera (Koul and Singh, 2017). The fruit, which has transparent, luscious flesh and a rough, scarlet exterior, is not only delicious to eat but also a nutrient-rich source of bioactive chemicals with several health advantages. Because of its high regard and widespread application in traditional Chinese medicine, lychee is frequently referred to as the "King of Fruits" in China (Soni and Agrawal, 2017). Beyond its nutritional benefits, lychee is notable due to its strong pharmacological qualities. Phytochemicals such flavonoids, phenolics, and triterpenoids are abundant in the plant's fruit, seeds, leaves, and pericarp. Lychee is a topic of interest in pharmacognosy and phytochemistry because to these chemicals' shown antioxidant, anti-inflammatory, anticancer, and antibacterial properties (Sun et al., 2021; Koul and Singh, 2017). The fruit is also a vital part of several Asian traditional medical systems. Lychee is used to relieve pain, support digestive health, and boost immunity in traditional

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Chinese medicine. Many of these traditional applications have been confirmed by contemporary research, which emphasizes lychee's potential for both prevention and treatment of a wide range of medical disorders (Sun et al., 2021).

The review aims to detail the botanical and ethnobotanical background of *Lychee chinensis*, summarize its phytochemical constituents, and evaluate its pharmacological properties. It also seeks to discuss the safety profiles and identify research gaps and future directions.The article covers the pharmacognosy, phytochemistry, and pharmacological properties of *Lychee chinensis*, organized into sections on botanical description, chemical composition, pharmacological activities, and safety.

2. Pharmacognosy of *Lychee chinensis*

2.1 Taxonomy and Classification

The lychee, or Litchi chinensis Sonn., belongs to the Sapindaceae family, which is sometimes referred to as the soapberry family and has over 2,000 species and 150 genera. Other commercially significant fruit crops like longan and rambutan are part of this family, which is distinguished by its spread throughout tropical and subtropical regions (Lora and Hormaza, 2018). Originating from southern China, namely the provinces of Guangdong and Fujian, lychee has been grown for more than two millennia. Since then, it has expanded to several locations with favorable conditions, including South Africa, India, and Southeast Asia (Pareek, 2016).

The taxonomic classification of *Lychee chinensis* is as follows:

- **Kingdom:** Plantae
- **Phylum:** Angiosperms
- **Class:** Eudicots
- **Order:** Sapindales
- **Family:** Sapindaceae
- **Genus:** Litchi
- **Species:** Litchi chinensis (Soni and Agrawal, 2017)

Since lychee is an entomophilous crop—one that is extremely dependent on insect pollinators, particularly honeybees—it is highly cross-pollinated. In order to preserve genetic variety and improve fruit set and quality, cross-pollination is essential (Soni and Agrawal, 2017). Three subspecies—Litchi chinensis subsp. chinensis, Litchi chinensis subsp. philippinensis, and Litchi chinensis subsp. javensis—make up the single species of the genus Litchi. The one that is grown for commercial purposes the most is Litchi chinensis subsp. chinensis (Tran et al., 2019). Significant genetic variation has been found among lychee cultivars according to genetic research employing microsatellites and other molecular markers. Breeding strategies that seek to improve characteristics like fruit quality, disease resistance, and environmental adaptation need this variety (Tran et al., 2019).

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Thanks to recent developments in genetic analysis, scientists now have a greater understanding of the genetic diversity and interactions across lychee cultivars. For instance, a research by Tran et al. (2019) highlighted the genetic variety both within and across populations by using microsatellites to examine the genetic diversity of lychee and its wild cousins in Vietnam. Research of this kind is essential to the preservation and long-term application of lychee genetic resources.

2.2 Morphological Characteristics

Evergreen lychee trees normally reach heights of 10 to 12 meters, while under ideal circumstances, some can grow as high as 15 meters. The trees have spreading branches and a thick, rounded canopy. The leaves are pinnate, with four to eight glossy, leathery, dark green leaflets per leaflet. Before developing into a rich green tint, new leaves have a reddish-bronze appearance. *Lychee chinensis* has huge, terminal panicles that may grow up to 30 centimeters in length as its inflorescences. Numerous tiny, unisexual or bisexual, greenish-white to yellow flowers bloom from these panicles. Typically, flowering happens in the spring, however the exact time might change based on the weather (Koul and Singh, 2017).

The lychee tree bears drupes, which have a diameter of around 2.5 to 4 cm. When ripe, the pericarp, which is initially green but eventually turns crimson or pinkish-red, becomes rough and bumpy. The tasty aril within may be easily revealed by peeling off the thin, brittle pericarp. Transparent, white, and juicy, the aril has a taste that is sweet and somewhat acidic. While certain cultivars provide fruit with little or aborted seeds, which are more acceptable for food, the seed itself is big, glossy, and brown (Anjum et al., 2017).

Lychee trees frequently yield huge crops one year, followed by light or no crop the next year due to their alternation of bearing. Climate, tree age, and cultural traditions are some of the elements that affect this uneven bearing pattern. Production may be stabilized and this problem can be lessened with proper management and trimming. The physical characteristics of lychee trees vary greatly across varieties. For the purpose of locating and choosing cultivars with desired traits for commercial production, these distinctions are crucial. For example, cultivars differ in terms of leaf size, shape, and color; some have bigger, more elongated leaves, while others have smaller, rounder leaves (Nikmah et al., 2021).

Another important factor in the cultivation of lychees is flower shape. The blooms are carried on huge terminal panicles and are usually tiny and barely noticeable. Different cultivars have different blooming times and durations, which can affect fruit set and production. It's critical to comprehend these differences in order to maximize fruit output and pollination. The fruit itself varies widely in terms of flavor, color, and size. Some of the most popular cultivars for processing and fresh consumption include 'Brewster,' 'Mauritius,' and 'Hak Ip,' due to their big, delicious fruits with little seeds (Pareek, 2016). The pericarp's texture can be rough or smooth, and its color can vary from brilliant red to pinkish-red. The edible portion, called aril, is highly

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valued for its distinct taste profile—a combination of sweetness and a hint of acidity—and juiciness (Koul and Singh, 2017).

2.3 Adaptations and Growth Requirements

Tropical and subtropical regions are ideal for lychee tree growth, and they need particular environmental factors in order to properly develop and bear fruit. They favor organic matter-rich, somewhat acidic soils that drain well. Sufficient moisture is crucial, especially in the blooming and fruiting stages. But as Anjum et al. (2017) point out, lychee trees are susceptible to waterlogging, which can result in root rot and other illnesses. Another important element in the cultivation of lychees is temperature. For the trees to blossom, they need a time of moderate temperatures, which a mild winter usually provides. Flowering and fruit set can be negatively impacted by extreme heat or cold. In areas where the wintertime lows are insufficient, there may not be enough blooming, which results in low fruit yields (Anjum et al., 2017).

2.4 Biotechnological Advances

Modern biotechnology developments have given rise to new instruments for lychee propagation and enhancement. Tissue culture, micropropagation, genetic engineering, and other approaches may be able to address some of the difficulties encountered in lychee farming. For instance, genetic engineering may be used to impart features like disease resistance and increased fruit quality, while micropropagation enables the quick creation of disease-free planting material (Pandey et al., 2017). Research on genetic engineering and the creation of transgenic lychee plants has demonstrated potential for improving characteristics like disease resistance and shelf life. For example, introducing genes that promote stress tolerance and delayed ripening might greatly increase lychee's economic viability (Pandey et al., 2017).

2.5. Geographical Distribution and Cultivation

The evergreen lychee (Litchi chinensis Sonn.), a member of the Sapindaceae family, is indigenous to Guangdong and Fujian, two provinces in southern China. In these areas, where it has been grown for more than 2,000 years, the fruit is intricately woven into both cultural and commercial traditions. Lychee was first grown in these subtropical regions because of the pleasant climate, which includes high humidity, mild temperatures, and well-drained soils, according to historical records and botanical studies (Anjum et al., 2017). Lychees can be found naturally anywhere from sea level to around 1,000 meters in elevation. The tree grows best in regions with marked seasonal differences, especially in locations with typical chilly winters and hot, humid summers. The induction of blooming and subsequent fruits depend on certain weather conditions. The lychee tree's natural locations are perfect for its growth cycle since it needs a dormant phase brought on by milder temperatures in order to blossom successfully (Pareek, 2016).

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2.5.1 Cultivation Practices

Although lychee is still most widely grown in its home country of China, it is now grown in many other countries as well, such as South Africa, Australia, India, Thailand, Vietnam, and some portions of the United States (especially Florida and Hawaii). Cultivation techniques have been introduced and modified in each of these places to meet local environmental requirements and consumer preferences (Soni and Agrawal, 2017). Since its introduction to India in the 18th century, lychee has grown to be a substantial commercial crop. India's top lychee-producing states are Punjab, West Bengal, Uttar Pradesh, and Bihar. India is the world's second-largest lychee grower, making a substantial contribution to the worldwide lychee supply. In order to maximize productivity, Indian cultivators prioritize choosing high-yield cultivars like "Shahi," "China," and "Rose Scented" and putting them into practice with efficient orchard management strategies (Pareek, 2016).

Major lychee producers include Vietnam and Thailand, where lychee is extensively cultivated in the northern areas with a climate that supports its development. The goal in these nations has been to expand their export markets, especially in North America and Europe. In order to preserve fruit quality throughout transit, this has led to innovations in post-harvest handling and preservation procedures (Rabodomanantsoa, Razakaratrimo, and Jahiel, 2020). Lychee agriculture is mostly found in the subtropical areas of Mpumalanga and Limpopo in South Africa. Producers of lychees in South Africa have concentrated on cultivating types like "Mauritius" and "McLean's Red" that are well adapted to the region's climate. In order to address issues like worm infestations and fungal diseases, the business is supported by research into integrated pest control and sustainable agricultural techniques (Daneel and Steyn, 2021).

2.5.2 Cultivation Techniques

Cultivation of lychee involves several critical practices aimed at optimizing tree health and fruit production. These include:

- **Propagation Methods**: Air layering, which includes causing root growth on a stem that is still linked to the parent plant, is a typical method of propagating lychees. By using this technique, the desired features of the parent tree are preserved and genetic consistency is guaranteed. Because of the lengthy juvenile phase and the wide range of seedling traits, seed propagation is less prevalent (Anjum et al., 2017).
- **Planting and Spacing**: Planting distances for lychee trees range from 6 to 12 meters, depending on the cultivar and regional growth circumstances. Sufficient air circulation and sunshine penetration are ensured by adequate spacing, which is essential for disease control and good tree development (Pandey et al., 2017).
- **Soil and Nutrient Management**: Lychee thrives in well-drained soils that are slightly acidic and have a high concentration of organic matter. Regular soil testing and the application of balanced fertilizer are crucial for maintaining adequate nutrient levels. Essential nutrients for lychee

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cultivation include nitrogen (N), phosphorus (P), potassium (K), as well as micronutrients like zinc and boron. Fertilization regimens are frequently modified according to the growth stage of the trees, with specific focus on the pre-flowering and fruit development phases (Yang et al., 2015).

- **Water Management**: Sufficient water availability is crucial for the successful growth of lychee plants, particularly during the stages of blooming and fruit formation. Excessive watering might result in the development of root rot and various fungal infections. Regional climate circumstances dictate the irrigation strategies employed by producers, with a significant number opting for drip irrigation systems to provide accurate water distribution and reduce water loss (Koul and Taak, 2017).
- **Pruning and Canopy Management**: Regular pruning is essential for preserving the form of trees, increasing the amount of sunlight that reaches the lower branches, and improving the flow of air throughout the tree's canopy. Pruning is commonly performed post-harvest and prior to the start of the blooming period. Thinning of flowers and fruit clusters is a commonly used technique to enhance fruit size and quality by minimizing resource competition (Lora and Hormaza, 2018).
- **Pest and Disease Management**: Lychee trees are vulnerable to a range of pests and diseases, including lychee mite (Aceria litchii), fruit borer, and fungal infections including anthracnose and powdery mildew. To handle these risks, integrated pest management (IPM) tactics are used. These strategies involve the combination of biological control agents, cultural practices, and selective application of chemical pesticides. For instance, Quadrastichus spp., which are parasitoids, have been effectively employed in Taiwan to manage lychee gall midges (Chao et al., 2023).
- **Harvesting and Post-Harvest Handling**: Lychee fruits are collected when they achieve complete coloring and the ideal balance between sugar and acid. Manual harvesting is employed to limit any harm to the fragile pericarp. Post-harvest treatment include the processes of chilling, cleaning, and packing, which are carried out to prolong the shelf life and preserve the quality of fruits throughout transit. The use of sulfur dioxide fumigation is a standard practice to avoid pericarp browning and decay. However, researchers are now investigating alternate approaches to address the health risks linked with sulfur residues (Qi et al., 2015).

2.5.3 Challenges and Future Directions

Despite the advancements in cultivation practices, lychee growers face several challenges that impact productivity and profitability. These include:

- **Climate Variability**: Climate variations, such as changes in temperature and irregular rainfall, impact the timing of blooming and fruiting cycles. Ongoing research is being conducted to develop climate-resilient cultivars and adaptable production techniques in order to alleviate the consequences of climate change (Zhao et al., 2021).

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- **Pest and Disease Pressure**: It is crucial to continuously analyze and create new tactics for managing pests and diseases in order to effectively handle growing challenges. Biotechnological methods, such as genetic engineering to enhance resistance to diseases, are possible answers but need more research and governmental authorization (Pandey et al., 2017).
- **Market Access and Quality Standards**: Lychee farmers continue to face the problem of meeting rigorous export quality criteria, notably in terms of fruit size, color, and residue levels. Enhancing market access and competitiveness requires investments in post-harvest technologies and infrastructure (Musebe et al., 2017).
- **Sustainability and Resource Management**: Long-term viability relies heavily on the implementation of sustainable agricultural methods, which encompass effective water utilization, soil conservation, and integrated pest control. Promoting the use of these techniques through educational and supportive initiatives can improve the long-term viability of lychee agriculture (Daneel and Steyn, 2021).

2.6 Ethnobotanical Uses

For millennia, lychee (Litchi chinensis Sonn.) has been used in traditional medicine, mostly in China and other Southeast Asian nations. Rich phytochemical composition of flavonoids, saponins, tannins, and other bioactive substances is the basis of its many therapeutic uses (Ibrahim and Mohamed, 2015). Many diseases have been treated with different components of the lychee plant, including the fruit, seeds, leaves, and pericarp, by traditional Chinese medicine (TCM) and other traditional systems.

2.7Culinary and Nutritional Uses

Lychee is not only valued for its medicinal properties but also for its nutritional benefits and culinary versatility. The fruit is widely consumed fresh, dried, and canned, and is a popular ingredient in various dishes and beverages.

2.7.1 Nutritional Composition

Lychee is abundant in vital elements, such as vitamins, minerals, and antioxidants. It is a highly commendable source of vitamin C, offering a substantial amount of the daily necessary requirement in only one meal. This vitamin is essential for maintaining immunological function, promoting skin health, and providing antioxidant protection. Lychee is rich in essential minerals including potassium, phosphorus, magnesium, and copper. These minerals are crucial for maintaining cardiovascular health, promoting bone strength, and supporting general cellular function (Anjum et al., 2017).

2.7.2 Dietary Fiber and Digestive Health

Lychee has a significant amount of dietary fiber, which is advantageous for maintaining good digestive health. Fiber facilitates the process of digestion, mitigates the occurrence of constipation, and contributes to the maintenance of a healthy gut flora. Consuming lychee might enhance gastrointestinal regularity and promote overall digestive health (Pareek, 2016).

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2.7.3 Culinary Applications

Lychee is widely esteemed in culinary traditions due to its delectable and fragrant taste. The ripe fruit is commonly consumed as a revitalizing snack, but it is also included into other culinary preparations. Lychee is a versatile ingredient in Asian cuisine, commonly utilized in sweets, salads, and savory meals. It is a prevalent component in fruit salads, jellies, ice creams, and sorbets. Lychee juice and drinks are widely favored for their distinctive and unusual taste (Pareek, 2016).

2.7.4 Dried and Canned Lychee

Dried lychee, sometimes referred to as lychee nuts, is a widely consumed food in several cultural contexts. The act of drying causes the sugars to become more concentrated, resulting in a higher level of sweetness in the dried fruit. Preserved lychee is an additional practical choice, enabling consumption throughout the year. Canned fruit preserves a significant portion of its nutritious content and is frequently employed in the preparation of sweets and drinks (Soni and Agrawal, 2017).

2.7.5 Lychee in Traditional Cuisine

Lychee is commonly utilized in traditional Chinese cuisine to create a variety of meals and beverages that are considered to possess health-promoting properties. Lychee tea, derived from dehydrated lychee rind, is a customary cure for gastrointestinal ailments and overall health. Lychee is utilized in Indian cuisine to enhance the flavors of chutneys, curries, and sweets, showcasing its adaptability and cultural importance (Sun et al., 2021).

2.7.6 Modern Culinary Trends

Lychee's worldwide appeal has resulted in its integration into contemporary culinary trends. Lychee is being used by chefs and food fans worldwide in creative ways, including incorporating it into yogurts, smoothies, and sauces to add a distinct flavor. The fruit's distinctive flavor profile complements both sweet and savory elements, making it highly sought after in fusion cuisine (Pareek, 2016).

3. Phytochemistry of *Lychee chinensis*

Lychee, scientifically known as Litchi chinensis Sonn., is famous for its delectable taste and its abundant chemical content, which plays a significant role in its various health advantages. The chemical components of lychee may be categorized into main and secondary metabolites. Comprehending these substances is crucial for understanding the nutritional and therapeutic significance of lychee.

3.1. Primary Metabolites

Primary metabolites are essential compounds that are directly involved in the normal growth, development, and reproduction of plants. In lychee, these include carbohydrates, proteins, lipids, vitamins, and minerals.

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3.1.1 Carbohydrates and Sugars

Lychee has a substantial amount of carbohydrates, mostly in the form of sugars such as glucose, fructose, and sucrose. The sugars included in lychee are accountable for its sweet flavor and also add to its overall energy content. The lychee pulp has a sugar content of around 15-20%, which might vary based on the specific type of lychee and its level of maturity (Pareek, 2016). Lychee's high sugar content makes it a rapid source of energy.

3.1.2 Proteins and Amino Acids

While lychee is not a substantial protein source, it does contain crucial amino acids. The lychee pulp has a relatively low protein level, which is within the range of 0.7 to 1.1 grams per 100 grams of fresh weight. Lychee seeds contain a greater amount of protein, making them suitable for use in dietary supplements (Kilari and Putta, 2016).

3.1.3 Lipids

The lychee pulp has a relatively modest amount of lipids, however it does contain important fatty acids such as linoleic and linolenic acids. Fatty acids have a vital role in preserving the integrity of cell membranes and generating signaling molecules (Lopes et al., 2019).

3.1.4 Vitamins

Lychee is a highly abundant source of vitamins, particularly vitamin C (ascorbic acid). Vitamin C is a crucial antioxidant that safeguards cells against oxidative harm, enhances the immune system, and fosters skin health. Lychee is rich in B-complex vitamins, such as thiamine, riboflavin, niacin, and folic acid, which play a crucial role in energy metabolism and brain function (Contreras-Castro et al., 2022).

3.1.5 Minerals

Lychee is rich in vital minerals, such as potassium, phosphorus, magnesium, calcium, as well as trace elements like copper, zinc, and iron. These minerals are essential for several physiological functions, such as muscular contraction, bone health, and enzyme activity (Queiroz et al., 2015). For example, potassium plays a crucial role in the regulation of blood pressure and maintenance of fluid balance.

3.2. Secondary Metabolites

Secondary metabolites are chemical molecules that do not directly participate in the essential activities necessary for the survival of plants. However, they do have significant functions in plant defense, pigmentation, and interaction with the surrounding environment. The lychee fruit contains secondary metabolites such as phenolics, flavonoids, saponins, and terpenes, which are responsible for its therapeutic qualities.

3.2.1 Phenolic Compounds

Lychee has a large quantity of phenolic chemicals, which are a prominent category of secondary metabolites. These compounds, including phenolic acids, tannins, and anthocyanins, are renowned for their antioxidant qualities. The phenolic content in lychee differs across various

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plant components, with the seeds and pericarp often exhibiting the greatest quantities (Dong et al., 2018). These chemicals provide protection to the plant against UV radiation, infections, and herbivores. They have also demonstrated anti-inflammatory, anticancer, and cardiovascular protective properties in humans.

3.2.2 Flavonoids

Flavonoids are a wide-ranging collection of polyphenolic chemicals that have a role in the coloration and antioxidant properties of lychee. The main flavonoids found in lychee include quercetin, kaempferol, epicatechin, and procyanidins (Xiong et al., 2020). These chemicals display a diverse array of biological actions, such as anti-inflammatory, antiviral, and anticancer properties. For instance, studies have demonstrated that quercetin and kaempferol can hinder the growth of cancer cells and decrease inflammation by regulating the signaling pathways associated with immune responses (Dong et al., 2019).

3.2.3 Saponins

Saponins are glycosides that possess detergent-like characteristics and are present in several components of the lychee plant. These chemicals are recognized for their capacity to create enduring foams in water-based solutions and possess notable therapeutic characteristics. Lychee seed saponins have demonstrated antioxidant, anti-inflammatory, and anticancer properties. They have a role in the plant's defensive processes and have the potential to be used therapeutically to lower cholesterol levels and improve immunological function (Lopes et al., 2019).

3.2.4 Terpenes

Terpenes are a broad and varied group of chemical molecules that are synthesized by lychee. They have a vital function in the scent of the plant and possess many biological properties. Lychee contains notable terpenes such as linalool, limonene, and α-pinene. The compounds possess antibacterial, anti-inflammatory, and analgesic activities (Sun et al., 2021).

3.2.5 Anthocyanins and Carotenoids

Anthocyanins are hydrophilic pigments that give the lychee pericarp its red color. Lychee's health advantages are enhanced by its powerful antioxidant qualities, which effectively neutralize free radicals. Carotenoids, a distinct category of pigments, exist in lesser amounts and add to the yellow or orange tones found in certain lychee varieties. Anthocyanins and carotenoids both contribute to cell protection against oxidative stress and help lower the likelihood of chronic illnesses (Queiroz et al., 2015).

3.2.6 Alkaloids

Lychee seeds have been found to contain alkaloids, however they are not as prevalent as other secondary metabolites. These chemicals containing nitrogen can have strong pharmacological effects. Lychee seed alkaloids have demonstrated the capacity to regulate neurotransmitter function, suggesting their potential utility in the treatment of neurological illnesses (Dong et al., 2019).

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3.2.7 Volatile Compounds

The unique fragrance and taste of lychee are attributed to its volatile components. The fruit's sweet and flowery aroma is produced by a range of esters, aldehydes, and alcohols. The volatile component content can vary considerably across various lychee cultivars and ripeness stages (Rashid et al., 2019).

3.3. Methods of Extraction

Solvent Extraction

Phytochemicals from lychee are frequently isolated via solvent extraction, which is a widely employed technique. This method entails utilizing solvents like ethanol, methanol, and water to dissolve the specific chemicals from the plant material. Lopes et al. (2019) employed a comprehensive extraction technique using a 70% ethanol-water solution to get extracts from lychee leaves. This technique is used because to its straightforwardness and effectiveness in extracting a diverse array of polar and non-polar substances (Lopes et al., 2019).

Ultrasonic-Assisted Extraction (UAE)

Ultrasonic-assisted extraction (UAE) employs ultrasonic waves to improve the extraction process by breaking cell walls and enhancing the solvent's infiltration into the plant matrix. This method greatly decreases the amount of time required for extraction and enhances the overall yield. Chen et al. (2017) conducted a study where they enhanced the use of ultrasound-assisted extraction (UAE) to extract orientin and vitexin from Trollius chinensis. This refined method may also be employed to extract these compounds from lychee. The optimal settings consisted of a 60% ethanol volume fraction, 28 minutes of ultrasonic irradiation duration, and a power of 738W. These parameters resulted in effective extraction with a high level of repeatability (Chen et al., 2017).

Microwave-Assisted Extraction (MAE)

Microwave-assisted extraction (MAE) use microwave radiation to heat the solvent and plant material, leading to quick and effective extraction. The use of MAE is highly efficient in extracting polysaccharides and other chemicals that are sensitive to heat. Cheng et al. (2015) showcased the application of MAE (microwave-assisted extraction) to extract polysaccharides from Schisandra chinensis. They achieved impressive results by employing optimum conditions, including a microwave irradiation period of 10 minutes and an extraction temperature of 47.58°C, resulting in high yields (Cheng et al., 2015).

Supercritical Fluid Extraction (SFE)

Supercritical fluid extraction (SFE) utilizes supercritical CO2 as a solvent, often with the addition of co-solvents such as ethanol, to extract bioactive chemicals at elevated pressure and temperature. This approach is ecologically sustainable and yields extracts of exceptional purity. In their study, Dai et al. (2019) conducted an optimization of Supercritical Fluid Extraction (SFE) to extract lignans from Schisandra chinensis. This process involved applying certain

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conditions, including a pressure of 15 MPa, a temperature of 50°C, and the addition of 1% methanol as a co-solvent (Dai et al., 2019).

Enzyme-Assisted Extraction (EAE)

Enzyme-assisted extraction (EAE) employs cellulase and pectinase enzymes to degrade cell walls and enhance the liberation of phytochemicals. This technique is very valuable for isolating large-sized molecules such as polysaccharides. Cheng et al. (2015) employed EAE (enzymatic-assisted extraction) to improve the extraction of polysaccharides from Schisandra chinensis. They achieved an extraction yield of 7.38% by optimizing the extraction parameters (Cheng et al., 2015).

Matrix Solid-Phase Dispersion (MSPD)

Matrix solid-phase dispersion (MSPD) is a method of preparing samples by spreading the plant material over a solid surface and extracting the necessary components using a solvent. In their study, Zhang et al. (2016) devised a novel MSPD technique to extract lignans from Schisandra chinensis. This approach shown superior performance in terms of both recovery rates and efficiency when compared to conventional extraction techniques (Zhang et al., 2016).

3.3.2. Analytical Methods

High-Performance Liquid Chromatography (HPLC)

HPLC, or high-performance liquid chromatography, is a commonly employed technique for effectively separating, identifying, and quantifying phytochemicals in lychee. This method offers exceptional precision and sensitivity, making it well-suited for examining intricate combinations of bioactive substances. For instance, Jin et al. (2017) employed high-performance liquid chromatography (HPLC) in conjunction with mass spectrometry (MS) to concurrently identify and quantify 12 active constituents in the roots of Pulsatilla chinensis. Analogous HPLC techniques may be utilized to examine the phytochemical composition of lychee (Jin et al., 2017).

Gas Chromatography-Mass Spectrometry (GC-MS)

GC-MS is employed for the analysis of volatile chemicals in lychee. This method is very valuable for creating a detailed profile of essential oils and aroma components. Gas chromatography-mass spectrometry (GC-MS) offers comprehensive insights into the chemical composition and concentration of volatile substances. Ahmed et al. (2022) employed GC-MS to analyze the volatile chemicals in lychee that were treated with zinc oxide nanoparticles to assess their antifungal properties (Ahmed et al., 2022).

4. Pharmacological Properties of *Lychee chinensis*

Table 1 provides a concise summary of the pharmacological properties of Lychee chinensis, highlighting its diverse health benefits and the specific compounds responsible for these effects, supported by recent research findings.

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4.1 Antioxidant Activity

Various studies have shown that *Lychee chinensis*, specifically its leaves, pulp, peel, and seeds, has notable antioxidant potential. The lychee leaves extract and fractions are rich in phenolic chemicals, flavonoids, and condensed tannins, which have strong antioxidant effects (Lopes et al., 2019; Contreras-Castro et al., 2022). Furthermore, research conducted by Su et al. (2016) has demonstrated that the phenolic compounds found in lychee pulp can safeguard the liver from damage caused by oxidative stress. This is achieved by effectively neutralizing harmful free radicals and regulating mitochondrial dysfunction (Su et al., 2016). Moreover, the chemical substances extracted from lychee seeds have demonstrated antioxidant properties, indicating the potential application of lychee seed as a natural healthcare antioxidant (Dong et al., 2018). In addition, the watery extract of the outer layer of the lychee fruit has shown antioxidant properties in preventing protein oxidation and the formation of advanced glycation end products. This highlights its potential as an antioxidant in fighting issues related to diabetes (Kilari and Putta, 2016).

4.2. Anti-inflammatory Properties

Lychee chinensis, sometimes known as lychee, demonstrates strong anti-inflammatory characteristics, as evidenced by many research investigations. The ethanol-based extract derived from lychee seeds exhibited notable anti-inflammatory and analgesic properties in Wistar albino rats, suggesting its potential as a secure medicinal agent (KC et al., 2021). In addition, the phenolic compounds in lychee pulp were discovered to alleviate damage to the intestinal barrier and inhibit proinflammatory pathways, demonstrating its protective properties against colitis in mice (Huang et al., 2021). Moreover, a research investigation on the extract of lychee leaves and its constituent parts shown significant antibacterial properties, specifically against a range of bacteria, highlighting its potential in fighting against infections and inflammation (Lopes et al., 2019). The collective findings highlight the anti-inflammatory characteristics of many components of the lychee plant, positioning it as a strong contender for pharmaceutical uses and general health advantages.

4.3. Antimicrobial Effects

Extensive research has been conducted on the antibacterial properties of *Lychee chinensis*, which has demonstrated its potential in effectively battling a wide range of bacterial strains. Studies have demonstrated that extracts derived from several components of the lychee plant, including the leaves and seeds, possess notable antibacterial activities (Lopes et al., 2019; Singh et al., 2013). The extracts have exhibited favorable outcomes in inhibiting various bacteria such as Escherichia coli, Staphylococcus aureus, Bacillus subtilis, and Proteus mirabilis, as evidenced by the significant observation of inhibitory zones (Xiao et al., 2017). Moreover, lychee has antibacterial properties that may be utilized in food preservation. Studies have demonstrated that

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treatments using lychee extracts effectively limit decay and browning in lychee fruit after it has been harvested (Huang et al., 2021).

4.4. Anticancer Potential

Lychee chinensis, a tropical fruit abundant in bioactive components including as flavonoids, sterols, triterpenes, and phenolics, has noteworthy promise in fighting cancer (Sun et al., 2021). Three fractions of litchi polysaccharides (LPFs) were examined in a comparative research to determine their physical and chemical characteristics as well as their biological effects. LP-6 had the greatest levels of uronic acid and protein content, demonstrating a notable chemical antioxidant activity of 28.14 μmol TE/g DW. In contrast, LP-8 exhibited enhanced cellular antioxidant activity and a more prominent inhibitory impact on several cancer cell lines at doses ranging from 100 to 800 μg/mL (Huang et al., 2015). The pericarp extract of litchi fruit demonstrates anti-cancer properties against human breast cancer cells, both in laboratory settings and in living organisms. The extract causes DNA damage, hinders cell growth, and initiates programmed cell death via controlling genes associated with the cell cycle, programmed cell death, and the ability of cancer cells to invade other tissues. The extract's anticancer actions are linked to the regulation of ADPRTL1, CYP1A1, and HMMR, as stated by Wang et al. (2006).

4.5. Cardiovascular Benefits

Researchers showed that in high-fat/high-cholesterol fed hamsters, litchi-flower-water-extract (LFWE) dramatically lowered blood lipids, cardiac index, and hepatic lipids. This study looked at the cardiovascular advantages of LFWE. To further improve cardiovascular health, the extract also reduced FAS gene expression, raised fecal lipid and bile acid excretions, and elevated the expression of the LDL receptor and PPAR-α genes. Furthermore, LFWE decreased serum levels of malondialdehyde, suggesting a safeguarding antioxidant activity (Yang et al., 2010). A 70% ethanol extract from the fruit was found to significantly suppress platelet aggregation, lengthen coagulation periods, and boost fibrinolytic activity in another study (Sung et al., 2012). These findings imply the fruit's potential usefulness in avoiding thrombotic and cardiovascular illnesses.

4.6. Other Pharmacological Activities

Using UPLC-Q/TOF-MS, the study finds 21 chemicals while examining the hypoglycemic effects of Litchi chinensis seed extract (LSE) on type 2 diabetic rats. LSE shown promise in enhancing insulin resistance and glucose tolerance, affecting lipid metabolism, and raising Bax and NF-κB mRNA levels. This indicates that by preventing organ damage and reducing inflammation, LSE may have therapeutic potential for type 2 diabetes in its early stages. The study emphasizes the underappreciated anti-diabetic potential of litchi seeds, which are typically thrown away as leftover fruit (Man et al., 2016). The influence of several cultivars' phenolic profiles on the uptake of glucose by HepG2 cells is examined in this study. It shows that pulps with high epicatechin or procyanidin content, especially those from the cultivars Hemaoli and

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Feizixiao, significantly increase the intake of glucose, which is consistent with their antioxidant activity. According to Lv et al. (2014), these results point to the possibility of some litchi cultivars serving as hypoglycemic meals, providing a viable means of preventing diabetes (Lv et al., 2014).

The hepatoprotective properties of the lychee types Gimjeng and Chakapat are examined in relation to their ability to protect rats' livers from CCl4-induced damage. It draws attention to the fruits' high levels of phenolic and vitamin C, which support their potent anti-apoptotic and antioxidant properties. The findings validate the extracts' potential as liver-protective medicines by demonstrating a substantial reduction in apoptotic cells and liver enzyme levels. Gimjeng outperformed Chakapat in terms of antioxidant performance (Bhoopat et al., 2011). In a research investigating substitutes for silymarin in the management of liver injury, litchi pericarp extract (LPE) exhibited hepatoprotective characteristics. Rich in polyphenolic substances such as epicatechin (EC) and procyanidin A2 (PA2), LPE has been shown to lower blood enzyme levels, protect liver cells from carbon tetrachloride poisoning, and maintain the structure and antioxidative enzyme activities of liver cells in mice. According to Chen et al. (2017), PA2 also shown promise in liver cell regeneration, indicating the possibility of LPE as a synergistic therapeutic strategy (Chen et al., 2017).

The study investigates the neuroprotective effects of lychee seed saponins (LSS) on rats with Alzheimer's disease (AD), showing that LSS inhibits apoptosis to improve cognitive performance and lessen neuronal destruction. It demonstrates that LSS administration upregulates Bcl-2 and downregulates caspase-3 mRNA and Bax protein expression, indicating its potential as a medication or dietary supplement for the prevention and treatment of AD. The results emphasize the function of LSS in controlling the apoptotic process to guard against neuronal damage brought on by AD (Wang et al., 2017). Two polyphenols in lychee seed fraction (LSF), catechin and procyanidin A2, have been shown to suppress neuroinflammation in BV-2 cells generated by Aβ in a study on Alzheimer's disease (AD). Through their modulation of the NF-κB signaling pathway, these drugs were discovered to decrease apoptosis and pro-inflammatory cytokines, providing prospective therapeutic insights for the treatment of AD. Future therapeutic development depends on additional in vivo confirmation of their anti-neuroinflammatory properties (Tang et al., 2018). The study uses a triple-transgenic mouse model to examine the effects of Oligonol®, a lychee fruit extract high in flavanols, on Alzheimer's disease (AD). The findings imply that early AD patients may benefit from clinical trials since continuous Oligonol® therapy lowers cognitive impairments and AD pathology, including tau and amyloid beta phosphorylation levels (Chen et al., 2021).

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Table 1. Pharmacological Properties of Lychee chinensis

Pharmacological Activity	Description	References
Antioxidant Activity	Lychee exhibits strong antioxidant properties due to its rich content of phenolic compounds, flavonoids, and condensed tannins, which protect against oxidative stress and mitochondrial dysfunction.	(Lopes et al., 2019; Contreras-Castro et al., 2022; Su et al., 2016; Dong et al., 2018; Kilari & Putta, 2016)
Anti-inflammatory Properties	Extracts from lychee seeds and pulp show significant anti-inflammatory effects, reducing intestinal barrier damage and proinflammatory pathways in mice. Lychee leaf extracts also display antibacterial properties.	(KC et al., 2021; Huang et al., 2021; Lopes et al., 2019)
Antimicrobial Effects	Lychee extracts from leaves and seeds demonstrate antimicrobial activity against various bacterial strains, including Escherichia coli, Staphylococcus aureus, Bacillus subtilis, and Proteus mirabilis.	(Lopes et al., 2019; Singh et al., 2013; Xiao et al., 2017; Huang et al., 2021)
Anticancer Potential	Lychee contains bioactive compounds such as flavonoids, sterols, triterpenes, and phenolics, which exhibit anticancer properties by inducing DNA damage, inhibiting cell growth, and promoting apoptosis in cancer cells.	(Sun et al., 2021; Huang et al., 2015; Wang et al., 2006)
Cardiovascular Benefits	Lychee extracts have been found to lower blood lipids, cardiac index, and hepatic lipids, reduce FAS gene expression, and increase the expression of LDL receptor and PPAR-α genes, thereby improving cardiovascular health.	(Yang et al., 2010; Sung et al., 2012)
Antidiabetic Effects	Lychee seed extracts improve insulin resistance, glucose tolerance, and lipid metabolism, indicating potential as a therapeutic agent for type 2 diabetes. Certain lychee cultivars also show promise as hypoglycemic foods.	(Man et al., 2016; Lv et al., 2014)
Hepatoprotective Properties	Lychee extracts, rich in phenolic compounds and vitamin C, demonstrate hepatoprotective effects by reducing liver enzyme levels, protecting liver cells, and maintaining antioxidant enzyme activities.	(Bhoopat et al., 2011; Chen et al., 2017)

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Neuroprotective Effects	Lychee seed saponins and polyphenols exhibit neuroprotective properties by inhibiting neuronal apoptosis, reducing pro-inflammatory cytokines, and improving cognitive function in Alzheimer's disease models.	(Wang et al., 2017; Tang et al., 2018; Chen et al., 2021)

5. Future Perspectives and Research Directions

Research on the lychee, *Lychee chinensis*, has provided important new understandings of its pharmacological, phytochemical, and botanical characteristics. Even with these developments, further research is still needed in a few areas to fully realize this amazing fruit's potential. Comprehensive pharmacological investigations, sustainable farming methods, and biotechnology advancements should be the main areas of future study.

Biotechnological Improvements

Biotechnological methods provide a possible way to improve fruit quality and lychee farming. Long juvenile periods and genetic heterozygosity are two obstacles that traditional breeding methods must overcome and that restrict the applications of conventional breeding (Pandey et al., 2017). These restrictions could be removed by developments in molecular biology and genetic engineering. Selective methods like as genetic transformation and marker-assisted selection can be employed to create cultivars that possess desired characteristics including resistance to disease, longer shelf life, and better nutritional value. For instance, lychee has previously demonstrated promise for the insertion of genes that provide a prolonged shelf life (Pandey et al., 2017). In order to make precise improvements, future research should concentrate on using CRISPR/Cas9 technology for targeted genetic changes.

Sustainable Cultivation Practices

Pests, illnesses, and climatic fluctuation are just a few of the biotic and abiotic factors that can affect lychee agriculture. The sustainability of lychee production over the long run depends on the use of sustainable agriculture methods. It is important to continue developing and implementing Integrated Pest Management (IPM) techniques, which integrate biological control agents with little or no chemical inputs. For example, using parasitoids like Quadrastichus spp. has demonstrated potential in Taiwan for managing lychee pests (Chao et al., 2023). Furthermore, as potassium usage is essential for both fruit quality and productivity, research should concentrate on improving fertilization techniques (Yang et al., 2015). Technologies used in precision agriculture, such drone-based monitoring and sensors for measuring soil moisture, can improve the effectiveness of fertilizer and water management.

Pharmacological Studies

Even though lychee's therapeutic benefits have been the subject of several studies, more thorough pharmacological research is still required. According to Dong et al. (2018), the

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bioactive components of lychee, such as flavonoids, triterpenoids, and phenolics, have been shown to offer a number of health advantages, including anti-inflammatory, anticancer, and antioxidant properties (Dong et al., 2018). But the majority of research has been done using animal models or in vitro. To confirm these results in people and ascertain the safety and effectiveness of chemicals obtained from lychees for medicinal purposes, clinical studies are required.

Exploration of New Bioactive Compounds

Lychee has a broad and varied phytochemical profile. The goal of future studies should be to separate and identify novel bioactive substances from various plant sections, such as the pericarp, seeds, and leaves. Novel substances with potential health advantages can be identified more easily with the use of sophisticated analytical techniques like nuclear magnetic resonance (NMR) spectroscopy and high-resolution mass spectrometry (HRMS). Furthermore, metabolomics techniques can offer a thorough comprehension of the metabolic pathways involved in these chemicals' formation (Lopes et al., 2019).

Nutritional Enhancement and Functional Foods

Lychee is a significant ingredient in functional meals because of its rich nutritional profile, which includes its high vitamin C concentration and antioxidant qualities. Research ought to focus on creating nutraceuticals and functional meals based on lychee that have particular health advantages. For instance, lychee extracts might be included to dietary supplements meant to decrease inflammation or strengthen the immune system. Furthermore, the creation of snacks and drinks enhanced with lychee may satisfy the increasing market for natural, healthful goods.

Post-Harvest Technologies

In the cultivation of lychees, post-harvest losses from pericarp browning and spoiling pose serious issues. Post-harvest technological advancements are essential for preserving the quality and prolonging the shelf life of lychee fruits. Modified atmosphere packaging (MAP) and edible coatings are two examples of creative packaging solutions that might lessen oxidative damage and microbiological contamination. Additionally, as an alternative to artificial chemicals, the use of natural preservatives including plant extracts with antibacterial qualities have to be looked into (Basu and Kumar, 2017).

Environmental Impact and Climate Change

The production of lychee is at risk from climate change because of its effects on temperature, precipitation patterns, and the frequency of pests and illnesses. The goal of research should be to create lychee cultivars that are resistant to emerging pests and can tolerate harsh environmental conditions. Furthermore, research on the greenhouse gas emissions and water usage efficiency associated with lychee farming might help develop sustainable methods that reduce their negative effects on the environment.

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Conclusion

Tropical fruits like lychee (Litchi chinensis Sonn.) are rich in nutrients, have therapeutic uses, and are valuable economically. This study emphasizes the ancient usage and contemporary health advantages of lychee by highlighting its extensive botanical, phytochemical, and pharmacological characteristics. Its antioxidant, anti-inflammatory, and anticancer activities are attributed to a wide range of bioactive chemicals, including phenolics, flavonoids, and triterpenoids, which have been discovered by sophisticated extraction and analysis procedures. To fully fulfill the promise of lychee, future research should concentrate on biotechnological advancements, sustainable growing methods, and clinical trials. Through the integration of contemporary scientific methodologies with conventional wisdom, lychee has promise for continued development as a medicinal agent and valued functional food that promotes health and prevents disease.

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