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REVIEW

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Litchi chinensis: nutritional, functional, and nutraceutical properties

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Abstract

Litchi chinensis is a tree in the Sapindaceae family. It is originally from China but grows in countries with tropical or subtropical climates. It has great commercial value because of its juiciness and fresh pulp. It is a rich source of nutrients and bioactive compounds (procyanidin type A and B, epicatechin, rutin, and quercetin). The compounds present in litchi have been reported to confer functional properties, such as antioxidant, anticancer, antimicrobial, and nutraceutical properties, and are believed to have the potential to develop new functional foods or products. This review summarizes the botanical characteristics and cultivation methods of litchis. Its nutritional composition has also been described, which includes a macronutrient and micronutrient profile; its functional properties, such as antioxidant, anti-inflammatory, and anticancer potential; and the relationship between bioactive compounds and their medicinal potential. Despite their beneficial qualities, litchi fruits face significant challenges in terms of conservation. Rapid browning of the pericarp is a major problem resulting in considerable product loss. Therefore, producers must develop sustainable strategies for the conservation and valorization of fruits and their byproducts. Therefore, it is necessary to look for innovative solutions that take advantage of the bioactive properties of litchi, which can be used to develop innovative pharmaceutical, food, or cosmetic products.

Keywords Bioactive compounds, Functional properties, Litchi chinensis, Traditional medicine

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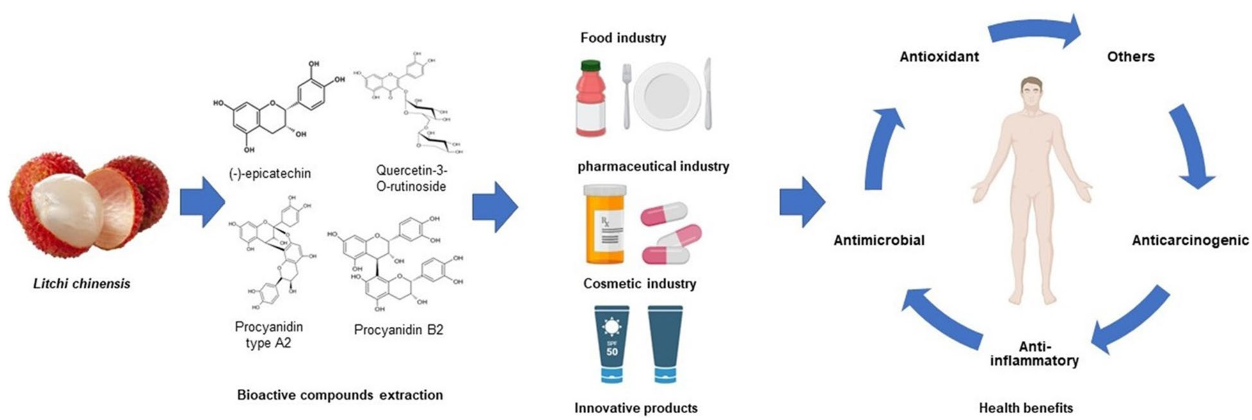
Graphical Abstract



Introduction

Litchi chinensis, a tree belonging to the Sapindaceae family, is commonly known as litchi or lychee and is native to China. It is widely cultivated in India, Australia, Africa, Israel, Asia, and Mexico, with an estimated global production of approximately 2.1 million tons. China is the leading producer, accounting for 90% of global production (Castillo-Olvera et al., 2022; Qu et al., 2021). In Mexico, litchi production is estimated to be approximately 24 thousand hectares, with Veracruz, Puebla, and Oaxaca being the primary producers (Aguas-Atlahu et al., 2014). Litchi is an economically important fruit due to its attractive red color, sweet and juicy pulp, and high content of bioactive compounds. It is also an excellent source of nutrients such as polysaccharides, vitamins, polyphenols (flavonoids, steroids, terpenes, phenols, and flavan-3-ol molecules), and minerals (Kumar et al., 2020; Qu et al., 2021). These compounds confer functional and nutraceutical properties, but the fruit also contains nutrients, such as nitrates, oxalic acid, and phenolic compounds. However, these compounds are not present in amounts that are harmful to human health (Estela et al., 2015).

The bioactive compounds present in litchi, such as epicatechin, procyanidin A2, malvinide-3-glucoside, cyanidin-3-rutinoside, and kaempferol, have been found to impart antioxidant, anti-inflammatory, antimicrobial, and anticancer activities (Upadhyaya & Upadhyaya, 2017). These properties protect cells from oxidative damage and reduce the risk of developing chronic diseases (Chukwuma et al., 2021). Furthermore, bioactive compounds present in litchi fruits have been found to confer nutraceutical properties, making them potential therapeutic sources (Chukwuma et al., 2021).

Litchi has been used in traditional medicine to treat a variety of ailments, such as cough, testicular swelling, stomach ulcers, and pain, thereby underscoring its potential for use in the development of products or functional foods across multiple industries, including food, pharmaceutical, and cosmetic sectors (Castillo-Olvera et al., 2022; Mir & Perveen, 2022).

In this review, the nutritional profile, functional properties, and biological activity of litchi byproducts were examined and evaluated, given their potential to serve as a source of bioactive compounds with promising applications in the pharmaceutical, food, and cosmetic industries owing to their high content of such compounds.

Botanical and taxonomic characteristics of the *litchi* tree

The Litchi tree is a medium-sized plant that can grow up to 10–15 m in height. The evergreen, pinnate, and leathery leaves are divided into two to nine elliptic or lanceolate, acuminate, and glabrous leaflets 5–7 cm long, which are red in the early stages but become glossy and bright green as the tree matures (Fig. 1). The flowers are small, greenish-white to yellow, have a distinctive fragrance, and are borne by branched terminal panicles that are either male or female. The calyx was tetramerous, and the corolla was absent. The fruits are covered by a rough, leathery, deep red or pinkish red to strawberry red rind or shell that envelops the fruit, which is oval, heart-shaped, or nearly round, 2–5 cm in diameter, with a deep red or pinkish red to strawberry red color surrounding the fruit. The aril, which is the edible part of the fruit, is fleshy, translucent, firm, and milky-white in color, and has a sweet, fragrant, and delicious taste. The seed is located inside the aril and is

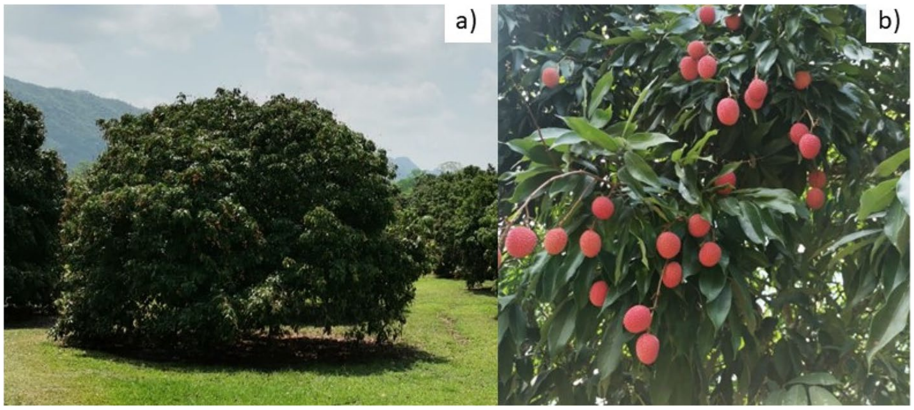


Fig. 1 *Litchi chinensis* tree from a Huichihuayan, S.L.P. Mexico (**a**), Fruit of *L. chinensis* (**b**)

1–2 cm long, globular, or oblong, with a smooth, shiny brown or reddish-brown surface (Anjum et al., 2017; Soni & Agrawal, 2017; Zhao et al., 2020). It is worth noting that litchi is grown worldwide in tropical and subtropical regions, such as Hawaii, India, Israel, Australia, Mexico, subtropical Asia, Indonesia, Thailand, and the Philippines. According to recent estimates, the global production of litchi is estimated at 2.11 million tons, with more than 90% of this production occurring in China (Chaudhary & Dhaka, 2017; Ibrahim & Mohamed, 2015; Yao et al., 2021). In Mexico, the Agricultural and Fisheries Information Service (SIAP) reports that there are approximately 24 thousand hectares of litchi cultivated, with an annual production of over 28 thousand tons. The main buyers of this fruit are the United States, the United Kingdom, and France, which purchase more than six million dollars of litchi each year (Fig. 2). Litchi fruit was first introduced in Mexico at the beginning of the twentieth century and the first commercial plantations were established in Sinaloa, Veracruz, and San Luis Potosí. Currently, litchi is cultivated in 13 states, with Veracruz, Puebla, and Oaxaca being the primary producers (Fig. 2). The most widely cultivated commercial varieties of litchi

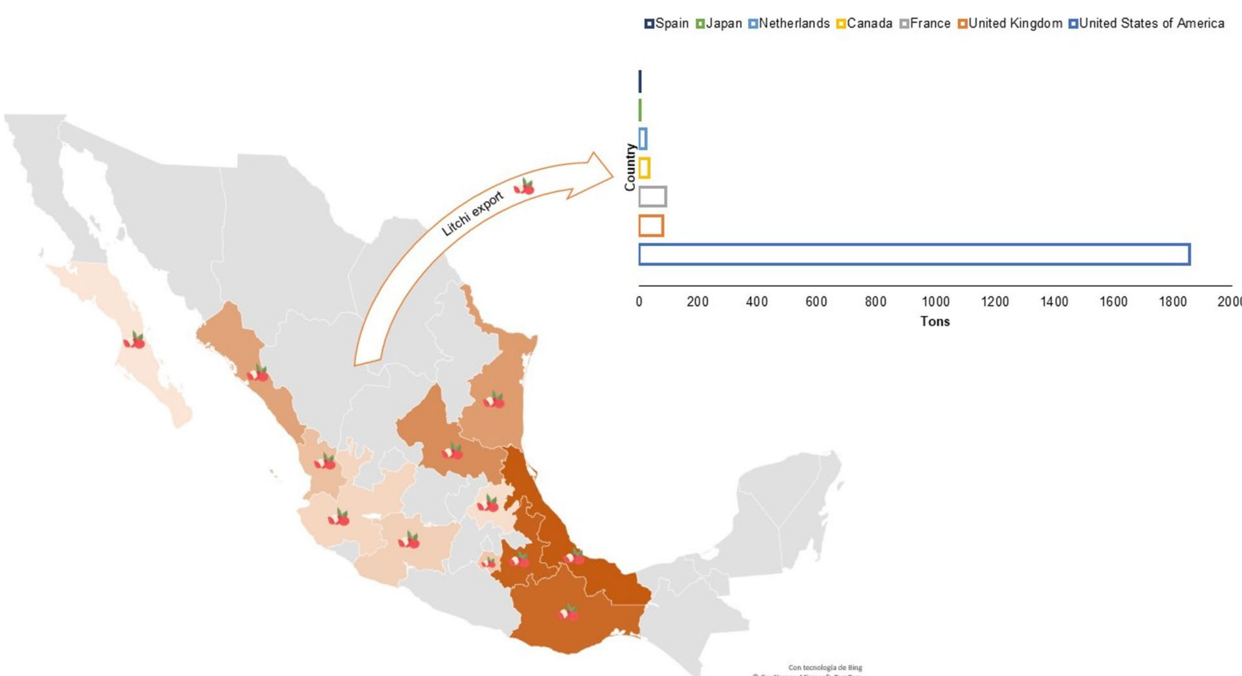


Fig. 2 Map of Mexico with *L. chinensis*-producing states and main *L. chinensis* buying countries

in Mexico are Mauritius and Brewster, whereas other varieties grown in Mexico include Fai Fi Ziu, Groff, Hak Yip, Salathiel, Kway May Pink, and Wai Che (Aguas et al., 2014; Secretaria de Agricultura y Desarrollo rural, 2022).

The problem of *litchi* conservation

Litchi, a commercially valuable fruit, is prized for its sweet and juicy pulp. Due to its non-climacteric nature, it is harvested at full maturity when the pericarp exhibits an intense red color. The fruit's short season, lasting approximately one month from May to June, is the primary marketing period. However, its high perishability and short shelf life, lasting only two–three days under typical environmental conditions, present a significant challenge. This decline in quality is attributed to enzymatic and non-enzymatic browning, pericarp desiccation, weight loss, anthocyanin degradation, and the action of polyphenol oxidase and peroxidase enzymes, which results in the oxidation of polyphenolic compounds and the formation of brown pigments (Reichel et al., 2017; Verma et al., 2018; Yun et al., 2021). Browning of the pericarp is a major hurdle for producers seeking to commercially exploit the fruit, and various strategies have been implemented to extend its shelf life. Currently, sulfur treatment is widely used to maintain fruit quality, although it is a readily available and inexpensive preservation method. However, excessive sulfur residues (over 10 mg/kg) can result in health issues and prohibit marketing (Deshi et al., 2021; Tang et al., 2020). Other fruit preservation methods include the use of preservatives, waxes or coatings, irradiation, freezing, chemical treatments, controlled atmospheres, ultraviolet treatments, ultrasonic treatments, or a combination of these methods. However, the excessive use of chemicals and preservatives can result in environmental pollution and pose a threat to human health, leading to displeasure or rejection by consumers (Liu et al., 2023; Yao et al., 2021). Another issue encountered in litchi is the serious disease of leaves, flowers, and fruit caused by fungal infection, which can result in decay, decreased economic value, and shortened shelf life. Chemical fungicides, such as dimethomorph, propamocarb, and metalaxyl, have been used to control this deterioration; however, the use of these chemicals poses a risk to consumers, contributes to environmental contamination, generates pathogen resistance, and creates serious food safety problems (Situ et al., 2023; Yu et al., 2023). Despite these treatments, the product continues to be lost and exhibits low diversification. Moreover, these treatments are often not feasible for producers due to availability and economics, highlighting the need for the development of new, sustainable strategies for the processing and conservation of litchi.

Nutritional value of *litchi* chinensis

Litchi, a fruit renowned for its delicious taste, juiciness, and nutritional properties, has been endorsed by its compositional profile. Its edible portion is a rich source of essential nutrients including polysaccharides, polyphenols, vitamins, and minerals. The presence of bioactive compounds in fruits and foods is of great importance to human health, and the high concentrations of these compounds in litchi highlight its significant nutritional value (Zhao et al., 2020).

Macronutrient and micronutrient profile

Macronutrients and micronutrients play a crucial role in maintaining a healthy diet. A balanced intake of proteins, carbohydrates, fats, vitamins, and minerals is essential for the overall well-being of the human body. Macronutrients such as proteins, carbohydrates, and fats serve multiple functions in the body, including energy production, tissue growth and repair, and cell signaling. Micronutrients, including vitamins and minerals, work together to support various body functions.

The litchi fruit is a rich source of both macronutrients and micronutrients. It contains a high percentage of water in its pulp, seed, and pericarp, ranging from 76

Table 1 Macronutrient and micronutrient contents of *L. chinensis* fruit per 100 g of fresh fruits

Nutritional composition of *litchi chinensis* per 100 g fresh fruit		
Macronutrients		
Humidity	71.11-84 g	(Pareek, 2016; Silva et al., 2020)
Protein	0.7-4.12 g	
Lipids	0.1-3.75 g	
Carbohydrates	15-89 g	
Macronutrients		
Vitamin C (ascorbic acid)	15 – 36 mg	(Pareek, 2016; Zhao et al., 2020)
Thiamine	0.02 mg	
Niacin	1.1 mg	
Riboflavin	0.07 mg	
Phosphorus	25 – 35 mg	
Iron (mg) 0,7	0.21 – 0.7 mg	
Calcium (mg)	4 – 4.90 mg	
Potassium mg	140 – 180 mg	
Magnesium	10.30 – 16 mg	
Sodium	3.20 – 7.90 mg	
Manganese	0.07 – 0.33 mg	
Zinc	0.16 – 0.28 mg	
Copper	0.17 – 0.23 mg	

to 91%. Additionally, litchi fruit contains carbohydrates, fats, proteins, amino acids, phenols, pectin, minerals, and vitamins (Table 1) (Pareek, 2016). The litchi fruit is particularly rich in minerals, including calcium, iron, phosphorus, potassium, sodium, and zinc. Furthermore, it contains a high content of vitamins, such as vitamin E, B6, folate, niacin, thiamine, and riboflavin. According to Anjum et al. (2017), itchi fruit contains various fatty acids, including linoleic acid, palmitic acid, stearic acid, myristic acid, and amino acids such as lysine, tryptophan, and methionine. Kilari and Putta, (2016) reported that litchi fruit contains 72 mg of vitamin C per 100 g, which accounts for 86% of the daily intake, and noted that the intake of 9 litchis meets this requirement. Moreover, the raw fruit contains several essential minerals, including copper (7%), phosphorus (4%), and potassium (4%), at an intake of 100 g, and is low in saturated fats and sodium.

The organic acid content of litchi pulp is predominantly composed of malic acid (80%), along with other acids, such as tartaric acid, citric acid, and ascorbic acid. The concentration of ascorbic acid in litchi pulp varies depending on the variety, with values ranging from 21–31 mg/100 g fresh weight for Hawaiian cultivars, 24.39 mg/100 g fresh weight for South African cultivars, and 17.64 mg/100 g fresh weight for litchi fruit in general. Furthermore, litchi pulp contains a small quantity of pectin (0.42%), protein (0.8–1%), and lipids (less than 1%) in the edible portion. Litchi pulp is a rich source of carbohydrates, which has been isolated and purified as a polysaccharide composed of various monosaccharides, including arabinose, galactose, mannose, rhamnose, glucose, as well as uronic acid. It also contained neutral sugars and proteins. The polysaccharides found in litchi may play an important role in health. The fractions of litchi pulp have also been isolated and characterized as arabinogalactan by gas chromatography, and a protein-bound heteropolysaccharide composed of arabinose, rhamnose, galactose, and glucose has been identified. Additionally, polysaccharides composed of rhamnose, fucose, mannose, and galactose, with arabinogalactan as the main component have been reported (Chen et al., 2023).

Litchi pericarp residues and litchi seeds are rich in various nutrients, including organic acids such as citric, succinic, luvulinic, glutaric, malonic, lactic, and ascorbic acids, as well as macronutrients such as carbohydrates (mannose, galactose, and arabinose) (Jiang et al., 2021; Sivakumar, 2011; Yang et al., 2006). The litchi pericarp residues make up 15% of the fruit weight and contain these nutrients. Litchi seeds are also rich in nutrients, containing 40.7% starch polysaccharides, 4.93% protein, 24.5% crude fiber, 3.2% oil content, and minerals such as magnesium, phosphorus, and calcium with percentages of 0.28%, 0.21%, and 0.11%, respectively (Bangar et al., 2021). In addition, litchi seeds contain 42% cyclopropanoic acid, 27% linoleic acid, 12% palmitic acid, and 11% linolenic acid (Bangar et al., 2021). Other polysaccharides have been identified in litchi seeds that were extracted in aqueous solutions and concentrated by adding anhydrous ethanol to concentrations of 40% and 80%. These polysaccharides are composed of arabinose, fructose, galactose, glucose, and mannose and have strong biological activity in DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging (Chen et al., 2011). Recently, heteropolysaccharide-type monosaccharides composed of arabinose, mannose, glucose, and galactose have been isolated and identified from litchi seeds (Wu et al., 2020).

The relationship between plant nutrition and fruit nutrient content

The influence of various environmental factors, such as geographical location, biotic and abiotic conditions, and other environmental factors, on the macronutrient and micronutrient content of litchi plants is well documented (Prem et al., 2022). Nutrition plays a critical role in flowering, fruit set, and sustainable fruit production of litchi plants, and productivity is influenced by climatic factors, vegetative growth, plant health, and soil fertility (Prem et al., 2022). Therefore, proper fertilization management is essential to ensure optimal nutrient content and productivity (Prem et al., 2022).

Considering the limited scientific data available on soil fertility, many litchi growers tend to apply fertilizers without proper consideration, which often leads to reduced fruit yield, quality, and color (Jain et al., 2022; Yi et al., 2022). Despite the potential to increase fruit yield through fertilization, improper fertilizer application and the absence of essential nutrients can cause fluctuations in crop yield and nutritional content (Jain et al., 2022; Yi et al., 2022).

Studies have demonstrated that the levels of nitrogen (N) and potassium (K) in leaves, as well as their availability in the soil, are closely related to litchi yield and quality (Jain et al., 2022), and excess K in leaves can enhance photosynthesis, water use efficiency, stomatal conductance, yield, and quality of litchi (Jain et al., 2022). Therefore, it is essential to optimize the application of fertilizers and other nutrient sources to ensure optimal nutrition in litchi. In a study conducted by Prem et al. (2022) on an Indian litchi crop, the nutrient composition of litchi leaves was examined. The results revealed that the calcium (Ca) content was less than 28.1% in most orchards, followed by nitrogen (N) at 26.4% and manganese (Mn) at 23.2%. After the application of a nutrient matrix in the orchard, a positive and significant correlation was found for K, Ca, and Mn content. Additionally, foliar N and K were significantly correlated with yield, caliber, weight, pulp quantity, and pulp/seed ratio. The study also found that the contents of N and K were mainly related to the improvement in fruit yield, whereas the contents of Ca, Zn, Fe, and Cu significantly influenced the physical and quality parameters of litchi.

Antinutrients

Nutrients are regularly known to be beneficial to human health. Antinutrients, on the other hand, are less well known, highly bioactive, and have harmful effects; however, they also have beneficial effects on the human body. These compounds are widely available in foods of plant origin. Although antinutrients may have negative effects on nutrient absorption in the human body, they also exhibit high biological activity (Table 2). In addition, they play an important role in different biological or ecological functions of plants, functioning as defense mechanisms against microorganisms, insects, herbivorous animals, and allelopathy, as well as in attracting pollinators and seed dispersers. In addition, antinutrients may be important for plant competition and the regulation of plant growth and development. Compounds (antinutrients), whether naturally occurring or synthetic, can interfere with the absorption of essential nutrients and may be responsible for the harmful effects related to nutrient absorption. This depends on the amount of antinutrient ingested. Some of the symptoms that occur when consuming high amounts are nausea, headaches, skin rashes, swelling, and nutritional deficiencies (Kumar et al., 2022; Popova & Mihaylova, 2019). Some common antinutrients include lectins, phylates, oxalates, phenolic compounds, tannins, nitrates, phytic acid, and oligosaccharides. Enzyme inhibitors such as trypsin, chemotrypsin, and α-amylase inhibitors were also incorporated into the study. These compounds are commonly found in a range of foods including grains, legumes, vegetables, and fruits. While some of these compounds can be reduced or eliminated through various processing methods such as sprouting, cooking, milling, autoclaving, and fermentation, others may have beneficial effects at low concentrations. Notably, some of these compounds can be removed or reduced using the appropriate processing methods (Kumar et al., 2022; Popova & Mihaylova, 2019; Samtiya et al., 2020; Thakur et al., 2019).

In this context, litchi is a fruit that, owing to its short postharvest life, must be consumed fresh, dehydrated, canned, in juice, ice cream, or in beverages such as juice or fermented as liquor. In a variety of litchi (Bengal), The presence and quantity of anti-nutritional components in the fresh pulp, pericarp, seed, and both fresh and processed fruits were studied. The highest levels of anti-nutritional compounds were found in the litchi pericarp and seed; however, the pulp, both fresh and dried, had lower levels (Estela et al., 2015). Table 3 shows the content of each antinutrient evaluated, and it was observed that drying influences the content of antinutrients. An increase in the phenolic content was observed. There was no significant change in the nitrate content, and oxalic acid was not present. However, the inhibitor activity increased for trypsin and α-amylase inhibitors, and decreased for lipase inhibitors (Estela et al., 2015) Litchi pericarp residues are generally discarded by the industry and the consumer, so they are of industrial interest because the antinutrients present in litchi are not found in amounts harmful to health and can be used for the development of new products or as a nutrient alternative.

Table 2 Antinutrient content in fresh and dried *L. chinensis* per 100 g

Part of the fruit	Phenolic compounds (mg of tannic acid equivalent / 100 gr fruit)	Nitrate (mg)	Oxalic acid
Fresh pericarp	22.0	339	-
Fresh seed	11.45	148	-
Fresh pulp	21	51	-
Dry pericarp	71	351	-
Dry seed	34	154	
Inhibitory activity			
Part of the fruit	Trypsin (TIU g)[a]	α-amilasa (AIU 100 g)[a]	Lipase (LIUg)[a]
Fresh pericarp	14.61	-	0.19
Fresh seed	3.17	-	0.22
Fresh pulp	-	7.23	0.75
Dry pericarp	24.75	1.13	0.06
Dry seed	13.83	1.08	0.07

[a] Activity expressed in trypsin inhibitor units (TIU), α-amylase inhibitor units (AIU) and lipase inhibitor units (LUI). Adapted from (Estela et al., 2015)

Table 3 Antioxidant activity of different compounds bioactive of *Litchi chinensis*

Part of the fruit	Identified bioactive compounds	Extraction conditions	Study models	Concentration	Reference
Pericarp	A-type procyanidin	Ethanol 70% at 50 °C for 2 h Purification by AB-8 macroporous resin column	In vivo Male Sprague–Dawley rats	IC_{50} 9.34 µg/mL DPPH IC_{50}143 µg /mL Hydroxyl radical (-OH)	(Sui et al., 2021)
	(-)-epicatechin Procyanidin	Ethanol 70% in a water bath at 70 °C and Purification AB-8 resin column	In vitro	IC_{50} 0.148–0.364 µg/mL Hydrogen peroxide (H2O2) IC_{50} 23.03–56.01 µg /mL Superoxide radical (O2-) IC_{50} 7.3–14.8 µg /mL DPPH IC_{50} 162.6–350.6 µg/mL Hydroxyl radical (OH)	(Zhou et al., 2019)
	4-hydroxycinnamic acid,, 3,4-dihydroxy-cinnamic acid, and proanthocyanidin A2	Ultrasonic-microwave, power 307 W, time 17 min, temperature 46 °C, and material.liquid and biotransformation by *Lactobacillud plantarum*	In vitro	IC_{50} 2.86 µg /mL DPPH IC_{50} 4.16 µg /mL ABTS 40.88 umol TE/mg DW ORAC	(Liu et al., 2023)
	Procyanidin A2, B2 epicatechin, rutin, quercetin, (+)-catechin, (-)-epigallocatechin, epigallocatechin gallate	The freeze drying, continued in a saturated aqueous Na2CO3 solution at pH 10 at 60 °C	In vitro	IC_{50} 0.68 µg/mLDPPH IC50 0.83 µg /mL ABTS	(Yang et al., 2022)
Pulp	Uronic acid Galactose Mannose	Ethanol 80% at 4 °C for 24 h	In vitro	22.08 – 28.14 umol TE/g DW ORAC 4.72 – 10.79 µmol QE/ g DW Celular antioxidant activity	(Huang et al., 2015)
	Epicatechin, procyanidin B2, procyanidin C1, and A-type procyanidin trimer	Lyophilized, 70% aqueuos methanol by sonication for 30 min	In vitro	IC_{50} 1.88 – 2.82 µg/mL DPPH IC_{50} 1.52 – 2.71 µg/mL ABTS	(Lv et al., 2015)
Seed	Flavonoids, terpenoids, tannis, saponins, and alkaloids	Ethanol 30% at 4 °C for 72 h with occasional shaking	In vitro	IC_{50} 274 µg /mL DPPH IC_{50} 31 µg/mL ABTS	(Aktar et al., 2022)
	Polymeric proanthocyanidins	Acetone 70% with 0.1% ascorbic acid	In vitro	IC_{50} 87.52 µg/mL DPPH IC_{50} 73.56 µg /mL ABTS 5.51 mmol AAE/g FRAP	(Zhou et al., 2011)

Functional properties of *Litchi* chinensis

According to the Food and Agriculture Organization of the United Nations (FAO), functional food is defined as a source that provides the human body with the necessary amounts of nutrients, such as proteins, carbohydrates, fats, vitamins, and minerals, to maintain health. According to the European Food Safety Authority (EFSA), a food item can be considered beneficial if it provides benefits beyond basic nutritional content, such as improving health and well-being, and reducing the risk of disease. However, the definition of "health claims" in the U.S. may differ from that of the EFSA. The functional Center (FFC) describes it as a real food or biologically active compound that, in the right nontoxic amounts, benefits human health or provides scientifically validated uses for the prevention, treatment, and control of chronic or symbiotic diseases. In this context, it could be said that a functional food is one that, in addition to its nutritional composition, contains bioactive compounds that improve the target of the organism, providing health benefits and treatment or control of diseases (Sheikha, 2022). Therefore, in recent years, great attention has been paid to functional foods, which have additional functions related to health promotion or disease prevention.

In this context, litchi fruit is currently a potential functional food because of its nutraceutical properties, chemical composition, and biological activities, such as antioxidant, anti-inflammatory, antimicrobial, and anticarcinogenic activities. Not only the edible part of the fruit, the pulp, which contains bioactive compounds that exert biological activities but also the pericarp and seed are enriched with potentially beneficial properties (Emanuele et al., 2017). It has been reported that litchi pericarps have been used in traditional medicine with hemostatic and acesodyne functions in ancient times. Therefore, a high bioactive compound content can prevent certain diseases. For example, a high concentration of procyanidins has been reported to be effective for the treatment of hyperuricemia and/or gout and has a protective effect against cardiovascular diseases. Therefore, they have been considered natural dietary supplements because of their high biological activity in vivo (Lasrado & Rai, 2018; Varzakas et al., 2016).

On the other hand, litchi seeds, which are considered waste products, are rich in starch. Thus, interest in litchi seeds has increased because of their unique functional and structural properties, which are attributed to their low amylose and high amylopectin contents. The starch contained in the seed has a higher pasting viscosity than other starches such as mango seeds or logans, which are suitable for delayed drug delivery (Morales-Trejo et al., 2022).

Functional characteristics of *Litchi* chinensis, such as antioxidant, anti-inflammatory, antimicrobial, and other biological activities

In traditional Chinese medicine, litchi fruit has been used to treat various conditions including wounds, neuralgic pain, testicular inflammation, nerve inflammation, gastralgia, orchitis, hernia, intestinal problems, digestive ulcers, and excretory and reproductive problems (Anjum et al., 2017; Ibrahim & Mohamed, 2015). Recent research has shown that crude and purified extracts of *L. chinensis* have a wide range of biological activities, such as antioxidant, anti-inflammatory, antimicrobial, anti-obesity, hepatoprotective, anticancer, antidiabetic, and antiviral activities. These activities are attributed to the high content of bioactive compounds present in *L. chinensis* fruit; the functional characteristics of litchi are described below (Upadhyaya & Upadhyaya, 2017).

Antioxidant potential

Oxidative damage caused by reactive oxygen species can contributes to the development and progression of neurogenic, cardiovascular, and carcinogenic diseases. Antioxidants such as flavonoids, tannins, and phenolic acids can inhibit the production of free radicals by chelating metal ions (Jaiswal & Kumar, 2015; Kumar et al., 2017). Therefore, antioxidant application or enhancement is a promising strategy for combating the effects of oxidative damage.

The mechanism of antioxidant action of litchi is due to its high content of bioactive compounds, in the literature mentions that these bioactive compounds act as scavengers or inhibitors of free radicals using assays such as DPPH (2,2-diphenyl-1-picrylhydrazyl), 2, 2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS), ferric reducing antioxidant power (FRAP) and reactive oxygen species, for example the DPPH assay when discolored by the donation of an antioxidant compound the DPPH is discolored and can be quantified from the absorbance changes. Therefore, bioactive compounds in litchi donate electrons to free radicals, such as superoxide radicals (O_2), hydrogen peroxide (H_2O_2), hydroxyl radical (OH), hypochlorous acid (HOCl), and peroxyl radical (ROO-), as well as enzymatic and non-enzymatic oxidation (Jaiswal & Kumar, 2015; Kumar et al., 2017; Putta & Kilari, 2017). Free radicals can also be inhibited by a chelation reaction using metal ions with the help of bioactive compounds present in litchi (Upadhyaya & Upadhyaya, 2017). They also inhibit xanthine oxidase, an enzyme that catalyzes the oxidation of hypoxanthine to xanthine and subsequently to uric acid, producing oxygen-free radicals, including hydrogen peroxide, as a by-product. Therefore, compounds present in litchi can neutralize free radicals and protect cells and tissues from oxidative damage. (Sui et al., 2021).

Table 3 shows the different IC_{50} values of the antioxidant capacity of the compounds identified in *L. chinensis*, as well as their different extraction methods. It can be observed that the IC_{50} concentration differs according to the type of extraction and assay; however, it is important to mention that the IC_{50} value is low and has a higher antioxidant capacity, suggesting that the bioactive compounds present in litchi have a high electron-donating capacity, which allows the neutralization of free radicals and protection against oxidative damage.

Litchi pericarp was reported to have antioxidant activity due to its content of polymeric compounds, such as proanthocyanidins. The antioxidant capacity of these compounds has been demonstrated by their ability to inhibit DPPH and ABTS radicals at concentrations of 0.096 and 0.086 mg/mL, respectively (Zhou et al., 2011). Such activity may vary depending on the chemical structure, degree of polymerization, and type of binding of bioactive compounds present in litchi and is related to the presence of compounds such as epicatechin, procyanidin A2, procyanidin B2, and procyanidin trimer type A (Li et al., 2012).

In addition, procyanidins have been shown to have regenerative effects on damaged liver cells as well as beneficial effects on diabetes, lipid metabolism, and the reduction of oxidative stress caused by hyperglycemia (Chung et al., 2017; X. Li et al., 2018). Taken together, these studies indicate that litchi extracts have a high antioxidant potential owing to their electron-donating capacity (Kumar et al., 2017).

Anti-inflammatory potential

Inflammation is a protective mechanism initiated by the immune system in response to various harmful stimuli including injuries, infections, and toxic substances. Its primary objective is to safeguard the body and facilitate restoration of the affected tissues. However, uncontrolled inflammation can cause tissue and cell damage, triggering chronic inflammatory diseases and even cancer. Treatment with standard anti-inflammatory drugs, such as steroids and non-steroids, has undesirable side effects due to prolonged use, and some of the disorders that occur include gastrointestinal disorders, immunodeficiency, and mood disorders. Currently, therapeutic alternatives for the treatment of selective inflammatory responses are being developed from natural products to develop safer and more effective therapies for the control of inflammation without causing side effects (Kc et al., 2021; Rivera et al., 2022).

The proinflammatory mediator of inflammation is nitric oxide (NO), which is produced by inducible nitric oxide synthase (iNOS), which is induced by the proinflammatory cytokine interleukin 1β (IL-1β). On the other hand, interleukin 6 (IL-6), prostaglandins and tumor necrosis factor α (TNF-α) are also found. IL-6 is produced by different cells, such as T lymphocytes, macrophages, and adipocytes, as an adipokine. Therefore, the inhibition of some proinflammatory mediators by some compounds indicates that it has an anti-inflammatory effect (Nishizawa et al., 2011).

Litchi is rich in flavan-3-ol type bioactive compounds, it has been reported to have a remarkable ability to reduce nitric oxide (NO) production by suppressing the expression of inflammatory genes such as inducible nitric oxide synthase (iNOS), it also regulates the transcription of inflammatory genes by decreasing the promoter activity of the iNOS gene, which causes the decrease in NO production induced by interleukin 1β. It also has an inhibitory effect on the activation of nuclear factor kB (NF-kB), which is a key regulator of the expression of inflammatory genes; inhibition of proinflammatory mediators such as cyclooxygenase-2 (COX-2) and prostaglandin E2 (PGE2); suppression of α/β kinase inhibitor κB activation; and negative regulation of extracellular signal-regulated kinase (ERK) and Janus kinase 2 (JAK2)/signal transducer and activator of transcription 3 (STAT3) activation pathways. Therefore, the compounds present in litchi act by inhibiting these proinflammatory mediators and effectively suppressing inflammation (Nishizawa et al., 2011; Yamanishi et al., 2014; Yang et al., 2014; Zhou et al., 2012).

Considering its composition, litchi possesses a diverse array of bioactive compounds that have potential anti-inflammatory effects and can affect various pathological processes related to both acute and chronic inflammation. Various studies have identified compounds such as epicatechin, procyanidin A2, and methyl jasmonate that can decrease the levels of inflammatory markers (Yao et al., 2021). On the other hand, phytochemical studies have been conducted on litchi seed, in which several compounds analogous to methyl jasmonate, lignanoside, and flavonoids have been isolated; these compounds were shown to have anti-inflammatory properties (Dong et al., 2019). In another study, the acute toxicity, anti-inflammatory, and analgesic effects of litchi seed ethanol extract in vivo were evaluated in Wistar albino rats, and the results showed that the extract was non-toxic up to 5000 mg/kg body weight. Moreover, it significantly inhibits carrageenan- and hot-plate-induced rat paw edema (Kc et al., 2021). Taken together, the bioactive compounds of litchi extract may be therapeutic candidates as safe and effective anti-inflammatory agents or may be consumed as anti-inflammatory agents in functional foods.

Antimicrobial potential

The antimicrobial activity of litchi extracts has not been widely studied; however, some phenolic compounds with activity have been reported in aqueous extracts. Significant inhibition of microorganisms such as *Salmonella typhi*, *Vibrio cholerae*, *Shigella dysenteriae*, *Enterococcus faecalis*, *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, and *Candida albicans* has been reported using the aqueous extract of litchi through well diffusion studies. On the other hand, the acetonic leaf extract and aqueous seed extract have also been reported to have activity against gram-positive pathogenic bacteria such as *S. aureus*, *Streptococcus pyogenes*, and *Bacilllus subtillis* and gram-negative bacteria such as *E. coli* and *Pseudomonas aeruginosa*. Antimicrobial compounds have been identified in litchi pulp, seeds, and pericarp extracts, such as epicatechin, procyanidin A2 and rutin. It is worth mentioning that these compounds have been found in ethanol and acetone (Ganjewala, 2017; Kilari & Putta, 2016). On the other hand, in a study carried out on litchi leaf, the in vitro antimicrobial activity against *Propioni bacterium* acnes was evaluated, showing activity at 5 mg/mL (Thiesen et al., 2020). Therefore, litchi is a potential source of natural additives for food quality and preservation, as well as for the treatment of skin diseases in the cosmetics industry and drug development.

Anticancer

Cancer is a set of diseases that involve abnormal cell growth with the ability to invade or spread to other parts of the body due to an abnormal cell growth cycle (Abd-Aziz et al., 2020). It is the second leading cause of death in the world after cardiovascular diseases, and the synthetic drugs used in treatment have toxic effects on the human body and cause maximum side effects. Therefore, it is important to replace them with natural herbal medicines, because they have fewer side effects (Masal et al., 2022).

Polyphenols extracted from plants have pharmacological properties and are used for therapeutic purposes. Litchi has significant pharmacological properties that highlight its anticarcinogenic activity. The aglycone present in litchi has been shown to inhibit several cycles of cancer cell growth and cause gene changes, apoptosis, DNA damage prevention, and transduction. In addition, it downregulates genes associated with cancer cell invasion and malignancy (Hussain et al., 2021). In another study conducted on the effect of litchi pericarp on the proliferation of MCF-7 human breast cancer cells using the MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) assay, they also identified and evaluated the cytotoxic activity of compounds such as epicatechin and proanthocyanidin B2, which were higher in MCF-7 cells than in proanthocyanidin B4 compared to the reference drug paclitaxel, which has higher cytotoxic activity (Shakir et al., 2019).

On the other hand, the compounds responsible for anticancer activity could be anthocyanins, epicatechin, procyanidin B2, and procyanidin B4. These compounds have been evaluated both in vitro and in vivo against hepatocellular carcinoma and breast cancer, and have been shown to inhibit cancer cell proliferation and cause DNA damage, which induces apoptosis by up- and downregulation of cell proliferation and cell cycle genes (Chen et al., 2017; Kumar et al., 2017; Zhu et al., 2019). Litchi seeds are rich in procyanidins. In a recent study, procyanidins present in litchi seeds, such as procyanidin A, procyanidin D, cinnamtanin B1, and cinnamtanin B2, were found to significantly inhibit the proliferation and metastasis of CT26 colon cancer cells both in vivo and in vitro. The antimetastatic effect of procyanidins in mice with CT26 lung metastasis is based on the regulation of the gut microbiota and T-cell (T lymphocyte) immune response (Yao et al., 2023). Therefore, the consumption of fruits and vegetables rich in bioactive compounds, such as procyanidins, may be beneficial in the treatment of cancers, such as breast and colon cancer, as hepatoprotective agents, for the regeneration of liver cells, or as adjuvant drugs in clinical antitumor immunotherapy.

Other activities

Litchi is a nutrient-dense fruit that exhibits various biological activities, including antioxidant and anti-cancer properties, as detailed in this review. Additionally, its potential anti-obesity effects were assessed. Studies have shown that aqueous extracts contain flavonoids and saponins, which can inhibit preadipocyte differentiation and slow lipid oxidation, thereby reducing adipogenesis. In addition, a protein isolated from litchi seed has been shown to have pancreatic lipase inhibitory activity (Yao et al., 2021). In another study, it was found that litchi pulp and leaf extracts exhibit hepatoprotective activities owing to their antioxidant and anti-apoptotic effects, and they can protect the liver from damage. Additionally, pulp extracts can prevent lipid peroxidation and CCl4-induced apoptosis (Ibrahim & Mohamed, 2015; Kilari & Putta, 2016). On the other hand, litchi extracts, mainly from seeds, have strong potential for the treatment of diabetes because they can inhibit alpha-glucuronidase and improve insulin resistance due to their bioactive compounds, such as saponins, quercetin, A2-type procyanidins, and (2R)-naringenin-7-O-(3-O-αL-ramnopyranosyl-β-glucopyranoside). It can also reduce glucagon mRNA levels and enhance the expression of glucose transporters, thereby improving the metabolism. It also has other health effects such as lipid regulation, neuroprotection, and renoprotection (Zhang et al., 2021). These properties are highly related to the bioactive compounds present in litchi, which can act as safe and economical adjuvants. However, further research on its constituents and pharmacological effects is required to understand its potential for the treatment of diseases(Wu et al., 2020; Zhao et al., 2020).

Nutraceutical potential of *litchi chinensis*

Nutraceuticals are substances extracted from food sources that are related to the word's nutrition and pharmaceuticals, which provide additional health benefits, acting nonspecifically to promote the general well-being of people and as an alternative for the prevention or control of diseases (Ganapathy & Bhunia, 2015; Kaur et al., 2020).

Litchi chinensis has been shown to have several potential health benefits due to its high nutrient content and its high biological properties, as described in this review, which makes it a food with nutraceutical potential. However, further studies are needed to precisely determine the health effects of litchi and to determine the appropriate dose to obtain its benefits.

Bioactive compounds present in *litchi chinensis* and their medicinal potential

Chukwuma et al. (2021) reported that fruit waste, particularly the pericarp, and seeds, may contain more bioactive compounds, making it a potential therapeutic source. The use of plants as therapeutics dates back to ancient times; however, although they affect health, they are not essential nutrients. As a result, the use of these natural compounds has allowed for the development of traditional medicine, and their use has led to the isolation of many drugs (Mir & Perveen, 2022).

Traditional medicine in ancient cultures integrally used litchi, using practically all parts of the tree, from the fruit residues, which are the seed and pericarp, to the pulp, flowers, leaves, bark, and roots. They are used for the treatment of various diseases, such as cough, testicular swelling, orchitis, hernias, reduce polydipsia, trigger cold, neuralgia, smallpox, gastralgia, diabetes, obesity, stomach ulcers, epigastric pain, and for the elimination of intestinal worms. The different ethnomedicinal uses granted by nature make it a promising crop for the treatment of various diseases in humans (Castillo-Olvera et al., 2022; Mir & Perveen, 2022). On the other hand, it has been reported that the integral consumption of litchi, including pulp, seed, and pericarp, has shown positive effects in various medicinal applications. (Chukwuma et al., 2021; Sun et al., 2021a, 2021b).

Litchi is considered a new source of large amounts of polyphenols. In recent years, extraction, isolation, and identification of bioactive compounds from litchi have been reported. According to previous reports, litchi mainly contains anthocyanins, flavonoids, phenolics, coumarins, fatty acids, proanthocyanidins, sesquiterpenes, sterols, and lignans. The amount of polyphenols depends on the development and type of tissue as well as the type of cultivation, geographical location, and climatic conditions. Compounds such as epicatechin, epicatechin gallate, procyanidin A2, procyanidin B2, rutin, epicatechin monomers, malvidin-3-glucoside, cyanidin-3-glucoside, cyanidin-3-rutinoside, quercetin-3-O-glucoside, kaempferol, and isorhamnetin aglycone have been identified in the pericarp. Table 4 summarizes the concentration of bioactive compounds quantified in litchi chinensis of different cultivars. It is worth mentioning that the concentration may vary according to the variety of the crop. These identified compounds are related to previously described bioactivities (antioxidant, anti-inflammatory, and anticancer) (Ganjewala et al., 2017; Jiang et al., 2013; Upadhyaya & Upadhyaya, 2017; Yao et al., 2023).

Table 4 The concentration of bioactive compounds in *Litchi chinensis*

Part of the fruit	Bioactive compounds	Concentration	Reference
Pericarp	Epicatechin (EC)	9.83 mg ECE /g DW	(Deng et al., 2018)
	Procyanidin A2	17.61 mg PA2E /g DW	
	Procyanidin B2	4.71 mg PB2E /g DW	
	Quercetin-3-O-rutinoside-7-O-α-L-rhamnosidase (QRR)	1.63 mg QRRE/ g DW	
	Cyanidin-3-glucoside (CGE)	1.18 mg CGE / 100 g FW	(Li et al., 2012)
	Cyanidin-3-rutinoside (CR)	16.99 mg CRE / 100 g FW	
	Malvidin-3-glucoside (MG)	1.98 mg MGE/100 g FW	
Pulp	Galic acid (GA)	0.011—0.105 mg GAE/100 g FW	(Zhang et al., 2013)
	Chlorogenic acid (CA)	0.092—0.181 mg CAE /100 g FW	
	(+)-catechin (C)	0.200—0.594 mg CE/100 g FW	
	Caffeic acid (CA)	0.059—0.135 mg CAE/100 g FW	
	(-)-epicatechin (EC)	0.238 – 0.705 mg ECE/100 g FW	
	Rutin	0.099 – 2 mg RE/100 g FW	
Seed	3,5-Dihydroxy-benzoic acid	1.02 mg / g	(Man et al., 2016)
	3,4-Dihydroxy-benzaldehyde	0.94 mg / g	
	Procyanidin D	2.87 mg / g	
	Cianidanol	6.31 mg / g	
	Scopoletin	7.84 mg / g	
	Rutin	9.65 mg / g	
	Phlorizin	1.33 mg / g	

However, bound or non-extractable polyphenols have received less attention. These are bound to the plant matrix even after extraction with water or mixtures of aqueous/organic solvents since they are covalently bound to the plant matrix either with cellulose, pectin, and polysaccharides through ester bonds and are difficult to hydrolyze, so chemical or enzymatic treatment is needed before solvent extraction to release them (Ding et al., 2020). Extractions of polyphenols bound by alkaline and acid hydrolysis from litchi pulp were performed, and compounds such as (+)-catechin, vanillic acid, caffeic acid, syringic acid, (-)-epicatechin, 4-methyl catechol, rutin, and quercetin were identified (Su et al., 2014). Shu et al., (2022) identified polyphenols bound in litchi pulp after heat-pump drying as (+)-gallocatechin, protocatechui aldehyde, isorhamnetin-3-O-rutoside, 4-hydroxybenzoic acid and 3,4-dihydroxybenzeneacetic acid and also showed that they increased their biological activity.

These compounds possess high free radical-scavenging activities and can be used as anti-inflammatory, anticancer, analgesic, and natural antioxidant agents. Recent studies have suggested a potential role of litchi extracts in the prevention and treatment of various diseases.

Different nutraceuticals have been developed from litchi e.g., (Ting et al., 2018) studied the effects of a nutraceutical rich with quercetin, lycopene, taurine, and litchi flower extract for the treatment of against obesity in rats induced by a high-fat diet, rats receiving the nutraceutical showed a significant loss of body weight from 490 g ± 11 to 441 g ± 11, and fat 112. 9 g ± 4.5 to 86.6 g ± 5.7, as well as decreased serum triglyceride levels 102.5 g ± 7.3 to 90.7 g ± 6.5 compared to the group that did not have supplementation. Four compounds were identified from the litchi seed extract 4 compounds were identified which were pavetannin B2, procyanidin A2, and ursolic acid, which are related to the inhibition of α-glucosidase. The inhibition of α-glucosidase by the crude extract, an enzyme associated with carbohydrate metabolism, was evaluated using an IC_{50} assay, and an inhibition of 0.0007 mg/mL was obtained (Choi et al., 2017). In Japan, a nutraceutical for peripheral circulation and cold sensitivity has been developed, which reduces the quality of life, mostly in women, and is formulated by an oligomerized polyphenol from litchi fruit extract. A trial was conducted with 25 participants by supplementing capsules with oligomerized polyphenols from litchi extract or placebo capsules for 14 days. Oligomerized polyphenols increase blood flow and skin temperature (Waki et al., 2020). Another innovative formulation, oligonol-L, derived from litchi fruits, has great potential to prevent and protect against light-induced injuries, skin aging, cancer, and other diseases such as diabetes, inflammation, and kidney disorders. Oligonol inhibited the development of adenomas initiated by azoxymethane and was promoted by sodium dextran sulfate in mice. On the other hand, it also induces apoptosis of MCF7 and MDA-MB-231 breast cancer cells and inhibits lung metastasis originating from melanoma in mice (Emanuele et al., 2017).

This suggests that litchi may have more beneficial properties than currently available. However, further research is needed to understand the exact mechanism of action of the bioactive compounds and to exploit the therapeutic and preventive potential of this fruit (100%), as well as innovative nutraceutical applications to improve health (Mir & Perveen, 2022).

Development of products

Fruits are essential for maintaining healthy nutrition because they provide essential nutrients. However, most of the waste produced by food consumption is a byproduct, such as pericarp, seed, and pomace. These residues still contain large amounts of bioactive compounds such as proteins, carbohydrates, polyphenols, and carotenoids. In recent years, attention has been given to the recovery of these bioactive compounds from byproducts owing to their beneficial potential for health benefits (Coman et al., 2020).

Litchi fruit is commonly eaten fresh; however, it has been used to produce various products such as dried litchi, canned litchi, litchi wine, litchi honey, and litchi jelly (Yao et al., 2021). In contrast, pulp is rich in polysaccharides, several of which have been identified, one of which is a heteropolysaccharide. Natural polysaccharides are essential in the industry because they can be used as thickeners, emulsifiers, texture modifiers, and gelling stabilizers. Litchi fruit polysaccharides have strong shear-thinning characteristics at different concentrations, high viscosity, and temperature insensitivity, and are desirable functional characteristics that can be widely applied in the development of new products or foods (Huang et al., 2018). Litchi seeds also have these characteristics since they contain high amounts of polysaccharides. One of their main components is starchy polysaccharides, which have wide applications in the industry as thickeners, emulsifiers, and gelling agents. Litchi seeds have been used to prepare sweet and aromatic wines (Punia & Kumar, 2021). In addition, it has been determined that the aqueous extract of litchi seeds is effective in inhibiting adipogenesis and retarding lipid oxidation, which can be used for the application of meat products to improve their safety and quality (Sun et al., 2021a, 2021b).

Litchi fruit and its by-products (pericarp and seed) have a high commercial value because of their high nutritional contribution and phytochemical composition. They have received much attention owing to their

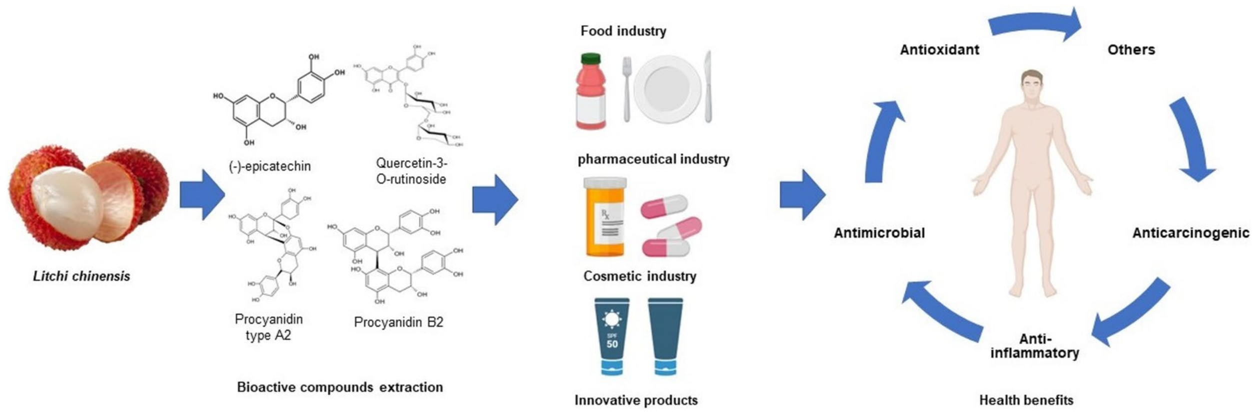


Fig. 3 Bioactive compounds present in *L. chinensis* for the development of innovative products and their benefits to health

biological properties, not only from the fruit but also from the pericarp, pulp, and seed. These bioactive compounds can be used as antioxidants, antimicrobials, and cancer preventive agents (Fig. 3). Therefore, reusing litchi byproducts as a rich source of bioactive compounds (Table 5) could be an interesting alternative for food improvement or innovative products (Sathya et al., 2023).

Use of byproducts

The litchi fruit is consumed as fresh or processed fruit, which generates a large amount of residue, mainly pericarps, and seeds, constituting approximately 30–40% (w/w) of the litchi fruit. World production is estimated at over 2 million tons of litchi per year, which can generate approximately 0.54 million tons of seed per year. Litchi fruit has received much attention because of its high content of bioactive compounds and its biological activities, which have been used in different industrial areas, such as sunscreens, shampoos, moisturizers, and ointments for the treatment of skin diseases (Bangar et al., 2021; Sathya et al., 2023). On the other hand, the high fatty acid content of the seeds is formulated in detergents, lubricants, and dyes (Upadhyaya & Upadhyaya, 2017).

On the other hand, litchi seed and shell is an economical and effective carbon source; the seed has been used to denitrify wastewater with high salinity as a marker for the selective detection of methylene blue and fluorescent imaging of HeG2 cells. In addition, bioactive compounds, such as (-)-epigallocatechin and cyanide-3-glucoside, are used as environmentally friendly inhibitors of mild steel corrosion. As for litchi pericarp, nanosheet materials with porous carbon particles are manufactured that can be used as electrodes of supercapacitors, in lithium-sulfur batteries, and the mixture with iron particles and magnetic properties for the treatment of wastewater contaminated with pharmaceutical dyes, as well as effective sorbent for heavy metals such as Cr (VI) and Pb (II) (Yao et al., 2021).

Other uses that have been given to litchi by-products are in traditional medicine, where it is used for the treatment of various diseases; for example, litchi seed is used as a pain reliever in disorders such as orchitis, hernia, lumbago, neuralgia, intestinal problems, cold, testicular inflammation caused by inversion of the hepatic channel, and premenstrual and postpartum abdominal pain. A mixture of litchi seed with litchi peel and ground cumin has been used for the treatment of hernia or testicular pain. It is also used to dispel stagnant moods and to eliminate parasites. Litchi seed is used in powder form either by making extractions by infusion and then ingested as a tea, and extracts have also been made in ethanol to treat intestinal problems (Ibrahim & Mohamed, 2015; Zhao et al., 2020). Litchi pericarp ingested in the form of tea is used to treat smallpox rashes, diarrhea, flatulence, cough, and diabetes, and as an analgesic for different diseases. Litchi by-products are used in the form of decoctions and powders, which can be consumed orally or used externally for the treatment of various diseases (Yao et al., 2021).

Conclusion

L. chinensis has expanded its cultivation in various countries with tropical or subtropical climates. This is because of its delicious flavor, nutritional content, functional properties, and wide range of pharmacological properties. Scientific research has demonstrated a high content of nutrients and bioactive compounds including epicatechin, procyanidins, malvidin, quercetin, and rutin. These compounds provide benefits to human health and have been evaluated by in vitro and in vivo tests in human cell lines and animal models using litchi extract to demonstrate its importance

Table 5 Main bioactive compounds in *L. chinensis*, biological properties and developed products or applications

Fruit part	Bioactive compounds	Biological activity	Study models	Products developed or applications	Reference
Pericarp	-	Anti-aging Antihyperpigmentation	Humans	Litchi serum for the treatment of hyperpigmentation in skin	(Lourith & Kanlayavattanakul, 2020)
	Epicatechin, A-type dimer, A-type trimer, caffeic acid, and shikimic acid	Antioxidant Anti-hyperuricemia	Male Sprague–Dawley rats	-	(Sui et al., 2021)
	-	Antioxidant	Sheep meat nuggets	Litchi serum for the treatment of hyperpigmentation in skin	(Das et al., 2016)
	-	Antioxidant Antimicrobial	-	Biofilms	(Liu et al., 2021)
	(-)-epicatechin (−)-epigallocatechin Procyanidin B2 Procyanidin B4 (+)-catechin Procyanidin B1 Cyanidin-3-rutinoside Cyanidin-3-glucoside Quercetin-3-rutinoside Quercetin-3-glucoside	Antioxidant Antimicrobial Anti-inflammatory Anti.cancer	Human embryonic lung fibroblast (HELF) than on human breast cancer cell MCF-7	Drug agents Food additives Cosmetic	(Zhu et al., 2019)

Table 5 (continued)

Fruit part	Bioactive compounds	Biological activity	Study models	Products developed or applications	Reference
Pulp	Quercetin-3-O-rutinose-7-O-α-L-rhamnose Rutin, and Procyanidins	Anti.inflammatory	Male C57BL/6 mice	Supplement for the treatment of intestinal tract inflammation	(Huang et al., 2021)
	Flavonoids and organic acids	Antihiperglucemiant Antioxidant	Wistar rats orally, DPPH, and ABTS	Supplement for the treatment of encephalopathy or hypoglycemia	(Contreras-Castro et al., 2021)
	galacturonic acid, glucose, arabinose, galactose, mannose, glucuronic acid, xylose and/or rhamnose	Probiotic	*B. adolescentis, B. infantis, and B. longum*	Probiotic	(He et al., 2022)
	Phenolic Flavone exopolysaccharide	Antioxidant	Male BALB/c mice, ORAC	Litchi juice fermented with *L. casei*	(Wen et al., 2020)
	Quinic acid Chlorogenic acid p-coumaric acid Rutin Naringin Quercetin-7-O- β-D-glucopyranoside Quercetin	Antioxidant	Litchi fruit, enzyme activity peroxidase, polyphenol oxidase, and laccase	-	(Tan et al., 2020)
	B-type procyanidin trimer Quercetin-3-O-rutinoside-7-O-rhamnoside Procyanidin B2 Epicatechin Quercetin glycosides	Antioxidant Hepatoprotective	Oxygen radical scavenging capacity (ORAC), cellular antioxidant ability (CAA), and hepatic lipid accumulation inhibitory activity	–	(Jia et al., 2022)
	(-)-epicatechin Rutin Quercetin-3-O-rutinoside-(1 → 2)-O-rhamnoside Kaempferol-3-O-rutinoside Quercetin-3-O-rutinoside-7-O-α-L-rhamnoside	Anti-inflammatory Hepatoprotective Anticancer Anti-obesity	-	canned litchi, litchi wine, litchi beverage (litchi juice), dried litchi, frozen litchi, litchi honey, litchi jelly	(Yao et al., 2021)

Table 5 (continued)

Fruit part	Bioactive compounds	Biological activity	Study models	Products developed or applications	Reference
Seed	Polysaccharides: starch	-	-	Thickerner Edible packaging, films, coatings Funcional ingredient Excipient in pharmaceutical products Targeted drug delivery	(Bangar et al., 2021)
	Procyanidin B" Epicatechin Cinnamtannin B" Procyanidin A1 Quercetina Rutin Litchioside C	hypertensive renal damage Antioxidant Anti-inflammatory	Male spontaneous hypertensive rats (SHRs) and normotensive control Wistar-Kyoto (WKY) rats	-	(Man et al., 2021)

as a protective agent against cancer, diabetes, obesity, and inflammation. However, little is known about how they work in humans, but it is believed that they have a high potential for the development of products, drugs, or functional foods, such as the development of preservatives in meats, skin care creams, manufacturing of packaging, and functional ingredients. Although several studies have been conducted on litchi, there is still little information on its metabolism and mechanism of action in humans. Therefore, it is essential to continue research to better understand the biological activities of litchi in order to determine its safety and potential in the food, pharmaceutical, and cosmetic industries.

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Authors' contributions
GCO: Conceptualization, Methodology, Formal Analysis, Writing—Review & Editing JSC: Methodology, Supervision JAAV: Methodology, Supervision JEWP: Methodology, Supervision OBAP: Methodology, Supervision MLFL: Methodology, Supervision CNA: Conceptualization, Supervision, Formal Analysis, Writing—Review & Editing, Visualization, Project administration, Funding acquisition.

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