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Review:

Pericarp and seed of litchi and longan fruits: constituent, extraction, bioactive activity, and potential utilization*

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Abstract: Litchi (*Litchi chinensis* Sonn.) and longan (*Dimocarpus longan* Lour.) fruits have a succulent and white aril with a brown seed and are becoming popular worldwide. The two fruits have been used in traditional Chinese medicine as popular herbs in the treatment of neural pain, swelling, and cardiovascular disease. The pericarp and seed portions as the by-products of litchi and longan fruits are estimated to be approximately 30% of the dry weight of the whole fruit and are rich in bioactive constituents. In the recent years, many biological activities, such as tyrosinase inhibitory, antioxidant, anti-inflammatory, immunomodulatory, anti-glycated, and anti-cancer activities, as well as memory-increasing effects, have been reported for the litchi and longan pericarp and seed extracts, indicating a potentially significant contribution to human health. With the increasing production of litchi and longan fruits, enhanced utilization of the two fruit by-products for their inherent bioactive constituents in relation to pharmacological effects is urgently needed. This paper reviews the current advances in the extraction, processing, identification, and biological and pharmacological activities of constituents from litchi and longan by-products. Potential utilization of litchi and longan pericarps and seeds in relation to further research is also discussed.

Key words: Bioactive compound; Extraction; Litchi; Longan; Pharmacological activity; Utilization
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1 Introduction

Litchi (*Litchi chinensis* Sonn.) and longan (*Dimocarpus longan* Lour.) are subtropical evergreen trees belonging to the family Sapindaceae. The two fruits have an indehiscent pericarp surrounding a succulent edible aril with a dark brown seed. Litchi and longan fruits have gained popularity as specialty fruits in subtropical areas, and are accepted by consumers on the international markets with increasing demand for their excellent flavors and semi-translucent to white arils (Jiang et al., 2002, 2006). The two fruits are grown commercially in some major countries, including China and Thailand, which account for most of the commercial litchi and longan production. Production of litchi and longan has increased greatly over recent decades because of significant improvements in crop practices and management. Increasing production of litchi and longan fruits requires prospects for better utilization of these two crops.

Litchi and Longan fruits have commonly been used traditionally in China as herbs for improvement of neural pain, swelling, the immunomodulatory

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ORCID: Yue-ming JIANG, https://orcid.org/0000-0002-4648-9572 system, and cardiovascular disease. Their pulps are very high in nutritive value with carbohydrates, protein, fiber, fat, lipids, vitamins, amino acids, and minerals. The pericarp and seed portions of litchi and longan are estimated to contain approximately 30% of the dry weight of the entire fruit and consist of significant amounts of bioactive compounds. In recent years, the extracts from litchi and longan pericarps and seeds have exhibited excellent antioxidant ability and good anti-tyrosinase, anti-inflammatory, immunomodulatory, and anti-cancer activities (Li and Jiang, 2007; Rangkadilok et al., 2007; Prasad et al., 2009a; Yang et al., 2009a, 2011). Thus, the two fruits can be used as an easily accessible source of natural antioxidants from their by-products and/or possible agents in the cosmetic and pharmaceutical industry. To better utilize pericarps and seeds of litchi and longan fruits, this paper reviews the recent advances in structural identification and functional evaluation of bioactive constituents present in the two fruits in relation to their potential applications. Some novel biological functions of litchi and longan pericarps and seeds with regard to human health are also discussed. The objective of this paper was to help relevant scientists, farmers, and industries to better utilize litchi and longan by-products in the future.

2 Phytochemical composition

Litchi and longan fruits contain a wide diversity of bioactive compounds. The major bioactive compounds consist of phenolics and polysaccharides, which have been shown to have potentially beneficial biological and pharmaceutical properties (Emanuele et al., 2017). The bioactive constituents of litchi and longan fruits are greatly influenced by the climate, region, cultivation conditions, fruit maturity, fruit portion, and extraction and processing methods (Wang HC et al., 2011). Although the potential health benefits of these bioactive constituents have achieved wide attention based on numerous in vitro studies, many reports have been conducted on the isolation, extraction, and identification of individual chemical compounds. Differences in the bioactive compositions of litchi and longan fruits could exist because of various cultivars, and extraction and processing methods.

2.1 Litchi

2.1.1 Pericarp

A broad spectrum of bioactive constituents has been isolated and identified in the litchi pericarp, as shown in Table 1. One significant characteristic of these bioactive constituents is that they contain many flavonoids (Table 2). The flavonoids present in ripe litchi pericarp include mainly flavonols and anthocyanins. The flavonols identified in ripe litchi pericarps were (−)-epicatechin, (−)-epigallocatechin, procyanidin B2, procyanidin B4, (+)-catechin, and procyanidin B1, whereas the important anthocyanins were identified as cyanidin-3-rutinoside, cyanidin-3-glucoside, quercetin-3-rutinoside, and quercetin-3-glucoside (Sarni-Manchado et al., 2000; Zhao et al., 2006; Bai et al., 2019). A novel compound, namely methylene-linked flavan-3-ol dimer, *bis*(8-epicatechinyl) methane, was also reported by Ma et al. (2014b), together with eight compounds, dehydrodiepicatechin A, proanthocyanidin A1, proanthocyanidin A2, 8-(2-pyrrolidinone-5-yl)-(−)-epicatechin, (−)-epicatechin 8-*C*-β-D-glucopyranoside, naringenin, 7-*O*-(2,6-*O*-α-L-rhamnopyranosyl)-β-D-glucopyranoside, and rutin. Furthermore, oligomeric procyanidins were isolated and then identified by liquid chromatography-electrospray ionization-mass spectrometry (LC-ESI-MS) analysis, including their 12 dimers and 6 trimers. Although the major flavan-3-ol monomer and oligomeric procyanidins present in ripe litchi pericarps were characterized as (−)-epicatechin, A-type dimers and trimers (epicatechin-(4β-8,2β-*O*-7)-epicatechin-(4β-8)-epicatechin) and procyanidin A1 (epicatechin-(4β-8,2β-*O*-7)-catechin) were reported for the first time by Sui et al. (2016). In particular, it is noted that the content of A-type procyanidins was much higher than that of B-type procyanidins. In addition, four lignans ((+)-isolariciresinol 9-*O*-α-L-arabinopyranoside, (−)-secoisolariciresinol 9-*O*-α-L-arabinopyranoside, burselignan 9-*O*-α-L-arabinopyranoside, and sisymbrifolin), a chromane (2α-methoxychroman-3α-5,7-triol), a benzophenone (garcimangosone D), and two sesquiterpenes (β-D-glucopyranosyldihydrophaseate and citroside A) were obtained from ripe litchi pericarps (Ma et al., 2014a). Jiang et al. (2013b) reported a novel phenolic compound, 2-(2-hydroxy-5-(methoxycarbonyl) phenoxy)benzoic acid, together with kaempferol, isolariciresinol, stigmasterol, 3,4-dihydroxybenzoate, butylated hydroxytoluene, methyl shikimate, and

Table 1 Phytochemicals present in litchi pericarps and seeds

Portion	Phytochemicals
Pericarp	Gallic acid, procyanidin B2, procyanidin B4, (−)-epicatechin, cyanidin-3-rutinoside, cyanidin-3-glucoside, brevifolin, quercetin-3-rutinoside, quercetin-3-glucoside, dehydrodiepicatechin A, proanthocyanidin A1, proanthocyanidin A2, 8-(2-pyrrolidinone-5-yl)-(−)-epicatechin, (−)-epicatechin 8-*C*-β-D-glucopyranoside, naringenin, rutin, kaempferol, isolariciresinol, 2-(2-hydroxy-5-(methoxycarbonyl)phenoxy)benzoic acid, butylated hydroxytoluene, 3,4-dihydroxybenzoate
Seed	Gallic acid, procyanidin B2, (−)-epicatechin, (−)-gallocatechin, (−)-epicatechin-3-gallate, 2α,3α-epoxy-5,7,3',4'-tetrahydroxyflavan-(4β-8-catechin), 2β,3β-epoxy-5,7,3',4'-tetrahydroxyflavan-(4α-8-epicatechin), 2,5-dihydroxy-hexanoic acid, 4-*O*-α-L-rhamnopyranosyl-ellagic acid, isoscopoletin, coumaric acid, protocatechuic acid, pterodontriol, narirutin, D-6-*O*-β-D-glucopyranoside, naringin, pinocembrin-7-neohesperidoside, pinocembrin-7-rutinoside

Table 2 Major phenolic compounds in litchi pericarps

Compound	Relative percentage (%)
Gallic acid	0.4
Procyanidin B1	1.0
(+)-Catechin	1.6
(+)-Gallocatechin	1.1
Procyanidin B4	5.3
Procyanidin B2	11.4
(−)-Epicatechin	32.5
(−)-Epigallocatechin	10.9
(−)-Epicatechin-3-gallate	0.3
Cyanidin-3-glucoside	31.7

Reprinted from Li and Jiang (2007)

ethyl shikimate. An interesting result is that butylated hydroxytoluene was detected as a natural antioxidant in this work. Thus, a great difference in the identification of these chemical compositions from litchi pericarps might be caused by the various cultivars and extractions.

Yang et al. (2006) reported that a large number of polysaccharides exist in ripe litchi pericarp tissues. In their study, DEAE anion-exchange column in combination with Sephadex G-50 gel-permeation column was used to obtain the major polysaccharides from ripe litchi pericarps. The greatest amount of the polysaccharide fraction depended largely on further purification by Sephadex G-50 filtration. The purified neutral polysaccharide exhibited a molecular weight of 14 kDa and consisted primarily of 65.6% mannose, 33.0% galactose, and 1.4% arabinose. The Smith degradation analysis identified 8.7% (1→2)-glycosidic linkages, 83.3% (1→3)-glycosidic linkages, and 8.0% (1→6)-glycosidic linkages in the polysaccharides. Biological analysis indicated that these various polysaccharide fractions from litchi fruit pericarp tissues exhibited strong antioxidant ability and anti-glycated activity (Yang et al., 2006, 2009a; Gao et al., 2017), suggesting that litchi polysaccharides could be explored as a new and potential alternative antioxidant.

2.1.2 Seed

Litchi seed has also been applied in traditional Chinese medicine since ancient times. Using the conventional extraction, followed by the reverse phase high-performance liquid chromatography (HPLC) in combination with a diode array detector and ESI-MS, gallic acid, procyanidin B2, (−)-gallocatechin, (−)-epicatechin, and (−)-epicatechin-3-gallate partially similar to those identified from litchi pericarps were obtained, which suggested that litchi seed could potentially be used as a good source of natural antioxidants (Xu et al., 2010). With increasing amount of seed samples used in this extraction, four novel compounds (2α,3α-epoxy-5,7,3',4'-tetrahydroxyflavan-(4β-8-catechin), 2β,3β-epoxy-5,7,3',4'-tetrahydroxyflavan-(4α-8-epicatechin), litchiol A, and litchiol B) and 12 known ones (2,5-dihydroxy-hexanoic acid, isoscopoletin, coumaric acid, protocatechuic acid, narirutin, naringin, pterodontriol, pinocembrin-7-rutinoside, pinocembrin-7-neohesperidoside, 2α,3α-epoxy-5,7,3',4'-tetrahydroxyflavan-(4β-8-epicatechin), D-6-*O*-β-D-glucopyranoside, and dihydrochalcone-4'-*O*-β-D-glucopyranoside) with protocatechuic acid, 2α,3β-epoxy-5,7,3',4'-tetrahydroxyflavan-(4β-8-catechin), and 2β,3β-epoxy-5,7,3',4'-tetrahydroxyflavan-(4α-8-epicatechin) exhibited moderate antioxidant activity (Wang LJ et al., 2011). Chemical analyses from A-type proanthocyanidins present in litchi seeds identified two new A-type trimeric proanthocyanidins containing two doubly bonded interflavanoid linkages, litchitannin A1 (epicatechin-(2β→*O*→7,4β→6)-epicatechin-(2β→*O*→7,4β→8)-catechin) and litchitannin A2 (epicatechin-(2β→*O*→7,4β→6)-epicatechin-(2β→*O*→7,4β→6)-epicatechin), accompanied by aesculitannin A, proanthocyanidin A1, proanthocyanidin A2, proanthocyanidin A6, epicatechin, epicatechin-(2β→*O*→7,4β→8)-epiafzelechin-(4α→8)-epicatechin, and epicatechin-(7,8-bc)-4β-(4-hydroxyphenyl)-dihydro-2(3H)-pyranone (Wang LJ et al., 2011). Moreover, litchitannin A2 was found to have in vitro antiviral activity against coxsackie virus B3, whereas aesculitannin A and proanthocyanidin A2 performed an herpes simplex virus 1 (HSV-1) activity (Xu et al., 2010).

Litchi seed contains rich polysaccharides. Chen et al. (2011) used ultrasound-assisted extraction and obtained polysaccharides from litchi seeds and found that the litchi seed polysaccharides consisted of arabinose, fructose, galactose, glucose, and mannose, with glycosidic linkages between monosaccharides and the relative molar percentage. The bioactive polysaccharide exhibited substantial antioxidant activity and could be utilized as a novel antioxidant, but further research needs to be conducted for food and biomedical application.

2.2 Longan

2.2.1 Pericarp

Substantial amounts of bioactive constituents present in longan pericarps could be responsible for their different bioactivities. Table 3 presents the major phenolic compounds in ripe longan pericarps. The major phenolic compounds consisted of gallic acid, quercetin, corilagin, ellagic acid and its conjugates, (−)-epicatechin, 4-*O*-methylgallic acid, flavone glycosides, glycosides of quercetin and kaempferol, protocatechuic acid, isoscopoletin, and proanthocyanidins C1 (Sun et al., 2007; Yang et al., 2011; Bai et al., 2019). The phenolic compounds present in longan pericarps were similar to those in litchi pericarps (Table 1), suggesting similar bioactive activities.

Longan pericarps also have substantial amounts of polysaccharides (Jiang et al., 2009b). Yang et al. (2009b) isolated and obtained a polysaccharicle from longan pericarps. The structural identification by gas chromatography (GC) indicated that the longan polysaccharicle contained 33.7% D-galactopyranose, 32.8% L-arabinofuranose, 17.6% D-glucopyranose, and 15.9% D-galacturonic acid, whereas the backbone structure included →5)-L-Araf-(1→, →6)-D-GIcp-(1→, →3)-D-Galp-(1→, →3)-D-GalpA-(1→, and →6)-D-Galp-(1→, with a molar proportion of 2:1:1:1:1. The infrared spectra and nuclear magnetic resonance (NMR) spectra further confirmed the α-form of the configuration of L-arabinofuranose and the β-forms of D-glucopyranose, D-galactopyranose, and D-galacturonic acid. Furthermore, the purified longan polysaccharicle molecular weight was estimated to be approximately 420 kDa by gel permeation chromatography. The polysaccharicle exhibited a potential ability in inhibiting a glycation reaction in the in vitro test (Yang et al., 2009a). In addition, two alkali-soluble polysaccharide fractions from longan pericarps were obtained. Four monosaccharides, namely Xyl, Ara, Glc, and Gal, were determined, whereas Xyl was identified as the dominant monosaccharide in the two alkali-soluble polysaccharides with a relative molar percentage of >60%. Further analysis of glycosidic linkage indicated that Xyl had two linkages, →3)-Xyl-(1→ and →3,4)-Xyl-(1→, whereas the substitution at the C-4 position showed that Xyl was in the pyranose structure, with the β-linkage configuration (Jiang et al., 2009a). These polysaccharides exhibited good antioxidant and tyrosinase inhibitory activities in a dose-dependent manner (Yang et al., 2008a, 2008b; Jiang et al., 2009b), which could be utilized for food additives and cosmetic products.

2.2.2 Seed

Longan as a leading fruit crop in Thailand is rich in antioxidant compounds (Table 3), mostly gallic acid and ellagic acid (Panyathep et al., 2013). Dried longan seed contains much larger amounts of antioxidant polyphenols than fresh seed. Major four compounds, *p*-coumaric acid-glycoside, (*S*)-flavogallonic acid, ellagic acid derivatives, and methyl ellagic acid glucopyranoside, were reported for the first time in longan seed using HPLC-ESI-MS (Sudjaroen et al., 2012). Chen et al. (2014) reported that ellagic acid and its derivative and *p*-coumaric acid-glycoside contributed mainly to the antioxidant activity of longan seed extract, but gallic acid, corilagin, ethyl gallate, (*S*)-flavogallonic acid, and methyl ellagic acid glucopyranoside had little contribution. Furthermore, Sudjaroen et al. (2012) reported the compositions of polyphenolic fraction from ground longan seed, i.e. 80.90 g/kg on dry weight basis was 25.84 g/kg ellagic acid, followed by 13.31 g/kg ellagitannins corilagin, 13.06 g/kg chebulagic acid, 9.93 g/kg ellagic acid 4-*O*-α-L-arabinofuranoside, 8.56 g/kg isomallotinic acid, and 5.79 g/kg geraniin, indicating ellagic acid as the dominate phenolic compound.

Table 3 Phytochemicals present in longan fruit pericarps and seeds

Portion	Phytochemicals
Pericarp	Gallic acid, corilagin, (−)-epicatechin, ellagic acid and its conjugates, quercetin, flavone glycosides, 4-*O*-methylgallic acid, flavone glycosides, glycosides of quercetin and kaempferol, protocatechuic acid, brevifolin
Seed	Gallic acid, corilagin, ellagitannins corilagin, ellagic acid 4-*O*-α-L-arabinofuranoside, isomallotinic acid, geraniin, ethyl gallate, grevifolinand, 4-*O*-α-L-rhamnopyranosyl-ellagic acid, *p*-coumaric acid-glycoside, isoscopoletin, proanthocyanidins C1, 1-*O*-galloyl-D-glucopyranose, (*S*)-flavogallonic acid, methyl ellagic acid glucopyranoside

With increasing attention to pharmacological benefits of plant polysaccharides, polysaccharides from longan seed were reported by Jiang et al. (2013a). The structural analysis indicated that four monosaccharides, namely arabinose, galactose, glucose, and mannose, were major components of longan seed polysaccharides, with →6)-Gal-(→1, Glc-(→1, and →6)-Glc-(1→ glycosidic linkages. These polysaccharides exhibited strong antioxidant and immunomodulatory activities (Jiang et al., 2013b; Zhang JC et al., 2017), which could be utilized further in the functional food industry.

3 Impacts of extraction and processing on phytochemical yields and compositions

Extraction as the key first step in isolating and obtaining various types of bioactive constitutes from fruit and vegetable tissues plays an important role in phytochemical yield and composition (Bao et al., 2016). In general, drying is necessary prior to extraction, but strongly affects the phytochemical compositions and bioactive activity. Yang et al. (2008c) evaluated the effects of various drying treatments on water-soluble polysaccharides, water-soluble total saccharides, and total phenols in pericarp tissues of three major longan cultivars, and found that the water-soluble polysaccharide content in a decreasing order was microwave radiation>solar radiation>lyophilization, whereas the content of total phenols was in a reducing order of lyophilization>microwave radiation> solar radiation.

In practice, the ideal extraction method is quantitative, non-destructive, and time-saving. There are various types of extraction methods, but there is no universal method for the effective extraction of the bioactive constituents from plant tissues because each method has its own advantage and disadvantage (Sun et al., 2011). It is also noted that a good extraction method in terms of a balance of yield and bioactive activity should be considered. Recently, application of green technology, such as ultrasonic extraction and high-pressure extraction, has been reported for extraction of bioactive constituents from various litchi and longan fruit tissues (Prasad et al., 2009b, 2009c, 2010a, 2010b; Yang et al., 2009c). Prasad et al. (2009b) and Gao et al. (2017) reported that application of high-pressure extraction had higher extraction efficiency in terms of extraction yield, compound content, and antioxidant activity from litchi and longan pericarps and seeds, compared with the conventional and ultrasonic extraction. Furthermore, Zhang RF et al. (2017) have optimized the ultra-high pressure assisted extraction procedures of procyanidins from litchi pericarps, which greatly increased the extraction yield and bioactive activity of the extract. In addition, Kessy et al. (2018) reported that the enzyme-assisted extraction using hydrolytic enzymes, such as hydropectinase, β-glucosidase, and tannase, can greatly increase enrichment and biotransformation of phenolic substituents from litchi pericarps. Lin et al. (2013) found the increased bioactivity, such as improved growth of *Lactobacillus bulgaricus* and *Streptococcus thermophilus*, and increased antioxidant activity of litchi pericarp polysaccharides biotransformed by *Aspergillus awamori* because of a significant change in the relative content of glucose, arabinose, galactose, rhamnose, xylose, and mannose, which suggested that *A. awamori* was very effective in degrading the polysaccharides into a bioactive mixture with lower molecular weight. Further study indicated that *A. awamori* transformed B-type condensed tannin (condensed flavan-3-ol via C4–C8 linkage) but exhibited little capacity to degrade the condensed tannin with A-type linkage subunits (C4–C8 coupled C2–*O*–C7 linkage) (Lin et al., 2016). In addition, biotransformation could effectively produce some new bioactive compounds. Lin et al. (2014) reported that two bioactive compounds, i.e. nigragillin and dihydrophaseic acid, at high levels were obtained from litchi pericarps via *A. awamori* fermentation. Furthermore, the two compounds exhibited antioxidant activity, a DNA protection effect, and an anti-cancer property, which suggested that the biotransformation by *A. awamori* is a potential way to produce bioactive constituents.

4 Pharmacological activity

The litchi and longan pericarp and seed extracts exhibit many biological activities, as summarized in Table 4. It has been reported that litchi fruit exhibits pharmacological properties. As mentioned above, litchi pericarps contain significant amounts of phenolic compounds, such as anthocyanins and flavanols. These anthocyanins and flavanols present in litchi pericarps could reduce the oxidation by chelating the metal ions and then forming copigment-metal complexes, and directly scavenging superoxide anions. Thus, litchi pericarp extract can be used as a strong natural antioxidant. Based on the recognition that litchi pericarp extracts were more effective than *O*-(β-hydroxyethyl) rutin in reducing anti-inflammatory and anti-edema ability and capillary permeability, it is suggested that anthocyanins or flavanols instead of rutin and its derivatives should be considered in the treatment of illnesses involving tissue inflammation and capillary fragility and swelling (Li and Jiang, 2007; Baskaran et al., 2018). Wang et al. (2006a, 2006b) found that litchi pericarp extract showed potential anti-cancer activity against hepatocellular carcinoma in vitro and in vivo, and human breast cancer. It is interesting to note that the aglycones, as the most abundant anthocyanins present in litchi pericarp tissues, exhibited the potential to inhibit the growth of human tumor cells in vitro in the micromolar range, but two anthocyanins, malvidin-3-β-glucoside and cyanidin-3-β-galactoside, had little effect on tumor cell growth (Wang et al., 2006a; Li and Jiang, 2007). Thus, further identification and fine elucidation of individual and combined anthocyanins accounting for the anti-cancer property against tumor cell growth require investigation. Similarly, the anti-cancer ability of flavanols present in litchi pericarp tissues is almost the same as that of anthocyanins. The anti-breast cancer activities of epicatechin, procyanidin B2, procyanidin B4, and the ethyl acetate fraction from litchi pericarps were evaluated in in vitro test by Zhao et al. (2007), who found that procyanidin B4 and ethyl acetate fractions exhibited stronger inhibition on human embryonic lung fibroblast (HELF) than on human breast cancer cell MCF-7, whereas epicatechin and procyanidin B2 showed lower cytotoxicity to MCF-7 and HELF than paclitaxel. Thus, Emanuele et al. (2017) suggested that it is possible that epicatechin and procyanidin B2 could be employed as components of anti-cancer agents. In addition to anti-cancer activity, Chen et al. (2017) found a hepatoprotective activity of litchi procyanidin A2 against carbon tetrachloride-induced liver injury in ICR mice. Recently, Choi et al. (2017) reported that litchi seeds could be a cost-effective medicinal food agent in terms of recyclable resources and might act as a natural alternative medicine against type-2 diabetes.

Longan also exhibits some good biological activities, including antioxidant ability and tyrosinase inhibitory activity from pericarps and seeds (Rangkadilok et al., 2007; Yang et al., 2008a, 2008b; Li et al., 2014; Tseng et al., 2014), metalloproteinase activity from seeds (Panyathep et al., 2013), anti-inflammatory property from pericarps (Kunworarath et al., 2016), and antibacterial activity from seeds (Rangkadilok et al., 2012), which have been conducted by combined in vitro and/or in vivo pharmacological studies (Table 4).

The bioactive polysaccharides from litchi and longan pericarps and seeds have attracted much

Table 4 Pharmacological properties in litchi and longan fruit portions

Pharmacological properties	Portion	
	Litchi	Longan
Antioxidant activity	Pericarp and seed	Pericarp and seed
Antimicrobial activity		Seed
Anti-cancer activity	Pericarp	
Anti-inflammatory property	Pericarp	
Immunomodulatory activity	Pericarp	Pericarp
Anti-diabetes	Pericarp and seed	Pericarp
Anti-cardiovascular activity	Pericarp	
Anti-edema	Pericarp	
Anti-fragility	Pericarp	
Anti-liver injury	Pericarp	
Antiviral activity	Seed	

attention by consumers and researchers because of their potential pharmaceutical properties and good safety, such as tyrosinase inhibition activity from litchi pericarps (Gao et al., 2017) and from longan pericarps (Yang et al., 2008a, 2008b; Prasad et al., 2010a, 2010b), anti-glycated activity from longan pericarps (Yang et al., 2009a), anti-cardiovascular diseases, immune modulation, and immunomodulatory activity from litchi and longan pericarps (Li and Jiang, 2007; Jiang et al., 2009b; Yang et al., 2011; Zhang JC et al., 2017). However, further identification of individual and combined polysaccharide responsible for these pharmaceutical properties needs to be investigated in the future.

5 Potential applications

Different portions of litchi and longan fruits are valuable sources of biological substituents from their by-products. The by-products from litchi and longan pericarps and seeds contain significant amounts of active compounds, which raises the need for further use and development of new products with added-commercial value in the cosmetic, food, and pharmaceutical industries (Li and Jiang, 2007; Yang et al., 2011; Kanlayavattanakul et al., 2012). As discussed above, litchi and longan pericarps and seeds contain many beneficial substituents with antioxidant ability, cancer prevention, anti-microbial, anti-inflammatory, and immunomodulatory functions. Thus far, the extracts from litchi and longan pericarps and seeds have been developed as functional food additives, cosmetic products, and Chinese herbs for the relief of neural pain and swelling. Although the pharmacological activities of litchi and longan pericarps and seeds have recently been documented, only a few reports have been conducted on the isolation, identification, evaluation, and elucidation of individual polysaccharides, and similarly, only a few in vivo tests have been conducted to evaluate the beneficial effects of these bioactive compounds present in the pericarps and seeds. Furthermore, although litchi or longan pericarp extract is a source of anti-tumor compounds that inhibit tumor cell viability in in vitro and in vivo models, data about the physiological and biochemical mechanisms responsible for the effects are quite fragmentary (Emanuele et al., 2017). Therefore, further utilization of valuable substituents from litchi and longan by-products is important work for researchers towards the development in producing food additives, and cosmetic and drug agents at a large scale. The investigations about the medicinal effects of extracts of litchi and longan by-products through in vitro and in vivo experiments and clinical trials in relation to safety evaluation of the new products are also very important.

6 Conclusions and future perspectives

It has been documented that the non-edible portions of litchi and longan fruits contain large amounts of health-enhancing substituents with substantial application potential in the cosmetic, food, and pharmaceutical industries. Unfortunately, very limited attention has been paid to some underutilized and neglected fruits, such as litchi and longan. On the basis of litchi and longan by-products as an excellent source of bioactive constitutes, their uses should be a prioritized scientific and technological problem in agricultural waste management from both economic and environmental viewpoints. Therefore, the utilization of valuable constitutes from litchi and longan by-products as food additives and cosmetic and drug agents is an important work for scientists. Additionally, the development of effective extraction technology with an emphasis on eco-friendly recovery techniques should be considered. Identification and elucidation of these physiologically key substances in relation to pharmaceutical functions from litchi and longan by-products need to be further investigated. It is also important to understand the bioavailability of these bioactive constitutes in living organisms. With the development of biotechnology, molecular genetic approaches can greatly improve the levels of bioactive compounds by selective breeding of new cultivars. Meanwhile, these industries should continue to develop new approaches for greater utilization of litchi and longan by-products to increase economic benefits.

Contributors

Xiang-rong ZHU, Hui WANG, Jian SUN, Bao YANG, Xue-wu DUAN, and Yue-ming JIANG partially wrote the manuscript. Yue-ming JIANG revised, edited, and checked the final version. All authors read and approved the final manuscript.

Compliance with ethics guidelines

Xiang-rong ZHU, Hui WANG, Jian SUN, Bao YANG, Xue-wu DUAN, and Yue-ming JIANG declare that they have no conflict of interest.

This article does not contain any studies with human and animal subjects performed by any of the authors.

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中文概要

题　目：荔枝、龙眼的果皮和种子：成分、提取、生物活性和潜在利用

概　要：荔枝（*Litchi chinensis* Sonn.）和龙眼（*Dimocarpus longan* Lour.）果肉白色透明，深受消费者欢迎。荔枝和龙眼果实作为我国传统中草药，可用于缓解神经疼痛和肿胀。荔枝和龙眼的果皮和种子部分占整个果实干重约30%，含有丰富的生物活性物质。近年来研究发现，荔枝和龙眼的果皮和种子的提取物具有抑制酪氨酸酶活性、抗炎、免疫调节、抗糖化、抗癌以及增强记忆等功能。随着荔枝和龙眼果实在世界上种植面积和数量的迅速增加，加强对生物活性物质的利用尤其必要。本文综述了对荔枝和龙眼的果皮和种子中生物活性化合物的鉴定、提取和药理活性等方面研究的最新进展，并讨论了其资源潜在利用以及未来研究方向。

关键词：活性物质；提取；荔枝；龙眼；药理活性；利用