Current Trends of Tropical Fruit Waste Utilization

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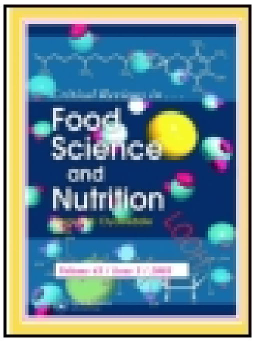

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Current trends of tropical fruit waste utilization

Choon Yoong Cheok[a], Noranizan Mohd Adzahan[b], Russly Abdul Rahman[c], Nur Hanani Zainal Abedin[c], Norhayati Hussain[b], Rabiha Sulaiman[b], and Gun Hean Chong[b]

[a]Department of Chemical and Petroleum Engineering, Faculty of Engineering, UCSI University, KL Campus (South Wing), Kuala Lumpur, Malaysia; [b]Faculty of Food Science and Technology, Department of Food Technology, Universiti Putra Malaysia, Selangor Darul Ehsan, Malaysia; [c]Faculty of Food Science and Technology, Department of Food Technology, Universiti Putra Malaysia, Selangor Darul Ehsan, Malaysia

ABSTRACT

Recent rapid growth of the world's population has increased food demands. This phenomenon poses a great challenge for food manufacturers in maximizing the existing food or plant resources. Nowadays, the recovery of health benefit bioactive compounds from fruit wastes is a research trend not only to help minimize the waste burden, but also to meet the intensive demand from the public for phenolic compounds which are believed to have protective effects against chronic diseases. This review is focused on polyphenolic compounds recovery from tropical fruit wastes and its current trend of utilization. The tropical fruit wastes include in discussion are durian (Durio zibethinus), mangosteen (Garcinia mangostana L.), rambutan (Nephelium lappaceum), mango (Mangifera indica L.), jackfruit (Artocarpus heterophyllus), papaya (Carica papaya), passion fruit (Passiflora edulis), dragon fruit (Hylocereus spp), and pineapple (Ananas comosus). Highlights of bioactive compounds in different parts of a tropical fruit are targeted primarily for food industries as pragmatic references to create novel innovative health enhancement food products. This information is intended to inspire further research ideas in areas that are still under-explored and for food processing manufacturers who would like to minimize wastes as the norm of present day industry (design) objective.

KEYWORDS
Tropical fruit wastes; bioactive compounds; fruit waste utilization; spectrophotometry; chromatography

Introduction

Tropical climate fosters the growth of numerous evergreen fruit trees. The consistency of this climate encourages the bearing of tropical fruits with slight fluctuation that is able to fulfill the global market demands. The worldwide popularity and demand for tropical fruits are reflected on the annual production as listed in Table 1. The most popular tropical fruit is the mango with an annual record production of 30 million tonnes produced by the three major countries of India, China, and Thailand. Pineapple, papaya, and jackfruit are among the other popular tropical fruits. Passion fruit and mangosteen are now emerging as popular tropical fruits due to their prominent nutritional values and pharmaceutical properties (Pedraza-Chaverri et al., 2008; Queiroz et al., 2012; Lewis et al., 2013; Ibrahim et al., 2016). The popularity of the durian is limited regionally because of its extremely strong unique aroma to which consumer preference is subjected by individual acceptance and tolerance.

Tropical fruits encompass a substantial amount of rind or skin, and seed which are disposed as wastes (Table 2). Amongst these, the durian, mangosteen, and jackfruit have rind and seed of more than 50% each. These fruit wastes are high in moisture content and rich in biodegradable organic ingredients which result in the waft of an unbearable stench during decomposition (Wang et al., 2014). The long-term disposal of these wastes to the environment not only results in greenhouse gas emission during decomposition (Dhillon et al., 2013), but also facilitates a breeding ground for bacteria, pest and mice which lead to the spread of plague. To minimize the environmental impact of a waste, the recovery of health benefit compounds and transformation to other useful biomass have become the focus of researchers in recent decades. The increase in global demand for health benefit phenolic compounds derived from natural plant materials is another factor urging researchers to gear towards recovery from fruit wastes. This trend is reflected in recent publications of relevant reviews (Table 3). The bioactive compounds found in fruit wastes that are important to human health have been reviewed. The potential uses of fruit wastes can be classified into food and nonfood applications (Table 3). Food applications are their uses for obesity remedy, food additives, and edible coatings and films. The major uses of fruit wastes in nonfood application are biosorbents to remove pollutants, heavy metals, and dyes from waste water.

This review aims to provide a comprehensive picture of the current trends of selected tropical fruit wastes' utilizations in order to inspire future research and discovery in areas that are underexplored. In order to justify and provide convincing reasons for future exploration in the recovery of valuable bioactive compounds from the wastes, the approaches included are highlights of bioactive compounds contained in different parts of a tropical fruit, the synthesis of spectrophotometric and

CONTACT Noranizan Mohd Adzahan noraadzahan@upm.edu.my Faculty of Food, Science and Technology, Department of Food Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia.

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Table 1. Major world production of tropical fruits.

Types of fruits	Major producing countries	Production (tonnes)	Reference(s)
Durian	Thailand, Malaysia, Indonesia	238,955	Siriphanich, 2011
Mangosteen	Thailand, Indonesia, Vietnam	345,558	FAO, 2011
Rambutan	—	—	—
Mango	India, China, Thailand	30,000,000	Yahia, 2011
Jackfruit	India, Bangladesh, Indonesia	2,702,000	Saxena et al., 2011
Papaya	India, Brazil, Nigeria	5,351,000	Singh and Rao, 2011
Passion fruit	Brazil, Ecuador, Peru	664,286	Schotsmans and Fischer, 2011
Dragon fruit	—	—	—
Pineapple	Thailand, Brazil, Indonesia	7,729,550	Hassan et al., 2011

chromatographic methods employed to quantify bioactive compounds in fruit wastes.

Bioactive compounds contained in different parts of a tropical fruit

Evaluation studies on bioactive compounds contained in different parts of a fruit serve as insight references for researchers or food manufacturers to further explore their uses. Therefore, a synthesis of scientific evidence which demonstrate the amount of bioactive compounds contained in different parts of a tropical fruit provides justification and reason as to why fruit waste should be recovered to be used in food applications besides minimizing its impact on the environment. Numerous scientific studies indicated that the total phenolic compound in the peel of mangosteen were significantly higher than in the pulp. The total phenolic and phenolic acid of mangosteen peel and rind has been revealed to be approximately eleven and two times higher, respectively, than in the aril (Zadernowski et al., 2009). The total content of seven main xanthones in mangosteen pericarp (4816.59 mg/100 g DM) has been reported to be approximately eight times higher than in the aril (562.48 mg/100 g DM) (Wittenauer et al., 2012). However, the rambutan, both fresh and dried pulp, has been revealed containing ascorbic acid content higher than in the peel, with showed a lower content of carotene (Johnson et al., 2013).

Table 2. Percent of flesh, rind/skin, and seed in tropical fruits.

Types of fruits	Flesh (%)	Rind/skin (%)	Seed (%)	Reference(s)
Durian	20–35	55–66	5–15	Siriphanich, 2011
Mangosteen	25–29	60–65	6–11	Chen et al., 2011; Ketsa and Paull, 2011
Rambutan	34–54	37–62	4–9	Sirisompong et al., 2011; Issara et al 2014
Mango	60–75	11–18	14–22	Mitra et al., 2013
Jackfruit	30–35	55–62	8–10	Saxena et al., 2011
Papaya	80–90	10–20	10–20	Lee et al., 2011; Parni and Verma, 2014
Passion fruit	44–54	45–52	1–4	Arjona et al., 1991; Almeida et al., 2014
Dragon fruit	54–74	22–44	2–4	Esquivel et al., 2007; Liaotrakoon et al., 2013b
Pineapple	60–71	29–40	—	Ketnawa et al., 2012; Choonut et al., 2014

It is worth noting that the flour processed from the mango peel has been found to contain significant superior qualities than the mango pulp in terms of total phenolic, carotenoids, anthocyanins, flavonoids, vitamin C, and antioxidant activities (Abdul Aziz et al., 2012). Mango peels contained mangiferin approximately three times higher than in the pulp (Ruiz-Montañez et al., 2014). Mango peels and kernels have been reported having amounts of gallotannins of 1.4 mg/g DM and 15.5 mg/g DM, while only small amounts of 0.2 mg/g DM were found in the pulp using rhodanine assay (Berardini et al., 2004). The detection of total amounts of flavonol and xanthone glucosides contents of up to 4860 mg/kg DM (Berardini et al., 2005) and 1091 mg/kg DM (Ribeiro et al., 2008) in the mango peels of various varieties evidenced they were a rich source of phenolic compounds, while only traces were detected in the pulp. The total phenolic contents of mango peels have been revealed to be about 13% to 47% higher compared to the flesh (Daud et al., 2010) and about 32% higher than in the seeds (Dorta et al., 2012). The peels of two mango cultivars, namely *langsra* and *chonsa*, showed significantly higher in total phenolic content and flavonoids as compared to the kernel, leaves, and stem bark (Sultana et al., 2012). On the contrary, although the total carotenoids obtained from mango peels were found to be significantly higher than in the kernel, it was lower in total phenolic and antioxidant activities (Sogi et al., 2013). Similarly, the total phenolic content (Barreto et al., 2008; Ribeiro et al., 2008) and gallotannins (Luo et al., 2014) in kernels of various mango cultivars have been found remarkably higher compared to the peels. However, Sultana et al. (2012) have a contradictory observation where they discovered the total phenolic and flavonoids contents of mango kernels were lower than in the peels for both mango cultivars of *langra* and *chonsa*. Both the peel and seed of the mango not only reported more superior than the pulp in total phenolics and antioxidant capacities (Matsusaka and Kawabata, 2010), but also in mineral contents (Chiocchetti et al., 2013). However, in terms of volatile oil constituents, the green Thai mango peel and pulp showed similar amounts (Tamura et al., 2001). In a more recent study, Fasoli and Righetti (2013) captured a total of 334 and 2855 unique protein species in mango peel and pulp.

The total phenolic content of papaya peels has been revealed to be approximately 1.2 times higher than in the seed (Ng et al., 2012). On the contrary, biochemical parameters of carbohydrate, protein, ash, crude fiber, phosphorus, iron and lipid peroxidation of papaya seeds have been discovered significantly higher than in the pulp (Parni and Verma, 2014) and peel (Parni and Verma, 2014; Santos et al., 2014), while it showed a lower content of total fiber (Santos et al., 2014). In terms of mineral compositions, the papaya seed has been revealed to be more superior than the peel in phosphorus, calcium, magnesium, zinc, and iron, while lower in potassium, sulphur, and copper (Santos et al., 2014). Regardless of their cultivars, vitamin C and total phenolic content of papaya peel have been discovered to be present higher than in the seed (Santos et al., 2014).

The total phenolic and flavonoids contents of yellow passion fruit pulp and seed demonstrated to be significantly higher in

Table 3. Recently published reviews on fruit wastes.

Content	Reference
Food applications	
Focuses on flavonoids, phenolic acids, tannins, stilbenes, and lignans in fruit residues, and their importance in human health. Overview of methods for determining antioxidant activity and extraction of polyphenolic compounds from fruit residue	Babbar et al., 2015
Overview of the nutritional, functional, and anti-infective properties of pomegranate peel and peel extract and their applications as food additives, functional food ingredients or biological active components in nutraceutical preparations	Akhtar et al., 2014
Tropical fruit waste components as a useful source of remedy for obesity	Asyifah et al., 2014
The fermentation of fruit wastes for production of phenolic antioxidants and their application in manufacture of edible coatings and films	Martinez-Avila et al., 2014
The feasibility and constraints of applying industrial symbiosis in recovering waste from agro-industry and the uses of these functional ingredients in the nutraceutical and pharmaceutical industries	Mirabella et al., 2014
Current situation and perspectives of fractionation of apple by-products as source of dietary fiber and phytochemicals	Rabetafika et al., 2014
Highlights the prospects of valorization of date palm fruit processing by-products and wastes employing fermentation and enzyme processing technologies	Chandrasekaran and Bahkali, 2013
Focuses the potential of apple processing wastes as low-cost substrates for bioproduction of high value products of organic acids, enzymes, natural antioxidants, dietary fibers, aroma compounds, biofuels, and biopolymers	Dhillon et al., 2013
Bioactivities of pomegranate peel's ellagic acid and punicalagin, and their nutracuetical properties on cardiovascular protective, anti-inflammatory, anti-allergic, anticancer, antimicrobial, anti-influenza, anti-malarial, and wound healing potential	Ismail et al., 2012
The occurrence of functional compounds in tropical fruit wastes and their possible uses as additives of antibrowning, antimicrobial, flavoring, colorant, and dietary fiber	Ayala-Zavala et al., 2011
Focuses on the chemistry of phenolic compounds in relation to antioxidant activity, the occurrence of phenolic compounds in agri-industrial by-product and their potential uses	Balasundram et al., 2006
The potential of anaerobic digestion for recovery of biodegradable matters of hemicellulose, cellulose and lignin, and methane production	Bouallagui et al., 2005
Addresses the olive mill waste bioactivity and the recovery of biophenols	Obied et al., 2005
Nonfood applications	
Highlights on the valorization approach of different agricultural peels of orange, pomelo, grapefruit, lemon, banana, cassava, jackfruit, pomegranate, and garlic as adsorbents for removal of diverse aquatic pollutants from water and wastewater	Bhatnagar et al., 2015
Focuses the use of orange, potato, and banana peels as dye adsorbents	Anastopoulos and Kyzas, 2014
Potential use of agricultural wastes as biosorbents for removal of heavy metals from wastewater	Nguyen et al., 2013
The problems, current management and prospects for utilization of the polysaccharide components derived from fruit wastes for biofuel production through enzymatic hydrolysis	Van Dyk et al., 2013
An updated summary of alternative adsorbents developed from fruits and vegetables wastes for carcinogenic pollutants removal from waste water	Patel, 2012
The potential and utilization of low-cost adsorbents prepared from different types of agriculture waste materials for removal of various aquatic pollutants	Bhatnagar and Sillanpää, 2010

comparison to albedo, although they contained lower content of total dietary fiber (López-Vargas et al., 2013). Meanwhile, both the peel and pulp of white- (*Hylocereus undatus*) and red-flesh (*Hylocereus polyrhizus*) dragon fruits contained a significant amount of pectic substances, whilst the peel of both dragon fruit species showed a higher amount of pectic than in the pulp (Liaotrakoon et al., 2013a). Total phenolic contents and radical scavenging activity of peels of *H. undatus* and *H. polyrhizus* have been revealed as significantly higher than in the pulp (Nurliyana et al., 2010). The rind of pineapple has been discovered as being remarkably higher in lutein, α-carotene, β-carotene, and vitamin A than the core except for vitamin C (Freitas et al., 2015). The extract from the crown of both pineapple cultivars of *Nang Lae* and *Phu Lae* (Ketnawa et al., 2012) and extraction solvents of distilled water and phosphate buffer (Umesh Hebbar et al., 2008) gave the highest bromelain proteolytic activity compared to the peel, core, and stem.

Methods used to identify and quantify bioactive compounds in tropical fruit wastes

Spectrophotometric Methods

Numerous studies have proven that total phenolic content (TPC) determining using the Folin–Ciocalteu (FC) method has a direct relationship with antioxidant properties (Palanisamy et al., 2008; Khonkarn et al., 2010). Most probably due to this reason, the FC method has become the most selected spectrophotometric method to quantify bioactive compounds in a fruit waste. Table 4 presents the TPC of fruit wastes quantified using the FC method. Gallic acid is the most selected standard to use in representing the phenolic contents in fruit wastes. Other standards, such as tannic acid, were also used. Thus far, no TPC evaluation has been done on the durian peel and seed. There is no evaluation of the TPC in the seed of mangosteen and dragon fruit, and peel of jackfruit. In summary, Table 4 shows that the rambutan peel has the highest phenolic content of 762 mg/g obtained using supercritical fluid extraction (Palanisamy et al., 2008). Besides the FC method for the TPC evaluation, aluminum chloride and pH-differential assays were also used to quantify the flavonoids and anthocyanins contents of fruit wastes as shown in Table 5. Catechin was the most selected standard to express flavonoids content in fruit wastes, followed by rutin and quercetin. Cyanidin-3-glucoside was employed to express the anthocyanins content in the pH-differential method. Despite total flavonoids and anthocyanins, tropical fruit wastes were quantified in terms of total tannins, proanthocyanidins, betacyanin, carotenoids, and saponins (Table 5).

Table 4. Total phenolic content (TPC) in tropical fruit waste determined using Folin–Ciocalteu method.

Fruit waste(s)	Extraction method	Yield(s)	Reference(s)
		Gallic acid equivalent (GAE)	
Mangosteen			
peel	80% methanol at room temperature for 1 h using an orbital shaker at 250 rpm	67.41 mg/g DM	Palakawong et al., 2013
	Sample was mixed with acidified 70% ethanol and sonicated for 25 min at 80% amplitude, then subsequently subjected to magnetic stirring for 1 h	245.78 mg/g powder	Cheok et al., 2013a
	Lyophilized and dried peel macerated in a blender and extracted three times using methanol for 1 h at room temperature	263.3 mg/g DF	Acuña et al., 2012
	2 h extraction time with 0.05 solid to solvent ratio and at 69.77% methanol concentration using magnetic stirring	140.66 mg/g powder	Cheok et al., 2012
	Methanol solvent and stirred for 20 h	75.035 mg/g powder	Cheok et al., 2012a
	Macerated with 95%ethanol at room temperature then fractionated with methanol	1.64 mg/mL	Khonkarn et al., 2010
	20% (v/v) ethanol and shaking for 2 h in the dark at room temperature	181.4 mg/g DW	Romier-Crouzet et al., 2009
	80% methanol at room temperature for 1 h using an orbital shaker at 250 rpm	218.1 g/kg dm	Zadernowski et al., 2009
Rambutan			
peel	Ultrasound-assisted extraction using distilled water at 50°C, ultrasound power of20 W, extraction time of 20 min and solid–liquid ratio of 1:18.6 g/mL	552.64 mg/100 g	Prakash Maran et al., 2017
	Microwave-assisted extraction using 80.85% ethanol concentration, 58.39 s extraction time, and liquid to solid ratio of 24.51:1.	213.76 mg/g DW	Sun et al., 2012
	Macerated with 95%ethanol at room temperature then fractionated with ethyl acetate	2.28 mg/mL	Khonkarn et al., 2010
	Supercritical fluid extraction at a pressure of 300 bar and temperature of 50°C for 2 h	762 mg/g extract	Palanisamy et al., 2008
seed	Powdered seed was mixed with ethanol with stirring	7.6 mg/g plant extract	Mehdizadeh et al., 2015
Mango			
Peel	—	15.84 g/g CE	Marina and Noriham, 2014
	Peel was homogenized with chilled phosphate buffer in a homogenizer and then added with 80% chilled acetone	Raspuri raw: 8.12 mg/g Raspuri ripe: 29.52 mg/g Badami raw: 10.45 mg/g Badami ripe: 28.10 mg/g	Ajila and Prasada Rao, 2013
	Freeze-dried peel subjected into 50% ethanol using microwave-assisted extraction at 75°C	9.8 g/100 g DW	Dorta et al., 2012
	Using 80% methanol in a shaker for 24 h at room temperature	Mango langra: 116.80 mg/g DM Mango chosa: 122.60 mg/g DM	Sultana et al., 2012
	Soxhlet extraction for 6 h sequentially with hexane, ethyl acetate, and water	1226 mg/g DW	Daud et al., 2010
	Macerated in 50% ethanol in a water bath at 30°C for 24 h	123 mg/g DW	Matsusaka and Kawabata, 2010
	Extracted using 60% methanol	57240 mg/kg DM	Ribeiro et al., 2008
peel and pulp's leftovers	50% ethanol extraction	376.12 g/100 g DB	Da Silva et al., 2014c
Seed/kernel	Freeze-dried seed using 50% acetone in a microwave-assisted extraction at 75°C	7.4 g/100 g DW	Dorta et al., 2012
	Using 80% methanol in a shaker for 24 h at room temperature	Mango langra: 63.89 mg/g DM Mango chosa: 69.24 mg/g DM	Sultana et al., 2012
	Macerated in 50% ethanol in a water bath at 30 °Cfor 24 h	153 mg/g DW	Matsusaka and Kawabata, 2010
	Extracted using 60% methanol	82540 mg/kg DM	Ribeiro et al., 2008
	Refluxed using 50% ethanol in a water bath at 70°C for an hour	117 mg/g	Soong and Barlow, 2004
Jackfruit			
seed	Sample mixed with boiling water and stirred for 4 hour	406 mg/100 g	Nair et al., 2012
	Refluxed using 50% ethanol in a water bath at 70°C for an hour	27.7 mg/g	Soong and Barlow, 2004
Papaya			
peel	—	3.23 g/g CE	Marina and Noriham, 2014
	90% acetone and 60 min extraction time	15.18 μg/mL	Ng et al., 2012
peel, pulp's leftovers and seed	50% ethanol extraction	783.37 g/100 g DB	Da Silva et al., 2014c
seed	Deionized water and 120 min extraction time	6.75 μg/mL	Ng et al., 2012
Passion fruit			
peel	Extracted with boiled water	4.67 mg/g	Da Silva et al., 2014a
	Extracted with boiled water	2.53 mg/g DM	Da Silva et al., 2014b
	Freeze-dried peel was sequentially extracted with methanol-HCl solution and acetone/water for 1 hours	482.56 mg/100 g db	Hernández-Santos et al., 2015
albedo	Vigorously shaken for 2 min in solvent of dimethyl sulfoxide and left for 2 h in an ultrasonic water bath	1.86 mg/g	López-Vargas et al., 2013
seed	50% ethanol extraction	451.06 g/100 g DB	Da Silva et al., 2014c
seed & pulp	Vigorously shaken for 2 min in solvent of dimethyl sulfoxide and left for 2 h in an ultrasonic water bath	4.31 mg/g	López-Vargas et al., 2013

(*Continued on next page*)

Table 4. (*Continued*)

Fruit waste(s)	Extraction method	Yield(s)	Reference(s)
residues	Soxhlet extraction at 60°C for 4 h using n-hexane, then using methanol for another 4 hour	41.2 mg/g dry extract	De Oliveira et al., 2009a
Dragon fruit			
peel	—	*H. polyrhizus* Fresh: 7.95 mg/g Dried powder: 7.84 mg/g	Chia and Chong, 2015
	50% methanol and magnetic stirring for 4 hour	*H. undatus:* 7.75 mg/g	Zhuang et al., 2012
	70% ethanol and shaking for 2 days	*H. undatus:* 36.12 mg/100 gH polyrhizus: 28.16 mg/100 g	Nurliyana et al., 2010
Pineapple			
residues	Soxhlet extraction using ethyl acetate at 50-55°C for 12 hour	99.8 mg/g extract	Riya et al., 2014
	Fixed-bed drying at 60°C and 1.5 m/s.	13.79 mg/100 g DB	Da Silva et al., 2013
	Soxhlet extraction at 60°C for 4 h using n-hexane, then using methanol for another 4 hour	9.1 mg/g dry extract	De Oliveira et al., 2009
peel and pulp's leftovers	50% ethanol extraction	2787.09 g/100 g DB	da Silva et al., 2014c
		Other standard	
Mango			
peel	Microwave-assisted extraction using 50% ethanol, extraction time of 60 min, solid-to-solvent ratio of 1:30 (w/v), three times extraction and pH 5.5.	Tannic acid 12.0 g/100 g	Dorta et al., 2013a
seed	Microwave-assisted extraction with 50% acetone, solid-to-solvent of 1:30 (w/v), an extraction time of 60 min, two times extraction, and a pH of 5.5.	Tannic acid 8.1 g/100 g	Dorta et al., 2013b

Chromatographic Methods

The chromatographic method is employed to identify and quantify specific compounds from tropical fruit wastes which have pharmaceutical importance to human health. Table 6 summarizes the bioactive compounds identified and quantified in tropical fruit wastes using chromatographic methods. The most commonly used methods were high performance liquid chromatography (HPLC) and gas chromatography (GC). Fatty acid compositions have been observed quantified using GC while bioactive compounds were quantified using HPLC. α-Mangostin is an active bioactive compound widely derived from mangosteen peel using the chromatographic method because of its scientific evidence on various pharmaceutical properties of antitumoral (Kaomongkolgit et al., 2011; Krajarng et al., 2011), anti-inflammatory (Cui et al., 2010; Chae et al., 2012), and antioxidant (Acuña et al., 2012).

A large scale recovery of geraiin of 21% yield from rambutan peel by fractionation using reverse-phase C18 column chromatography (Perera et al., 2012) most probably was driven by the discovery of its anti-hyperglycemic activity (Palanisamy et al., 2011a,2011b). Dorta et al. (2014) which discovered that the main phenolic group in mango peel was composed of gallates and gallotannins using the HPLC-electrospray ionization–quadrupole-time of flight-mass spectrometry. Gallotannins' profile in mango kernels has been analyzed using fast liquid chromatography and having been investigated for its antimicrobial activity (Engels et al., 2012). Ruiz-Montañez et al. (2014) discovered that the most effective extraction method employed to obtain the highest yields of mangiferin and lupeol from mango peels was the ultrasonic-assisted extraction. Gas chromatography–mass spectrometry was employed to identify and isolate compounds in mango kernel extracts which have been evaluated for their potential against human breast cancer cells (Abdullah et al., 2014).

Tropical fruit wastes utilizations and research trends

Durian (Durio Zibethinus)

Durian is popular as "king of fruit" in South-East Asia countries due to its rich sweet creamy delicious pulp and distinctive aroma. Besides the wonderful taste, the durian is rich in mineral contents of potassium, magnesium, sodium, and calcium, and nutritional values of vitamin A, β-carotene, and vitamin C (Ho and Bhat, 2015). In recent decades, the durian fruit and its wastes have been explored as food additives for various uses as preservative, thickening agent, antimicrobial agent, and for potential pharmaceutical applications (Ho and Bhat, 2015). The high percentage of nonedible parts from 60 to 81% of the durian (Table 2) has drawn the interest of researchers in pursuance of the transformation of durian biomass into highly valuable commodity such as a biosorbent, insulator, agro-pectin derivative, polysaccharide gel, and in biotechnological development (Foo and Hameed, 2011a).

Figure 1 illustrates the uses of the durian peel and seed in food and nonfood applications. Obviously, the durian peel has been discovered as having more utilities than the seed, which accounted about 85% for peel and 16% for seed, respectively. Useful compounds that have been derived from the durian peel for food applications were pectin (Wong et al., 2009; Wong et al., 2010b; Prakash Maran, 2015), polysaccharide gel (Hokputsa et al., 2004; Futrakul et al., 2010; Thunyakipisal et al., 2010), and fiber (Penjumras et al., 2014).

The transformation of the durian peel into a useful biomass commodity was started extensively in the year 2006 (Figure 1). The applications of the durian peel are more inclined along biomass transformation into a biosorbent (Hameed and Hakimi, 2008; Wong et al., 2010a; Abidin et al., 2011; Kurniawan et al., 2011; Adam et al., 2012), activated carbon (Chandra et al., 2007; Nuithitikul et al., 2010; Tham et al., 2011; Foo and Hameed, 2012e), and biocomposite (Rachtanapun et al., 2012; Charoenvai, 2014; Manshor et al., 2014). Although the durian

Table 5. Determinations of bioactive compounds in tropical fruit wastes using spectrophotometric methods.

Fruit waste(s)	Total flavonoids content (TFC) *Extraction method*	*Yield(s)*	*Reference(s)*
Mangosteen			
peel	80% methanol at room temperature for 1 h using an orbital shaker at 250 rpm	22.37 mg QE/g DW	Palakawong et al., 2013
	Macerated with 95% ethanol at room temperature	Two maturity stages: Young: 2.91 g QE/100 g extract Mature: 4.08 g QE/100 g extract	Pothitirat et al., 2009
Rambutan			
peel	Ultrasound-assisted extraction using distilled water at 50°C, ultrasound power of 20 W, extraction time of 20 min and solid-liquid ratio of 1:18.6 g/mL	104 mg RE/100 g	Prakash Maran et al., 2017
Mango			
peel	Peel was homogenized with chilled phosphate buffer in a homogenizer and then added with 80% chilled acetone	Raspuri raw: 0.101 mg CE/g Raspuri ripe: 0.332 mg CE/g Badami raw: 0.273 mg CE/g Badami ripe: 0.392 mg CE/g	Ajila and Prasada Rao, 2013
	Freeze-dried peel subjected into 50% ethanol using microwave-assisted extraction at 75°C	0.70 g CE/100 g DW	Dorta et al., 2012
	80% methanol for 24 h aided with shaking at room temperature	Two cultivars:langra: 90.89 mg CE/g DMc hosa: 92.55 mg CE/g DM	Sultana et al., 2012
seed	Freeze-dried seed using 50% acetone in a microwave-assisted extraction at 75°C	1.3 g CE/100 g DW	Dorta et al., 2012
	80% methanol for 24 h aided with shaking at room temperature	Two cultivars: langra: 45.56 mg CE/g DM chosa: 48.43 mg CE/g DM	Sultana et al., 2012
Passion fruit			
peel	Extracted with boiled water	1.17 mg CE/g	Da Silva et al., 2014a
albedo	Vigorously shaken for 2 min in solvent of dimethyl sulfoxide and left for 2 h in an ultrasonic water bath	5.12 mg RE/g	López-Vargas et al., 2013
pulp & seed	Vigorously shaken for 2 min in solvent of dimethyl sulfoxide and left for 2 h in an ultrasonic water bath	13.63 mg RE/g	López-Vargas et al., 2013
Pineapple			
peel	Fixed-bed drying at 46°C and 1.5 m/s	580.70 mg RE/100 g sample	Da Silva et al., 2013
	Total monomeric anthocyanins (TMA)		
Mangosteen			
peel	Mangosteen hull powder was mixed with Mexican lime juice acidified aqueous methanol solvent and stirring for 2 h at room temperature	4.742 mg cy-3-glu/g powder	Cheok et al., 2013b
	Mangosteen hull powder was mixed with methanol aqueous solvent, sonicated for 15 min with 20% amplitude and stirring for 1 hour at room temperature	2.92 mg cy-3-glu/g powder	Cheok et al., 2013a
	The mangosteen pericarp powder was extracted with 0.01% (v/v) hydrochloric acid (HCl) using methanol	13.2 mg/L	Zarena and Udaya Sankar, 2012
Rambutan			
peel	Ultrasound-assisted extraction using distilled water at 50°C, ultrasound power of 20 W, extraction time of 20 min and solid-liquid ratio of 1:18.6 g/mL	10.26 mg cy-3-glu/100 g	Prakash Maran et al., 2017
	Extracted at 25°C for 24 h with of 80% ethanol and 1% acetic acid solvent.	181.3 mg cy-3-glu/100 g of fresh pericarp tissues	Sun et al., 2011
Mango			
peel	Freeze-dried peel subjected into 50% ethanol using microwave-assisted extraction at 75°C	3.3 g cy-3-glu/100 g DW	Dorta et al., 2012
	Total tannins content		
Mangosteen			
peel	80% methanol at room temperature for 1 h using an orbital shaker at 250 rpm	35.08 mg GA/g DW	Palakawong et al., 2013
	Macerated with 95% ethanol at room temperature	Two maturity stages: Young: 51.25 g TA/100 g extract Mature: 36.66 g TA/100 g extract	Pothitirat et al., 2009
Rambutan			
seed	Powdered seed was mixed with ethanol with stirring	13.8 mg CE/g	Mehdizadeh et al., 2015
Jackfruit			
seed	Sample mixed with boiling water and stirred for 4 hour	198.38 mg GA/100 g	Nair et al., 2012

(*Continued on next page*)

Table 5. (*Continued*)

Fruit waste(s)	Total flavonoids content (TFC) *Extraction method*	*Yield(s)*	*Reference(s)*
	Proanthocyanidins		
Mango			
peel	Microwave-assisted extraction using 5% ethanol, extraction time of 120 min, solid-to-solvent ratio of 1:10, three times extraction, and pH 3.0.	228 g LE/100 g DW	Dorta et al., 2013a
seed	Microwave-assisted extraction using 5% acetone, extraction time of 0 min, solid-to-solvent ratio of 1:10, three times extraction, and pH 8.0.	1.2 g LE/100 g DW	Dorta et al., 2013b
	Betacyanin		
Dragon fruit			
peel	Sample was mixed with distilled water	Fresh: 41.55 mg/g Dried powder: 80.21 mg/g	Chia and Chong, 2015
	Spray-dried peel powder was weighed and diluted with McIlvaine buffer (pH 6.5) to reach an absorption value of 1.0.	Freshly prepared dried powder: 64.66 mg/100 g	Ee et al., 2014
	Extracted at 100°C for 5 min in a pH5 citric acid solution	24.03 mg/L	Harivaindaran et al., 2008
	Total carotenoids		
Passion fruit			
peel	Freeze-dried peel was sequentially extracted with methanol-HCl solution and acetone/water for 1 hour	4.85 mg β-carotene/100 g	Hernández-Santos et al., 2014
	Total saponins		
Rambutan			
seed	Powdered seed was mixed with ethanol with stirring	0.4 mg soya saponin/g	Mehdizadeh et al., 2015

CE: catechin; QE: quercetin; RE: rutin; TA: tannic acid; GA: gallic acid; LE: leucoanthocyanidin; PPPs: purified polymeric proanthocyanidins; cy-3-glu: cyanidin-3-glucoside

peel has been incorporated with coconut coir to develop a particleboard which served as an insulator (Khedari et al., 2003), there has been no further related researches since then.

The pasting properties of high dietary fiber content starch extracted from the durian seed have been characterized for its potential uses in the food, pharmaceutical, and cosmetics industries (Tongdang, 2008). Gum was first derived from the durian seed by Amin et al. (2007). The extraction of gum from the durian seed was optimized (Amid and Mirhosseini, 2012b) and its chemical compositions, rheological and viscoelastic behavior were characterized (Amid and Mirhosseini, 2012a; Amid et al., 2012). Emulsifying activity, particle uniformity, rheological properties (Amid and Mirhosseini, 2012c) and the influence of chemical extraction (Amid and Mirhosseini, 2012d) and effect of drying methods (Mirhosseini et al., 2013) on a natural polysaccharide-protein biopolymer from the durian seed were characterized and investigated. The gum derived from the durian seed has been tried to be used for the stabilization of water in oil in water emulsion (Amid and Mirhosseini, 2014).

Mangosteen (Garcinia Mangostana L.)

Mangosteen is known as the "queen of fruit" in South East Asia. The mangosteen fruit comprises more than 66% of wastes, with the peel alone already being 60 to 65%. However, it is the peel extract that has been discovered as having numerous medicinal properties. Besides its evidence on antioxidant properties (Suvarnakuta et al., 2011; Suttirak and Manurakchinakorn, 2014), it has been extensively revealed as having antitumor capabilities against cancers of the bone (Krajarng et al., 2011), brain (Chao et al., 2011), breast (Balunas et al., 2008), colon (Romier-Crouzet et al., 2009; Khonkarn et al., 2010; Watanapokasin et al., 2010), head and neck (Kaomongkolgit et al., 2011), leukemia (Ee et al., 2008), skin (Wang et al., 2011), and prostate (Hung et al., 2009).

It is most probably due to these recent discoveries on antitumoral capabilities where most researchers have recommended its use in cancer treatments, the peel is rarely processed into other applications either for food or nonfood as shown in Figure 2. Only pectin was derived from the mangosteen peel (Gan and Latiff, 2011) and seed (Ajayi et al., 2007) for food application.

In nonfood applications, mangosteen peel has been utilized as an activated carbon to remove Remazol Brilliant Blue R (Ahmad and Alrozi, 2010). Chen et al. (2011) characterized mangosteen peel-activated carbon prepared by K_2CO_3 activation utilizing two-stage carbonization process in a self-generated atmosphere, while Foo and Hameed (2012b) investigated microwave-assisted K_2CO_3 activation operational parameters including chemical impregnation ratio, microwave power, and irradiation time on carbon yield and adsorption capability. Mangosteen peel has been utilized as biosorbents to remove toxic metals of Pb(II), Cd(II), and Co(II) from aqueous solution (Zein et al., 2010). Ethanolic mangosteen peel extract, which showed a high photoelectrochemical performance, has been discovered as an effectual component as a sensitizer to fabricate dye-sensitized solar cells (Zhou et al., 2011). The 15% w/v citric acid mangosteen peel aqueous extract was also suggested as a useful alternative natural dye for the dyeing of cotton and silk yarn (Chairat et al., 2007).

Rambutan (Nephelium Lappaceum)

The rambutan comprises of 34–54% of edible flesh and 37–62% of nonedible peel and 4–9% of seed. In recent

Table 6. Identification and quantification of bioactive compounds in tropical fruit wastes using chromatographic methods.

Fruit wastes	Chromatographic system employed	Compounds identified/isolated	References
Durian			
Seed	HPLC: Lichrocart 250–4,6 purospher star NH_2 column	Carbohydrate compositions: galactose (48.6–59.9%) glucose (37.1–45.1%)	Amid et al., 2012
	HPLC: reversed phase column RP-C18	Amino acid: leucine (30.9–37.3%)	
	GC: fused silica capillary DB-Wax column	Fatty acid compositions: palmitic acid (C16:0) palmitoleic acid (C16:1) stearic acid (C18:0) oleic acid (C18:1) linoleic acid (C18:2) linolenic acid (C18:2)	
Mangosteen			
peel	HPLC: Zorbax Eclipse XDB	Three major components: α-mangostin: 1173.33 mg/100 g FW γ-mangostin: 303.64 mg/100 g FW gartanin: 70.41 mg/100 g FW	Wittenauer et al., 2012
	HPLC-UV vis: Varian Pursuit XRs	Anthocyanins contents: cyanidin-3-sophoroside: 76.1% cyanidin-3-glucoside: 13.4% pelargonidin-3-glucoside: 6.2%	Zarena and Udaya Sankar, 2012
	GC-MS: SPB-1 silica-fused capillary column	Total phenolic acid contents: protocatechuic: 3812.2 mg/kg DM p-hydroxybenzoic: 510.7 mg/kg DM vanillic: 414.3 mg/kg DM p-hydroxyphenylacetic: 345.0 mg/kg DM piperonylic: 203.3 mg/kg	Zadernowski et al., 2009
	HPLC-LCMS: Synergi® column	Anthocyanins contents: cyanidin-sophorosides: 3126 g/kg cyanidin-glucoside + cyanidin-glucoside X: 842 g/kg cyanidin-glucoside-pentoside: 125 g/kg	Palapol et al., 2008
Rambutan			
peel	HPLC: Merck Chromolith Performance RP-18 and Thermo BDS Hypersil C18 columns	Geraniin: 20.63%	Perera et al., 2012
	HPLC: Zorbax SB-C18 column	Free phenolics: syringic acid: 16.86 mg/g DW p-coumaric acid: 19.44 mg/g DW	Sun et al., 2012
	HPLC: Waters Xterra Prep RP18 OBD column	Geraniin: 211.2 mg/g	Palanisamy et al., 2011b
seed	HPLC: -	Polyphenol constituents: ellagic acid: 461.1 mg/kg geraniin: 423.2 mg/kg gallic acid: 98.0 mg/kg corilagin: 94.5 mg/kg	Mehdizadeh et al., 2015
	GC: CP Select CB column	Fatty acid compositions: Oleic acid: 36.60% Arachidic acid: 38.10%	Romain et al., 2013
	GC: flame ionization detection	Fatty acid compositions: Oleic acid: 40.45% Arachidic acid: 36.36%	Harahap et al., 2012
	GC: Supelco SP-2560 capillary column	Fatty acid compositions: Oleic acid: 36.79% Arachidic acid: 34.32%	Sirisompong et al., 2011
	GC: DB-5 capillary column	Fatty acid compositions: Oleic acid: 40.30% Arachidic acid: 34.50%	Solís-Fuentes et al., 2010
Mango			
peel	HPLC: RP18 column	Cultivar: Maqiesu penta-O-galloyl-glucoside: 18.47 mg/g hexa-O-galloyl-glucoside: 56.91 mg/g hepta-O- galloyl-glucoside: 111.94 mg/g octa-O- galloyl-glucoside: 136.16 mg/g nona-O- galloyl-glucoside: 117.79 mg/g Cultivar: Tainong-1 penta-O-galloyl-glucoside: 26.28 mg/g hexa-O-galloyl-glucoside: 48.62 mg/g hepta-O- galloyl-glucoside: 79.14 mg/g octa-O- galloyl-glucoside: 98.19 mg/g nona-O- galloyl-glucoside: 97.03 mg/g Cultivar: Zihuamang penta-O-galloyl-glucoside: 9.30 mg/g hexa-O-galloyl-glucoside: 17.44 mg/g hepta-O- galloyl-glucoside: 42.09 mg/g octa-O- galloyl-glucoside: 67.28 mg/g nona-O- galloyl-glucoside: 86.54 mg/g	Luo et al., 2014
	HPLC: C18 Thermo scientific column	Mangiferin: ≈13.25 mg/g DB	Ruiz-Montañez et al., 2014
	HPLC: Shim-pack PRC ODS	ethyl gallate: 11.2% penta-O-galloyl-glucoside: 32.2%	Jiang et al., 2010
	HPLC: C18 reversed-phase column	Cultivar: Van Dyke penta-O-galloy-glucoside: 17.71 g/kg DM methyl gallate: 15.46 g/kg DM tetra-O-galloy-glucoside: 7.22 g/kg DM mangiferin: 4.94 g/kg DM Cultivar: Embrapa-141-Roxa penta-O-galloy-glucoside: 2.76 g/kg DM methyl gallate: 0.87 g/kg DM tetra-O-galloy-glucoside: 1.19 g/kg DM mangiferin: 15.23 g/kg DM	Barreto et al., 2008
	HPLC: C18 Hydro-Synergy guard column	Mangiferin: 199 mg/kg DM Quercetin 3-O-gal: 151 mg/kg DM Quercetin 3-O-glc: 370 mg/kg DM Quercetin 3-O-xyl: 84.4 mg/kg DM	Ribeiro et al., 2008
seed	HPLC: RP18 column	Cultivar: Maqiesu penta-O-galloyl-glucoside: 45.85 mg/g hexa-O-galloyl-glucoside: 143.90 mg/g hepta-O-galloyl-glucoside: 211.93 mg/g octa-O- galloyl-glucoside: 154.90 mg/g nona-O- galloyl-glucoside: 94.03 mg/g Cultivar: Tainong-1 penta-O-galloyl-glucoside: 67.74 mg/g hexa-O-galloyl-glucoside:	Luo et al., 2014

(Continued on next page)

Table 6. (*Continued*)

Fruit wastes	Chromatographic system employed	Compounds identified/isolated	References
		161.63 mg/g hepta-O- galloyl-glucoside: 197.79 mg/g octa-O- galloyl-glucoside: 127.90 mg/g nona-O- galloyl-glucoside: 73.83 mg/g Cultivar: Zihuamang penta-O-galloyl-glucoside: 34.51 mg/g hexa-O-galloyl-glucoside: 102.16 mg/g hepta-O- galloyl-glucoside: 179.42 mg/g octa-O- galloyl-glucoside: 154.98 mg/g nona-O- galloyl-glucoside: 110.68 mg/g	
	HPLC: C18 reversed-phase column	Cultivar: Van Dyke penta-O-galloy-glucoside: 50.03 g/kg DM methyl gallate: 12.68 g/kg DM tetra-O-galloy-glucoside: 0.99 g/kg DM mangiferin: 6.40 g/kg DM Cultivar: Embrapa-141-Roxa penta-O-galloy-glucoside: 36.77 g/kg DM methyl gallate: 29.10 g/kg DM tetra-O-galloy-glucoside: 11.77 g/kg DM mangiferin: 8.98 g/kg DM	Barreto et al., 2008
Papaya			
seed	GC: Omegawax 52CB column	Fatty acid compositions: oleic acid: 66.7% palmitic acid: 19.7% stearic acid: 6.7% linoleic acid: 3.2%	Lee et al., 2011
	GC: BPX70025 capillary column	Fatty acid compositions: oleic acid: 75.9 – 76.8% palmitic acid: 12.8 – 13.9% stearic acid: 4.4 – 4.9% linoleic acid: 3.0 – 3.3%	Puangsri et al., 2005
Passion fruit			
peel	GLC: DB-225 capillary column	Monosaccharide compositions of pectin: uronic acid: 58.5 – 82.3% glucose: 4.8 – 13.5% arabinose: 4.1 – 9.5% galactose: 3.6 – 9.2% rhamnose: 2.6 – 5.9% xylose: 1.6 – 25% mannose: 0.7 – 1.8% fucose: 0.3 – 0.6%	Seixas et al., 2014
albedo	HPLC: C18 Teknokroma column	isoorientin: 7.1 mg/100 g isovitexin: 4.5 mg/100 g	López-Vargas et al., 2013
seed & pulp	HPLC: C18 Teknokroma column	isoorientin: 73.6 mg/100 g isovitexin: 42.35 mg/100 g	López-Vargas et al., 2013
Dragon fruit			
peel	GC: HP-5 capillary column	Predominant compositions: *H. polyrhizus*: β-amyrin: 15.87% α-amyrin: 13.90% octacosane: 12.2% γ-sitosterol: 9.35% octadecane: 6.27% 1-tetracosanol: 5.19% stigmast-4-en-3-one: 4.65% campesterol: 4.16% *H. undatus*: β-amyrin: 23.39% γ-sitosterol: 19.32% octadecane: 9.25% heptocosane: 5.52% campesterol: 5.27% nonacosane: 5.02%	Luo et al., 2014
	HPLC: Zorbax Eclipse Plus-C18 column	Monosaccharide composition of pectin: mannose: 17.78% rhamnose: 14.47% galacturonic acid: 39.11% glucose: 10.82% galactose: 11.91% xylose: 2.41% arabinose: 3.49%	Muhammad et al., 2014
	HPLC: Diamonsil C18 column	Major monosaccharide compositions of: Soluble dietary fiber: Rhamnose: 4.95% Galactose: 1.98% Galacturonic acid: 9.45% Insoluble dietary fiber: Xylose: 4.76% Galactose: 3.42% Klason lignin: 18.54%	Zhuang et al., 2012
seed	GC: BPX-70 capillary column	Fatty acid compositions: Red flesh: stearic acid: 5.49% oleic acid: 21.6% linoleic acid: 49.6% linolenic acid: 1.21% White flesh: stearic acid: 4.37% oleic acid: 23.8% linoleic acid: 50.1% linolenic acid: 0.98%	Ariffin et al., 2009
	GC: DB-5 semi-polar column	Major fatty acid compositions: oleic acid: 11.80 – 23.40% linoleic acid: 25.22 – 54.43%	Rui et al., 2009
	HPLC: Alltima HP C18 HL column	Fatty acid compositions: Red flesh: palmitic acid: 18.39% oleic acid: 23.61% linoleic acid: 45.21% White flesh: palmitic acid: 14.95% oleic acid: 18.67% linoleic acid: 55.43%	Liaotrakoon et al., 2013b
Pineapple			
peel	HPLC: Synergi^{TM} Hydro-RP column	L-Ascorbic acid: 252 – 288 mg/100 g DW Lutein: 288 – 297 mg/100 g DW α-carotene: 89 – 126 mg/100 g DW β-carotene: 2537 – 3225 mg/100 g DW Vitamin A: 215 – 584 mg/100 g DW	Freitas et al., 2015
	HPLC: Nucleosil 120 C18 column	Phenolics in high dietary fiber powder: Myricetin: 1576.0 μg/g DM Salicylic acid: 656.8 μg/g DM Tannic acid: 404.0 μg/g DM Trans-cinnamic acid: 19.8 μg/g DM p-coumaric acid: 13.4 μg/g DM	Larrauri et al., 1997
core	HPLC: Synergi^{TM} Hydro-RP column	L-Ascorbic acid: 426–488 mg/100 g DW β-carotene: 960–994 mg/100 g DW Vitamin A: 80–166 mg/100 g DW	Freitas et al., 2015

HPLC: high-performance liquid chromatography; GC: gas chromatography; GLC: gas-liquid chromatography

intensive quests for natural health benefit ingredients, these nonedible parts of the rambutan have been investigated for its potential pharmaceutical properties. Rambutan peels have been widely discovered having properties of antioxidants (Okonogi et al., 2007; Sun et al., 2011,2012) and antiproliferative activities against human cell lines (Khonkarn et al., 2010). In a recent study, the oral administration of a dose of 30 mg/kg body weight of rambutan

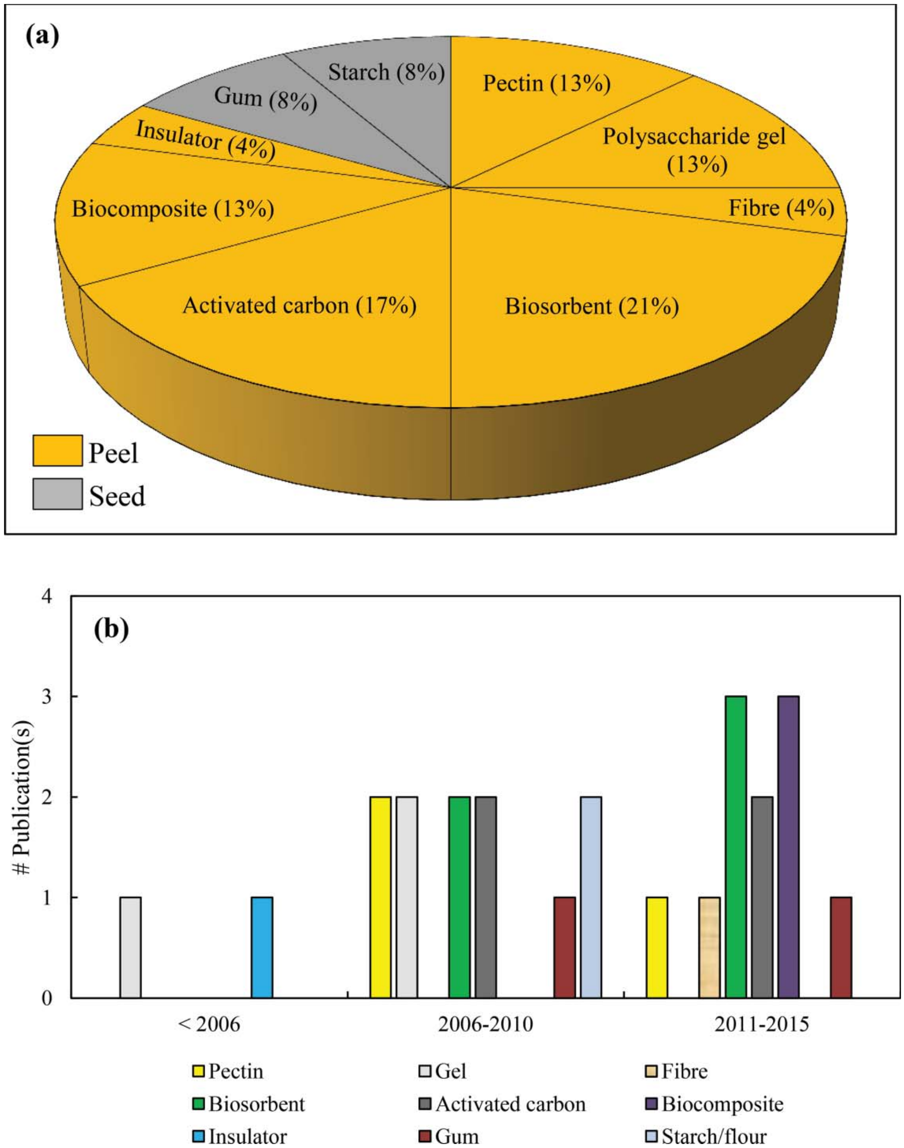


Figure 1. Durian wastes (a) utilizations and (b) research trend.

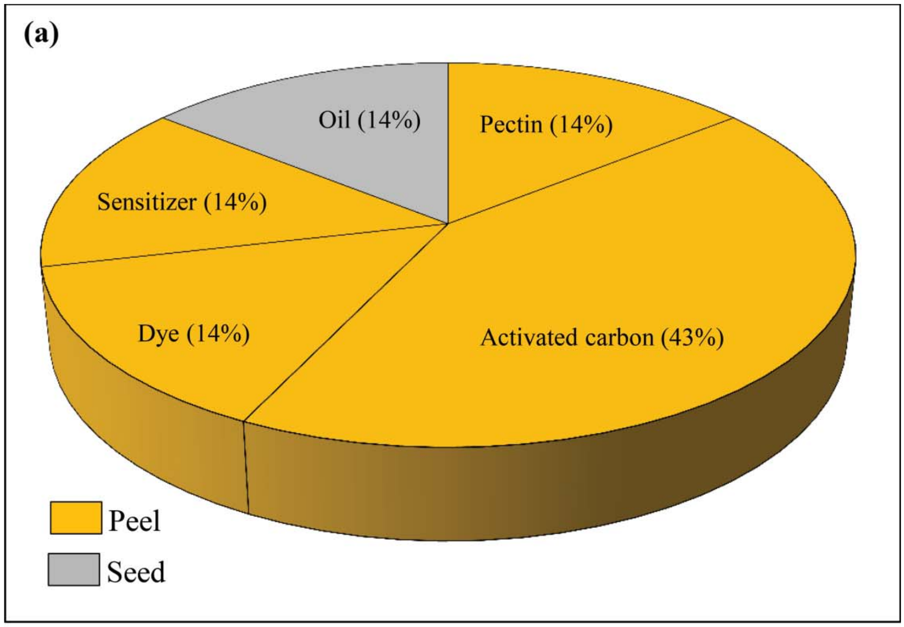
peel extract to an obese rat in every two days for 12 weeks resulted in the inhibition of body weight gain (Lestari et al., 2014). The rambutan seed aqueous extract has been revealed it possesses antimicrobial activities against gram positive including *Staphylococcus aureus, Streptococcus pyogenes*, and *Bacillus subtillis* and gram-negative bacterium including *Escherichia coli* and *Pseudomonas aeruginosa* (Bhat and Al-daihan, 2014).

Figure 3 demonstrates that the percentage of rambutan peel (57%) utilizations is greater than the seed (43%). However, only 10% of rambutan peel is derived to use for food purposes such as polysaccharide gel (Prakash Maran and Priya, 2014) and anthocyanins (Sun et al., 2011). The peel is quite extensively explored for nonfood applications of biosorbent (Rubcumintara et al., 2012), activated carbon (Ahmad and Alrozi, 2011a,2011b; Njoku et al., 2014), biocomposite (Ooi et al., 2011, Ooi et al., 2012a,2012b), and biomimetic synthesis (Yuvakkumar et al., 2014a,2014b,2015).

Although the rambutan seed was reported to have been utilized to produce biofuel as early as the year 1996 (Kalayasiri et al., 1996), no further relevant research was carried out since then (Figure 5b). The rambutan seed is a potential source of oil because it has been discovered to have a high amount of fat content from 33.4% to 37.35% in previous studies (Solís-Fuentes et al., 2010; Sirisompong et al., 2011; Romain et al., 2013). It possesses major fatty acids of oleic acid and arachidic acid (Avato et al., 2006; Solís-Fuentes et al., 2010; Sirisompong et al., 2011; Harahap et al., 2012; Romain et al., 2013; Sonwai and Ponprachanuvut, 2012; Yanty et al., 2013; Zzaman et al., 2014). As such, the potential of the rambutan seed fat as a source of cocoa butter substitute in confectionary products has been highlighted (Issara et al., 2014). In a recent nonfood application study, the rambutan seeds were investigated for its potential use as a biocoagulant to remove turbidity in water or wastewater treatment industry (Abidin et al., 2014).

Mango (Mangifera Indica L.)

Mango fruits' bioactive compounds, their related nutraceutical properties and potential significance health benefits to human



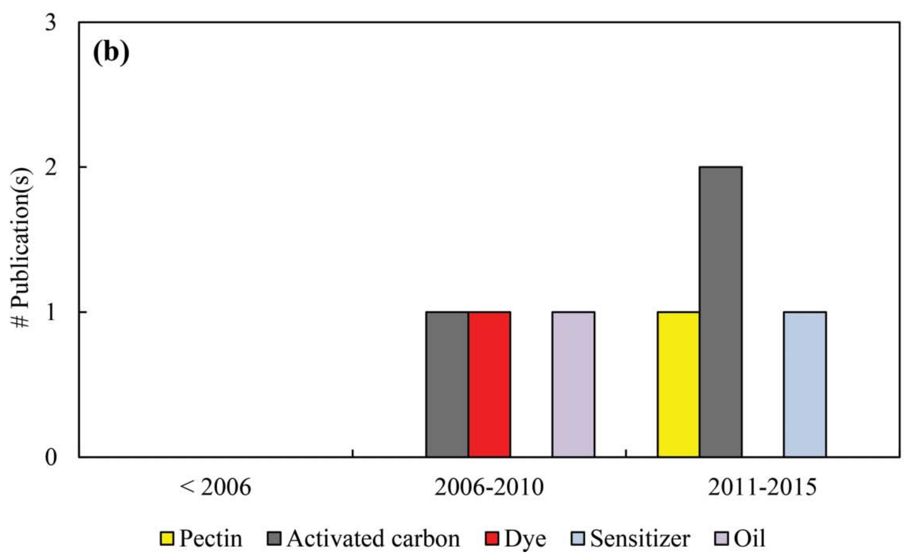


Figure 2. Mangosteen wastes (a) utilizations and (b) research trend.

have been highlighted in previous reviews (Masibo and He, 2008; 2009). The mango which comprises 14–22% seed and 11–18% peel (Mitra et al., 2013), has drawn the interest of researchers due to its superior content of bioactive compounds. Mango peel extract not only demonstrated its effectiveness in inhibiting human cervical cancer cell (Ali et al., 2012), it also showed an effect on adipogenesis more superior than the flesh (Taing et al., 2012; Taing et al., 2013). Mangiferin is one of the major bioactive compounds present in mango peel (Berardini et al., 2005; Schieber et al., 2003). Many studies have linked mangiferin as having pharmaceutical properties in promoting endothelial cell migration (Daud et al., 2010), and the prevention of oxidative stress-associated diseases (Luo et al., 2012). Rats with a mango peel diet supplement of 5% and 10% levels demonstrated a significant increase in urine sugar, urine volume, fasting blood glucose, total cholesterol, triglycerides and low density lipoprotein and a decrease in high density lipoprotein which implied that mango peel as a functional ingredient has an antidiabetic effect (Gondi et al., 2015). Mango kernel extract has been discovered having anticancer activity against breast cancer cells (Abdullah et al., 2014), and it was recently discovered having antiproliferative effects on breast, liver, and luekemia cancer cells (Luo et al., 2014). Gallotannins of mango kernels have been tested for its effectiveness in antimicrobial activity (Engels et al., 2009; Engels et al., 2012).

Pectin, enzyme, and fiber are mainly derived from mango peels for food applications, while only a few for nonfood applications as biosorbents (Figure 4). The yields of pectin (12.2 to 21.2%) with degrees of esterification (56.3–65.6%) obtained from the lyophilized peels of two mango cultivars, namely *Nam Dokmai* and *Ngowe* (Berardini et al., 2005), were good evidence to suggest mango peels as a promising source of high-quality pectin which subsequently, provoked numerous-related researches (Sirisakulwat et al., 2008; Koubala

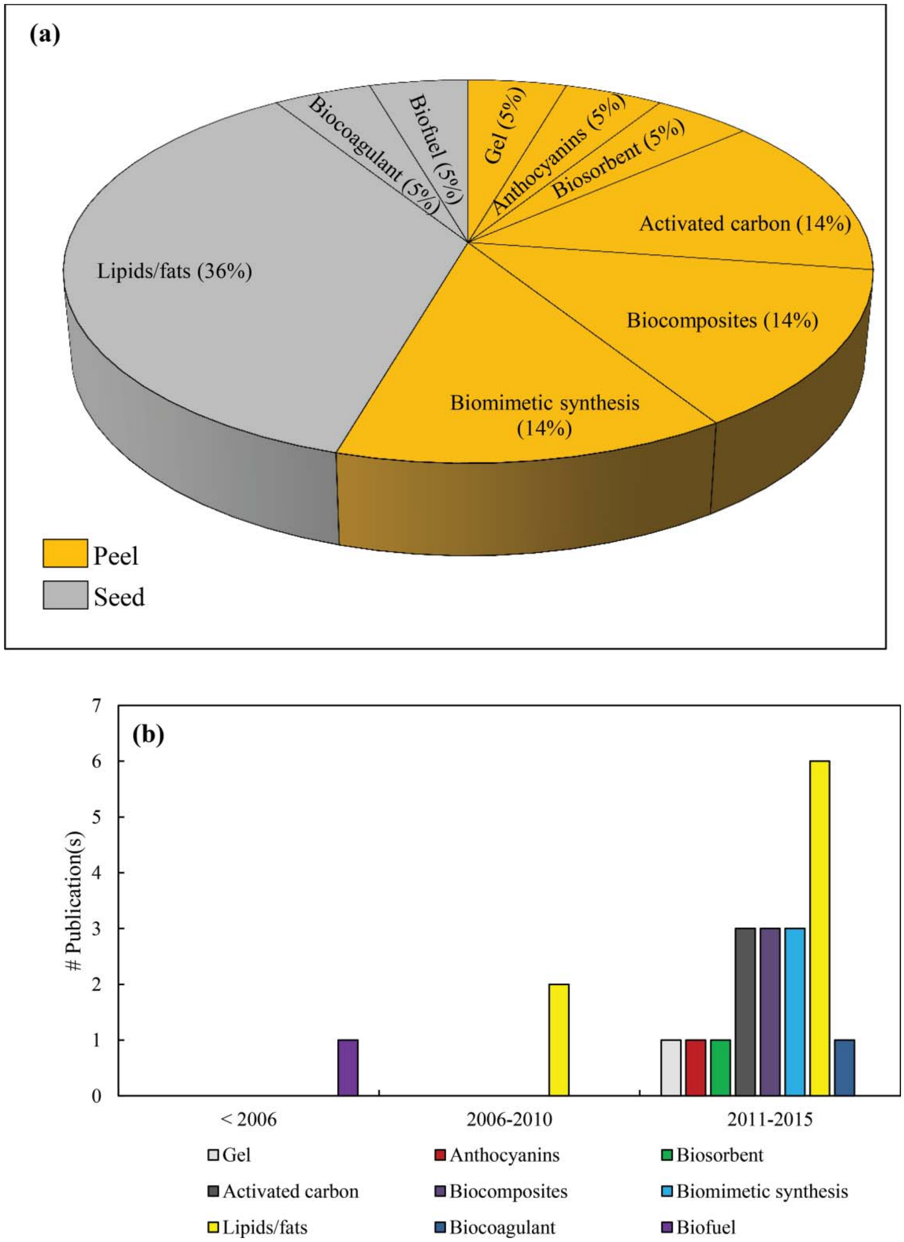


Figure 3. Rambutan wastes (a) utilizations and (b) research trend.

et al., 2009; Sirisakulwat et al., 2010; Kermani et al., 2014). Two important enzymes, protease (Amid et al., 2011) and pectinase (Amid et al., 2013), have also been discovered in mango peels. Due to the presence of a significant amount of dietary fiber in the mango peel (Ajila and Prasada Rao, 2013; García-Magaña et al., 2013), it has been recommended to be used as ingredients for functional food products. In nonfood application, mango peels are used as biosorbents to remove the heavy metals of cadmium and lead from aqueous solution (Iqbal et al., 2009).

The utilization of mango seeds as cocoa butter, natural antioxidants, cosmetic, antimicrobial compounds, starch and activated carbon has been reviewed (Kittiphoom, 2012). The mango seed has been discovered constituting 4.76–6.70% of protein and 71.90–76.28% of carbohydrate (Muchiri et al., 2012). Therefore, it has been further processed into flour as a potential ingredient for bread making (Menon et al., 2014). The fat obtained from the mango seed kernel via the soaking method in supercritical carbon dioxide, was regarded as premium grade cocoa butter analogy fats by blending with other vegetable fats (Jahurul et al., 2014). Oil recovery from fruit seed has become a popular research trend most probably due to the increase in global demand for plant oil. The mango seed has been discovered having a crude lipid content of 8.5 to 10.4 g/100 g dry matter with main fatty acids of 9-(z)-octadecenoic acid (46.37–58.59%) and octadecanoic acid (24.22–32.80%) which has the typical characteristics of a vegetable butter (Muchiri et al., 2012). The presence of a high amount of carbohydrate in mango seed (Muchiri et al., 2012) has made it a source of poultry feed as well (Diarra, 2014).

Cellulose extracted from mango seeds has been synthesized to produce methylcellulose, an adhesive mortar, uses for industries of pharmaceutical, food, petrochemical and civil construction (Da Cruz et al., 2012). Mango seeds are found utilizing as

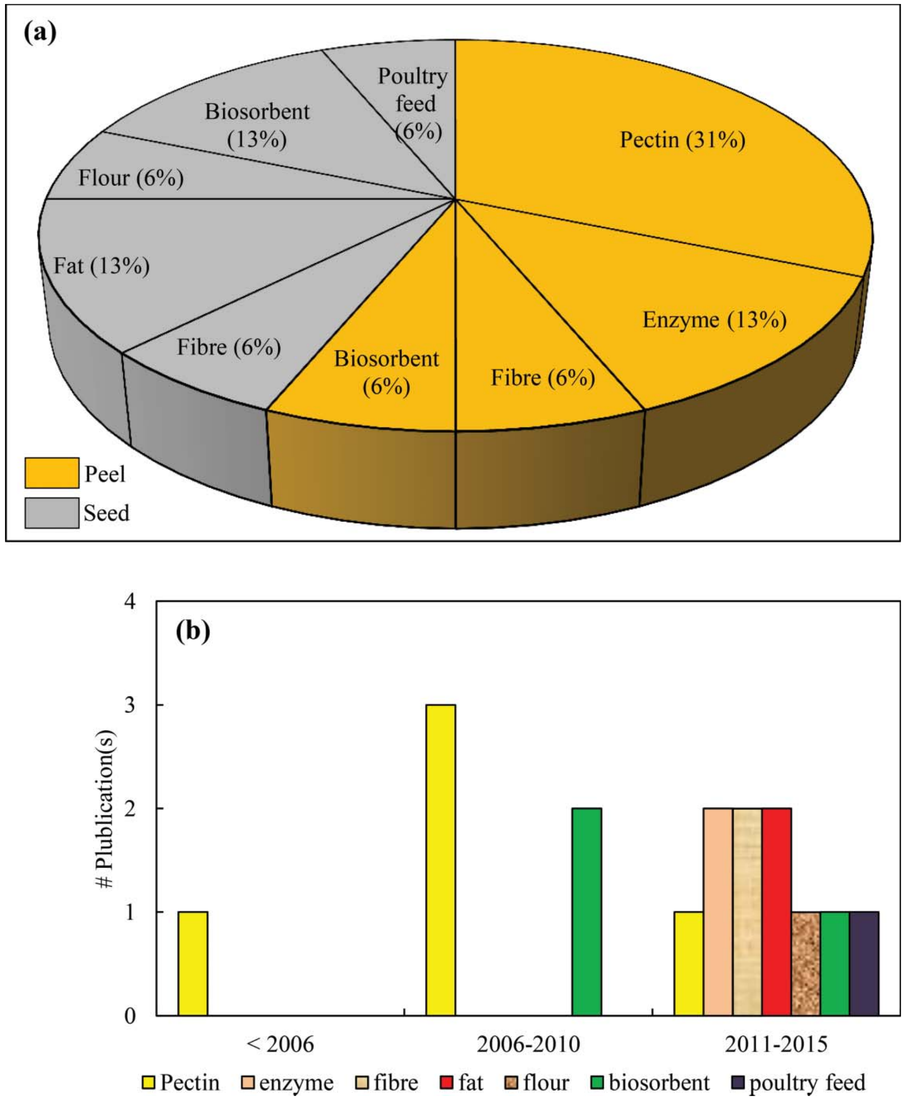


Figure 4. Mango wastes (a) utilizations and (b) research trend.

biosorbents to remove heavy metal of chromium (Premkumar and Shanthakumar, 2013) and dye of malachite green, which is widely used as a food coloring, textile, paper, and acrylic industries (Franca et al., 2010).

Jackfruit (Artocarpus Heterophyllus)

The jackfruit is categorized as a gigantic fruit with an average weight from 10 to 30 kg with its size and weight depending on factors including cultivar, climate, and regional growth geography (Saxena et al., 2011). The functional, medicinal, and physiological properties of jackfruit as related to human health have been reviewed (Swami et al., 2012). Nonetheless, only 30–35% is the edible portion of the bulb, whereas the rest of the skin (55–62%) and seed (8–10%) are regarded as wastes (Saxena et al., 2011).

The utilization of jackfruit peels for food application is surprisingly low with only 10% of pectin extraction, while 90% is for nonfood applications of biofilm, biosorbent, biohydrogen, and activated carbon (Figure 5). A higher yield of pectin (16.72–17.63%) was obtained from jackfruit peels using microwave-assisted extraction at 450W for an exposure duration of 10 min, compared to the conventional method using a water bath shaker at 90°C for 1 hour (Koh et al., 2014). Jackfruit peel flour is a good biodegradability promoter as evidenced by tensile properties reduction of film prepared from poly(vinyl alcohol) and jackfruit peel flour, which consequently stimulated the degradation rate (Ooi et al., 2011). Hydrogen has been generated by treating jackfruit peel waste with microflora isolated from cow dung (Vijayaraghavan et al., 2006). Low-cost biosorbents prepared from jackfruit peels have demonstrated their effectiveness in the removal of methylene blue (Hameed, 2009b) and rhodamine dye (Jayarajan et al., 2011) from aqueous solutions. The efficacy of activated carbons prepared from jackfruit peels was observed by their adsorption capacities of dyes of cadmium(II) (Inbaraj and Sulochana, 2004), rhodamine-B (Inbaraj and Sulochana, 2006), and petrochemical wastes of phenol and substituted chlorophenols (Jain and Jayaram, 2007) from aqueous solutions. Most probably because of these adsorption capacities, different activation methods of H_3PO_4 chemical (Prahas et al., 2008) and microwave-induced NaOH (Foo and Hameed, 2012d) have been

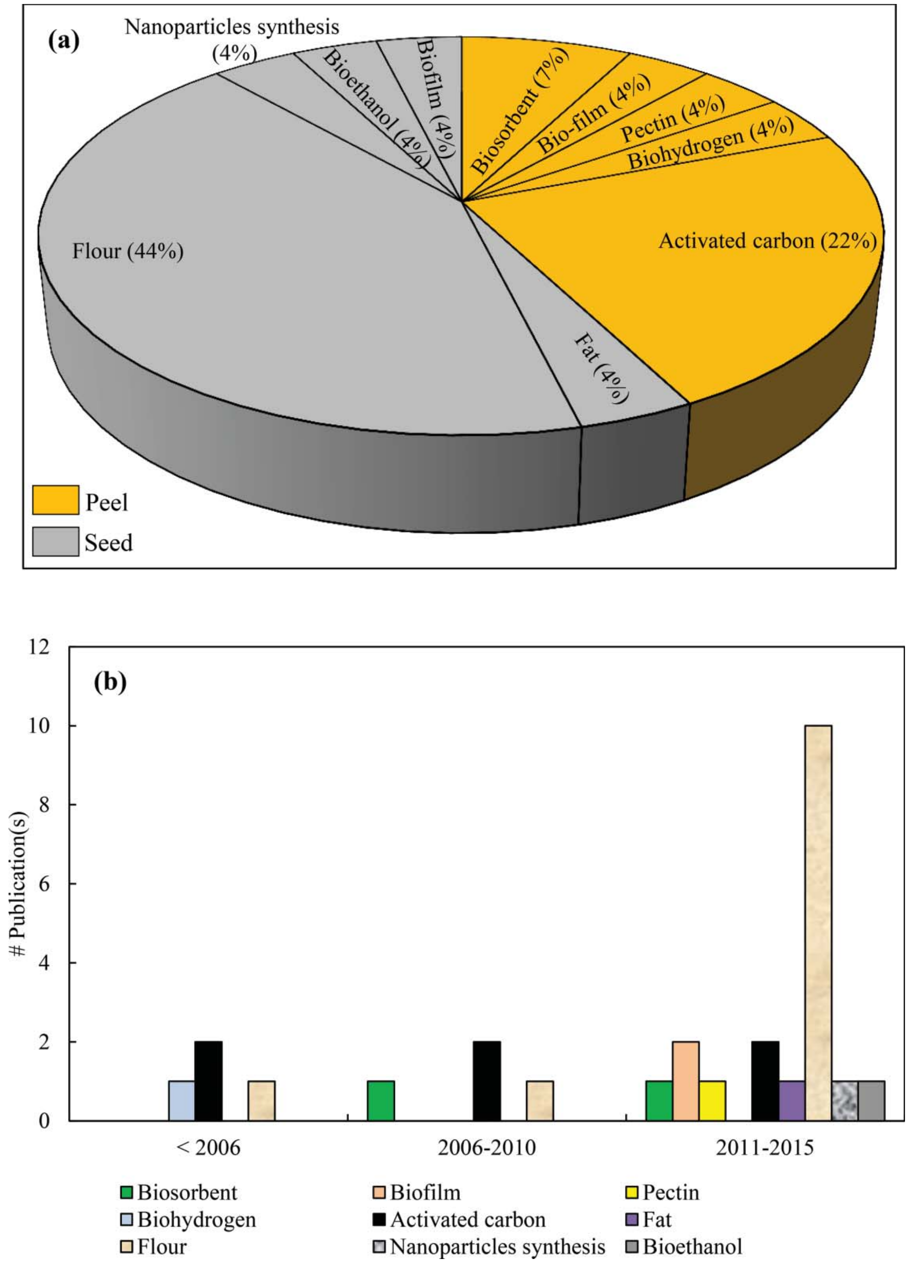


Figure 5. Jackfruit wastes (a) utilizations and (b) research trend.

attempted to activate carbons prepared from jackfruit peel. Microwave heating at 2.45 GHz and irradiation time of 3 and 4 minutes, not only proven in the preservation of the porous structure of a durian shell and jackfruit peel activated carbons loaded with methylene blue dye, but also to restore the original active sites to 80.51–81.63% and adsorption capacities to 181.43–207.57 mg/g (Foo and Hameed, 2012a).

The jackfruit seed has been utilized more than the peel by 58% and 43%, respectively (Figure 5a). As jackfruit seeds naturally possess high amounts of starch of more than 90% (Madruga et al., 2014) and high protein content (Madrigal-Aldana et al., 2011), the processing of jackfruit seeds into flour has become a current trend (Figure 5b) which covered 75% of jackfruit seed utilization. In addition, the jackfruit seed has been discovered to have antimicrobial activities against both gram positive and gram negative bacterial strains (Debnath et al., 2011). Jackfruit seed flour has been characterized and showed type-A crystallinity pattern (Mukprasirt and Sajjaanantakul, 2004; Tongdang, 2008; Madruga et al., 2014; Phrukwiwattanakul et al., 2014). In order to improve its process stability, jackfruit seed flour was modified using acid-alcohol (Dutta et al., 2011), hydroxypropyl (Kittipongpatana and Kittipongpatana, 2011; Naknaen, 2014), carboxymethyl and phosphate cross-linked (Kittipongpatana and Kittipongpatana, 2011) treatments. Jackfruit seed flour was used as a gum to incorporate with metformin HCl for ease of oral administration for diabetes mellitus patients (Nayak et al., 2014), as functional ingredients to produce low calorie chocolate cake (Siti Faridah and Noor Aziah, 2012) and bakery products (Chowdhury et al., 2012), and also as a thickener and stabilizer for chilli sauce (Rengsutti and Charoenrein, 2011). Besides the flour, the jackfruit seed has been discovered having a valuable oil with remarkable antioxidant properties and these essential fatty acids were recommended as priceless food in the maintenance of health and management of various chronic diseases (Nagala et al., 2013). Jackfruit seed powder is also used as a substrate in solid-state fermentation in production of *Monascus* pigments (Babitha et al., 2007).

In nonfood applications, jackfruit seeds are utilized for silver nanoparticle synthesis (Jagtap and Bapat, 2013), as a substrate for bio-ethanol production (Kumar et al., 2011), and a carbon source to produce pullulan (water-soluble exopolysaccharide) for bio-film (Sharmila et al., 2013).

Papaya (Carica Papaya L.)

The papaya is a popular fruit because of its high content of vitamin A, B, C, and proteolytic enzymes of papain and chymopapain which have antiviral, antifungal, and antibacterial properties (Vij and Prashar, 2015). To meet the overwhelming global demands for papaya fruits, a total world annual production of approximately 6642 tonnes is recorded from the major producing countries of India, Brazil, Nigeria, Indonesia, and Mexico (Singh, 2011). Although the papaya comprises wastes of only 10–20% of skin and 10–20% of seed (Hameed, 2009a; Lee et al., 2011; Parni and Verma, 2014), the wastes still attracted the interests of researchers due to their superior medicinal values. In this regard, a recent study which employed the high voltage electrical discharge treatment in extraction of high-added value compounds from papaya peels, has resulted in a significant increase of yields in proteins, carbohydrates, total phenolic content and antioxidant properties (Parniakov et al., 2014). Both the papaya peel and seed have been discovered having antioxidant properties (Ng et al., 2012). Besides high contents of carbohydrate, protein, ash, crude fiber, and phosphorus (Parni and Verma, 2014), the papaya seed has been reported to exhibit antimicrobial activities against *Salmonella choleraesuis* and *Staphylococcus aureus* and thus, was suggested as a potential wound-healing agent (Nayak et al., 2012).

As for the utilization of papaya wastes, the papaya peel (24%) is under-utilized compared to the seed (76%) as shown in Figure 6. Papaya peels have been explored solely for food applications as flour (Santos et al., 2014), derivations of protease enzyme (Chaiwut et al., 2010) and pectin (Koubala et al., 2014).

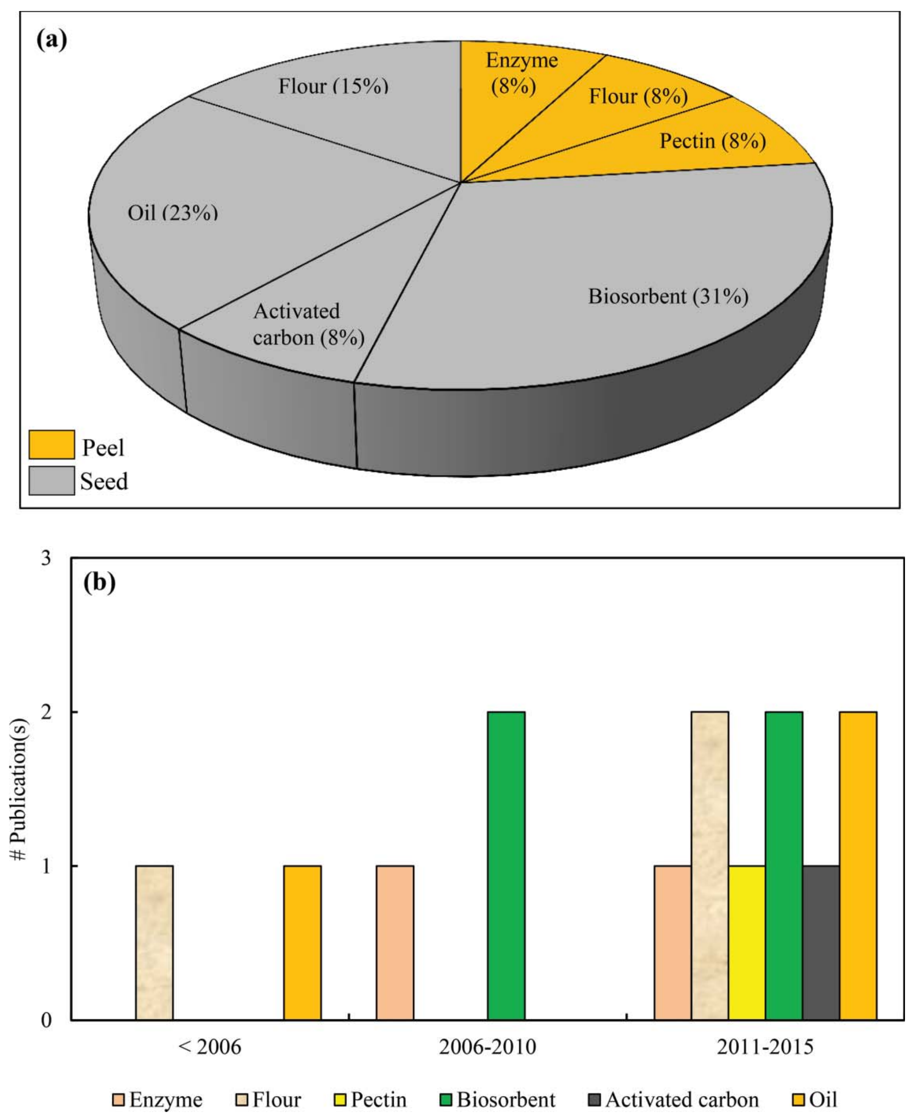


Figure 6. Papaya wastes (a) utilizations and (b) research trend.

Papaya seeds have been utilized in both food and nonfood applications. Oil is obtained from the papaya seed using methods of ultrasound-assisted extraction (Samaran et al., 2015), extrusion-expelling processes (Lee et al., 2011), and solvent and aqueous enzymatic extraction (Puangsri et al., 2005). Papaya seed flour has excellent foaming and emulsifying properties (Alobo, 2003) and contains high amounts of protein and dietary fiber (Santos et al., 2014), and therefore, has been recommended as an ingredient for food product formulations. For nonfood applications, papaya seeds are utilized as biosorbents to remove heavy metals of lead and cadmium (Gilbert et al., 2011), and dyes of crystal violet (Pavan et al., 2014) and methylene blue (Hameed, 2009a; Unuabonah et al., 2009) from aqueous solutions. Furthermore, Yadav et al. (2014) have successfully formulated papaya seed activated carbons with maximum adsorption capacities of 188.6–238.09 mg/g.

Passion Fruit (Passiflora Edulis f. Flavicarpa L.)

Passion fruit, which belongs to the family *passifloraceae*, has gained its popularity recently due to its pleasant taste and high nutritional values. Brazil is the largest producer of passion fruit in the world with 664 metric tonnes of average annual production and about 50% of the production is used in the juice processing industry (Canteri et al., 2012). This fruit produces 52% of residue from the juice industry (Almeida et al., 2015). The residues are mainly peel and seed which comprised of 45–52% and 1–4%, respectively, from a whole fruit. Due to the large percentage of peels, the utilization of peel is approximately 85% while the seed is only 17% (Figure 7). Many studies have validated the pharmaceutical properties of passion fruit wastes. Passion fruit peel flour has

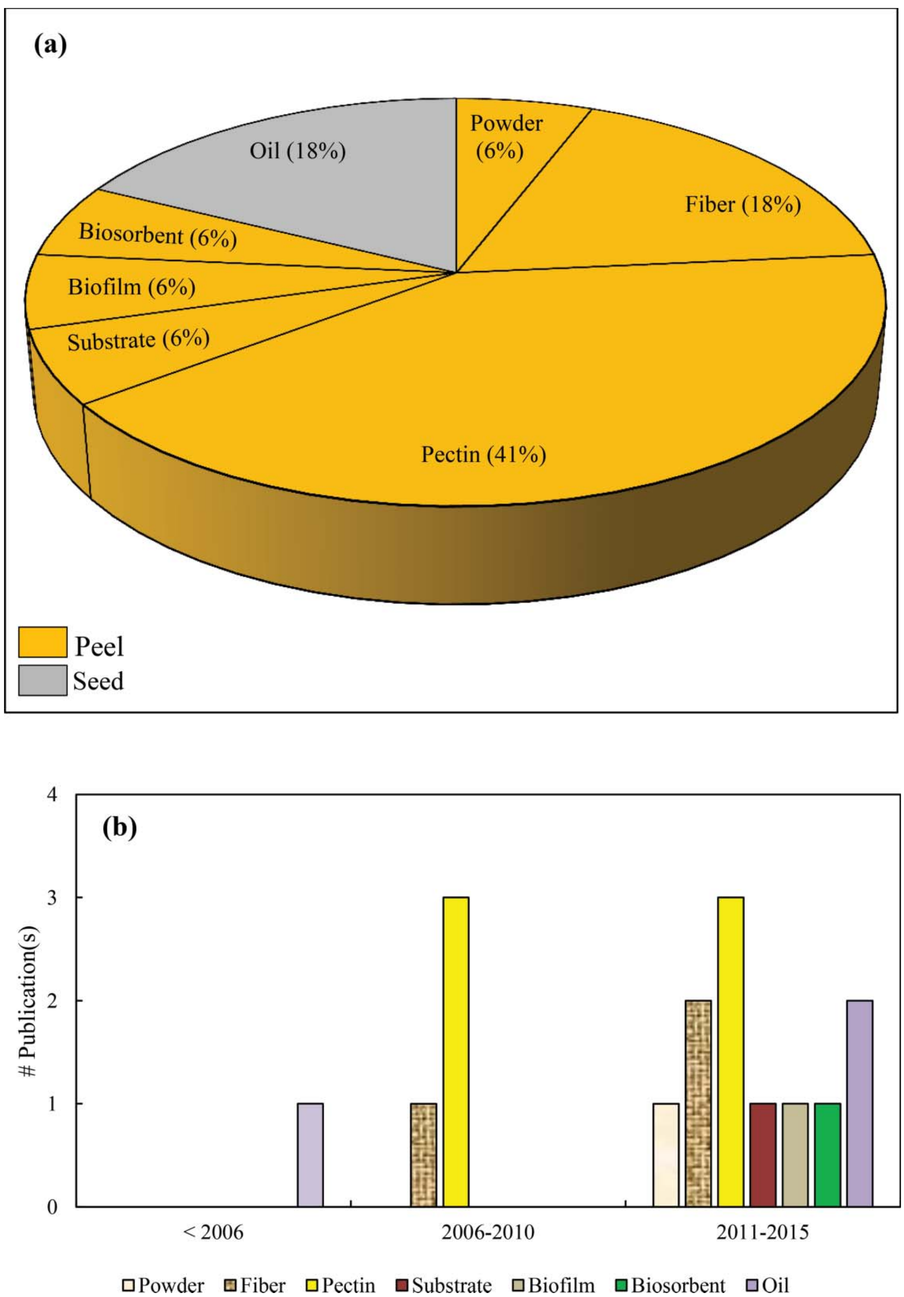


Figure 7. Passion fruit wastes (a) utilizations and (b) research trend.

not only discovered for an improvement of bowel health by increasing short-chain fatty acids production (Da Silva et al., 2014b), but has been suggested as a dietary supplement for type 2 diabetes mellitus patients because of its positive action in blood glucose control (Queiroz et al., 2012). The effectiveness of passion fruit peel extract on antihypertensive has been demonstrated in an *in vivo* study (Lewis et al., 2013). Besides the peel, the antifungal protein of passion fruit seeds has been described in detail (Ng et al., 2011).

In food applications, pectin is the most derived substance from passion fruit peels among the utilizations (Figure 7a). Both high- (Pinheiro et al., 2008; Kulkarni and Vijayanand, 2010; Canteri et al., 2012; Liew et al., 2014; Seixas et al., 2014) and low- (Yapo and Koffi, 2006; Kliemann et al., 2009) methoxyl pectins were obtained from passion fruit peels. Therefore, the recovery of pectin from passion fruit peels is regarded as an effective way to utilize passion fruit wastes.

Passion fruit peel has been revealed as possessing a high content of total dietary fiber of more than 73% (Yapo and Koffi, 2008), and also reported containing from 57.93 to 71.71 g/100 g db (Hernández-Santos et al., 2014). The incorporation of this passion fruit peel fiber has been discovered enhancing probiotic viability, fatty acid profile and increased conjugated linoleic acids content in yoghurts (Espírito Santo et al., 2012a). In textural wise, passion fruit peel powder increased firmness, consistency and cohesiveness of all skim yoghurts in which it was recommended to be included into both skim and whole probiotic yoghurts formulation (Espírito Santo et al., 2012b). Probiotic yoghurts enriched with passion fruit rind fiber received a score of "good" in a few sensory aspects of appearance, odor and color (Espírito Santo et al., 2013).

In nonfood applications, peels of passion fruit were used as substrates for enhanced production of β-glucosidases, an enzyme that acts as catalyst for various biotechnology processes including biomass hydrolysis for bioethanol production, by *Penicillium verruculosum* (Almeida et al., 2014). Passion fruit peel has been recommended as an alternative low-cost material to develop biodegradable flexible films (Nascimento et al., 2012) and as biosorbent with adsoption capacity of 204 mg/g to remove lead(II) from aqueous solution (Gerola et al., 2013).

The passion fruit seed has been revealed containing a rich amount of crude lipid (24.5 g/100 g) and total dietary fiber (64.8 g/100 g raw seed and 85.9 g/100 g defatted seed) for which it has been suggested to be used as a fiber source or low calorie bulk ingredient for food applications (Chau and Huang, 2004). Ultrasonic-assisted extraction with a green solvent of acetone was conducted and yielded 23.8% of oil recovery from passion fruit seeds (De Oliveira et al., 2013). The oil obtained from the seeds of industrial passion fruit residues, which possessed a high odoriferous strength with major aromatic volatile compounds of ethyl butanoate, ethyl hexanoate, and hexyl acetate, has been proposed for its potential use in the manufacture of aromatizing products (Leão et al., 2014).

Dragon Fruit (Hylocereus sp.)

Dragon fruit, also known as "pitaya", exists in two common genotypes which distinguished by its flesh color of red (*Hylocereus polyrhizus*) and white (*Hylocereus undatus*) (Esquivel et al., 2007). The dragon fruit comprises 22–44% of peel and 2–4% of seed discarded as wastes (Esquivel et al., 2007; Liaotrakoon et al., 2013b). These wastes are also researchers' interests to explore due to the increase in consumer demands for natural health-promoting bioactive compounds. Besides having antioxidant properties (Zhuang et al., 2012), dragon fruit peel extracts, which consist the main components of β-amyrin, α-amyrin, and γ-sitosterol, have demonstrated good cytotoxic activities against human prostate, breast, and gastric carcinoma cell lines (Luo et al., 2014).

Pectin is the main substance derived from dragon fruit peel and a popular subject of recent research (Figure 8). Peels from white-flesh and red-flesh dragon fruits have been discovered containing significant amounts of pectic substances that were lowly methyl-esterified (Liaotrakoon et al., 2013a). Yields of 26.4% (Muhammad et al., 2014), and 14.86% (Woo et al., 2010) of high methoxyl pectin and 11.96–20.14% of low methoxyl pectin (Ismail et al., 2012) were reported in the peels of red-flesh dragon fruits. Water and oxalate-soluble pectin were the major pectin fractions found in the cell wall of purple pitaya pericarp (Montoya-Arroyo et al., 2014). A recent study demonstrated the use of microwave-assisted extraction under conditions of a power of 400 W, a temperature of 45°C, an extracting time of 20 min and solid–liquid ratio of 24 g/mL which resulted a pectin yield of 7.5% from dragon fruit peel (Thirugnanasambandham et al., 2014).

The physical-chemical properties of dragon fruit peel powders prepared via drum drying (Chia and Chong, 2015), spray drying (Ee et al., 2014), and oven drying (Zhuang et al., 2012), have been characterized. The stability of betacyanins of red-flesh dragon peel was studied for its potential use as a natural colorant for food products (Harivaindaran et al., 2008). Amylose with enzyme activity of 648.4 U and specific activity of 14.2 U/mg has been extracted from dragon fruit peel (Amid et al., 2014).

Previous work reported that the most efficient method in obtaining the highest oil yield of 7.78 wt/wt % from dragon fruit seed was microwave-assisted extraction (Rui et al., 2009). Seeds of two varieties of dragon fruits, *Hylocereus undatus* and *Hylocereus polyrhizus*, have been revealed containing about 50% essential fatty acids while 48% is linoleic acid, and 1.5% is linolenic acid (Ariffin et al., 2009). Owing to the superb quality of this essential oil, dragon fruit seed oil was spray-dried microencapsulated to enhance its oxidative stability (Lim et al., 2012). In addition, the dragon fruit seed oil, which was observed containing a relatively high amount of tocopherols and low oxidation rate after three months of storage either at cold or room temperature, has further driven its value as a good oxidative stability essential oil (Liaotrakoon et al., 2013b).

Pineapple (Ananas Comosus)

Pineapple peel, a by-product of the pineapple processing industry, accounted for 29–40% (w/w) of total pineapple weight (Choonut et al., 2014). Abundant scientific evidence demonstrates the presence of important bioactive compounds in pineapple peels. Water-insoluble fiber-rich fraction from pineapple peel has been proven for its potential in improving intestinal function *in vivo* (Huang et al., 2014). This was evidenced by the

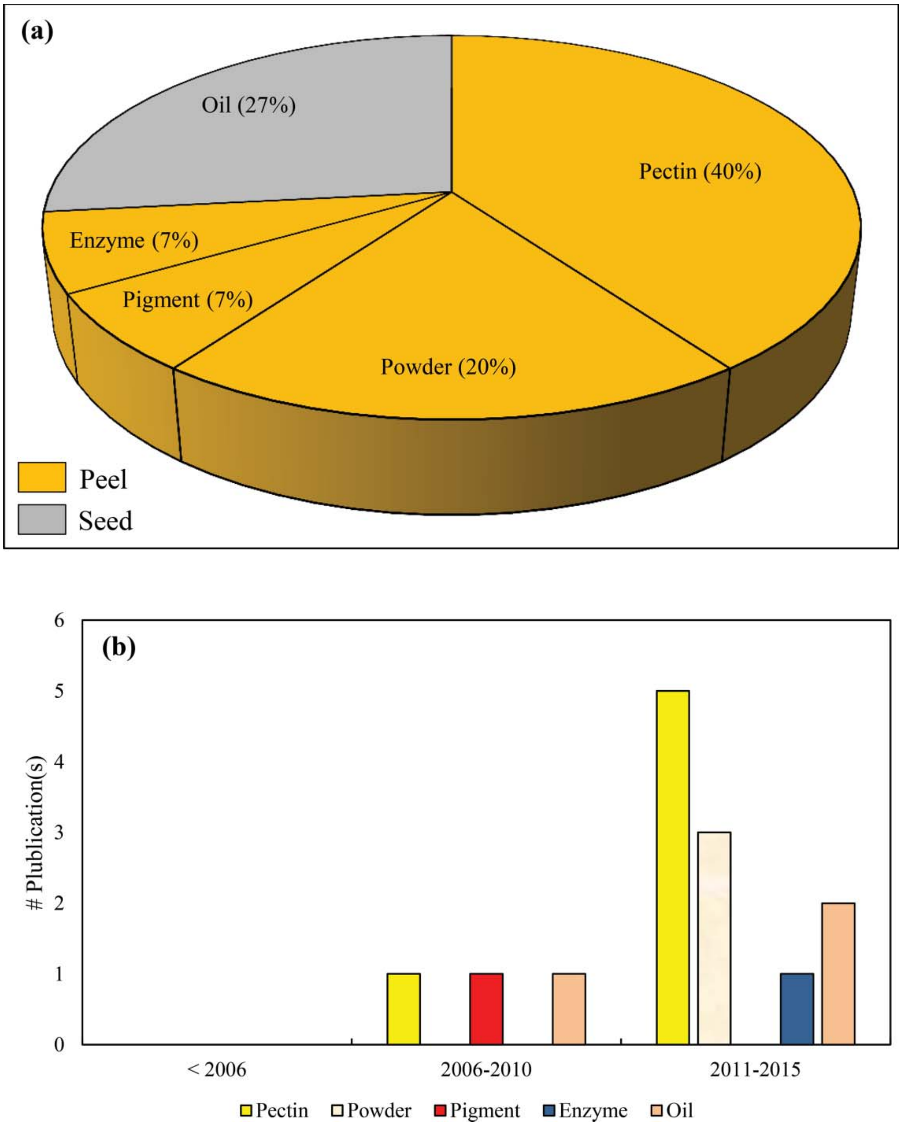


Figure 8. Dragon fruit wastes (a) utilizations and (b) research trend.

decrease of the daily fecal ammonia output; shortened the gastrointestinal transit time; reduced the activities of β-D-glucosidase, β-D-glucuronidase, mucinase, and urease in feces; and also enhanced the total amounts of short-chain fatty acid in the fecal content and the growth of gut microflora such as *Lactobacillus* spp and *Bifidobacterium* spp, with a supplementation of 2.5% water-insoluble fiber-rich pineapple peel (Huang et al., 2014). The ethyl acetate extract of pineapple fruit residue is discovered as having an adipogenic potential and anti-aglycation property while the methanolic extract possessed DNA damage protection capacity (Riya et al., 2014). Pineapple peel extract has modulatory effects on lipid peroxidation, catalase activity and hepatic biomarker levels in the blood plasma of rats (Okafor et al., 2011). In more specific researches, pineapple peel extract has been discovered exhibiting protective effects against alcohol-induced oxidative stress (Erukainure et al., 2011a), and changes in total phospholipids and lipid peroxidation (Erukainure et al., 2011b) in brain tissues. Treatment of UV radiation to pineapple by-products was an effort conducted to preserve vitamins C and E, β-carotene, α-carotene and lutein (Freitas et al., 2015).

Bromelain is an important proteolytic enzyme present in pineapple and is evidenced as a good anti-cancer agent (Chobotova et al., 2010) and speeded up the healing of firearm wounds (Wu et al., 2012). Pineapple peel, which accounts for 29–40% of the fruit waste, has suggested the most promise for bromelain extraction (Ketnawa et al., 2012). Hence, the derivation of bromelain from pineapple peels is predominant in overall utilizations as shown in Figure 9. In view of these facts, different extraction methods of reverse micellar systems (Umesh Hebbar et al., 2008) and aqueous two-phase (Ketnawa et al., 2011; Novaes et al., 2013) have been attempted to derive bromelain from the pineapple peels.

The flour obtained from pineapple peel has been revealed as a preference carbon source for the fermentation of probiotic bacteria of *Pediococcus pentosaceus* (Diaz-Vela et al., 2013). An attempt to incorporate 10.5% of pineapple pomace into corn flour produced an extrudate with no effect on hardness, yellowness, water absorption, and bulk density compared to the control which led to a recommendation of pineapple pomace in the production of nutritional value added extrudate snack (Selani et al., 2014). An incorporation of 5–10% of pineapple

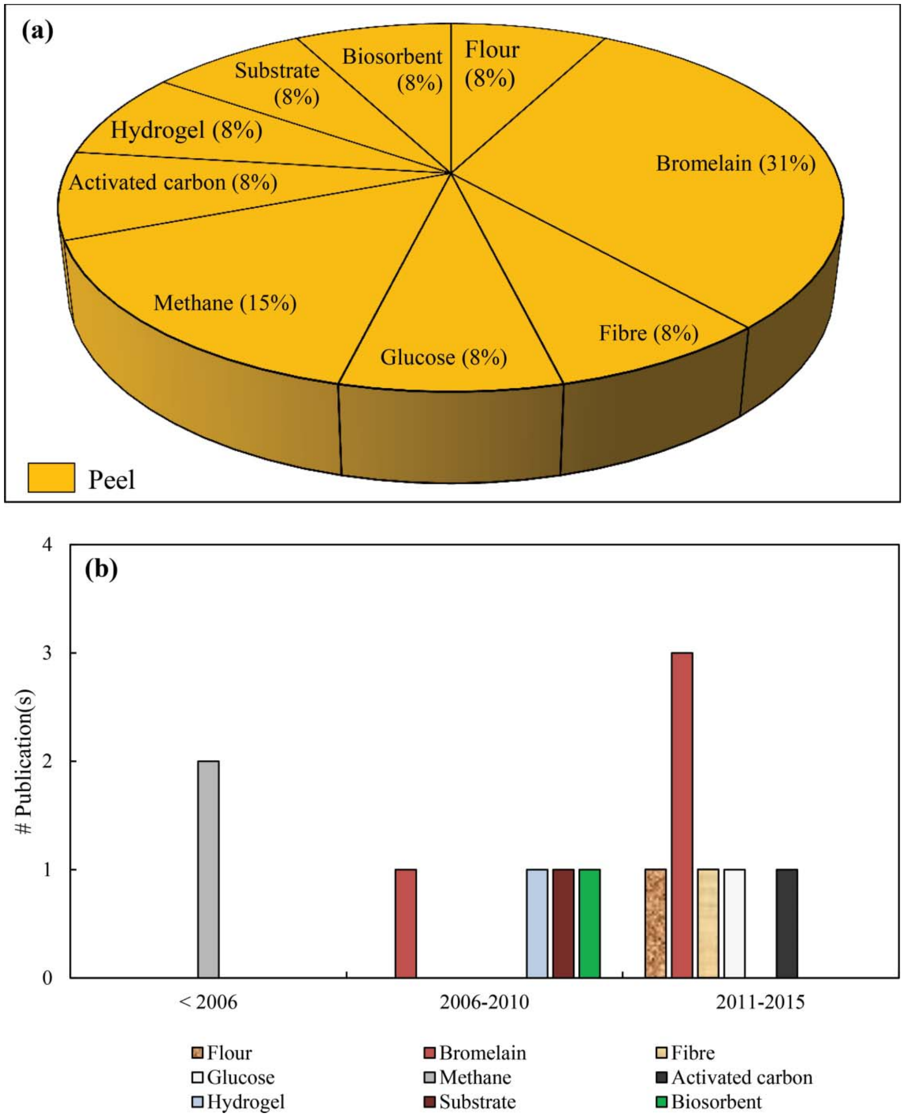


Figure 9. Pineapple peel (a) utilizations and (b) research trend.

peel fiber into steamed-bread formulation was recommended in order to increase the intake of dietary fiber (Wu and Shiau, 2015). Liquid pineapple wastes mainly consisting of peels, have been used to produce glucose by hydrolyzing sucrose in an immobilized invertase polyvinyl alcohol-alginate-sulfate beads (Seker and Zain, 2014).

In nonfood applications, pineapple waste, from a juice producing factory, is used as substrate in a solid state fermentation to produce citric acid using *Yarrowia lipolytica* (Imandi et al., 2008). Hydrogels and polyvinyl pyrrolidone composite hydrogels prepared from pineapple peel cellulose with 1-allyl-3-methylimidazolium chloride via different heating and cooling processes have been characterized using texture profile analysis (Hu et al., 2010). Mishra et al. (2010) reported that biosorbent prepared from pineapple peel was able to remove Zn(II) from aqueous solution with maximum uptake capacity of 0.45 mg/g, percentage removal of 22.9%, and minimum equilibrium concentration of 7.71 mg/l. Pineapple peel activated carbon prepared via microwave assisted (power of 600W and irradiation time of 6 min) KOH activation demonstrated a better development of pore structure, with the BET surface area of 1006 m2/g, total pore volume of 0.59 m^3/g, and average pore size of 23.44 Å (Foo and Hameed, 2012c). From more than a decade ago, pineapple peel has been utilized for biomethanation for energy generation (Bardiya et al., 1996; Rani and Nand, 2004).

Conclusions

Recent global demands for food sources not only satisfy basic hunger, but a diet to sustain optimum human health due to the increase in medical care expenses. Fruit waste is a part that cannot be consumed directly due to its unacceptable bitter taste. Because of this reason, the transformation of fruit waste, which contains abundant valuable bioactive compounds, as an alternative food source remains a great challenge for researchers or food manufacturers. Nonetheless, the quest for alternative food source especially from fruit waste appears pivotal because of the imbalance of growth between world's populations and food resources nowadays.

Durian peels are being mainly utilized as biosorbent, activated carbon, and biocomposite. Instead, they should be probed more for health benefit bioactive compounds such as dietary fiber and pectin. Since numerous evidence showed remarkable pharmaceutical properties in mangosteen peel, it is more worthwhile to be explored for food applications instead of nonfood purposes such as activated carbon. For the development of activated carbon and biorsobent, it is suggested to use other alternative agricultural wastes such as grass, coconut husk, rice straw, etc. The exploration of mango and passion fruit wastes are more inclined to food applications (≈80%) with only few for nonfood applications (≈9%). Meanwhile, jackfruit and pineapple wastes are equally scrutinized in both food and nonfood applications. Approximately 62% of papaya wastes are quested for food applications while 38% were for nonfood applications. Papaya wastes should be discovered more for food applications as they contain valuable medicinal properties that have health benefits. Thus far, dragon fruit wastes have been explored 100% for food applications.

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