Food Chemistry 168 (2015) 80–89

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Review

Exploring the potential nutraceutical values of durian (*Durio zibethinus* L.) – An exotic tropical fruit

Lee-Hoon Ho, Rajeev Bhat *

Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Minden, Penang, Malaysia

ARTICLE INFO

Article history:
Received 2 April 2014
Received in revised form 27 June 2014
Accepted 7 July 2014
Available online 11 July 2014

Keywords:
Exotic fruits
Consumers
Durian
Nutritional value
Bioactive compounds
Toxicity

ABSTRACT

This review focuses on providing informations on potential uses of durian, an exotic tropical fruit as a source of food, as well as a potential therapeutic agent. Apart from disseminating details on the traditional value, in this review we have focussed on the nutritional composition, presence of bioactive compounds, volatiles, antimicrobials, as well as on the toxicological effects of durian fruit consumption. Durian fruits are enjoyed for their unique taste and organoleptic qualities, but there is also a need to ensure that their potential is exploited for the international market. In addition, in the present socio-economic scenario, tapping the potential of exotic tropical fruit such as durian could benefit the health of consumers as well as support the local population who depend on farming for a livelihood. Overall, it is envisaged that identifying the nutraceutical potential of the edible and non-edible parts of durian fruits can benefit food and pharmaceutical industries.

Contents

1. Introduction

In the past decade, significant increase in the production, marketing, and intake of exotic tropical fruits in the local and international markets has been witnessed. This trend can be owed to the mounting recognition of the rich nutraceutical values and sensory attributes of such fruits. Of late, many researchers have reported that exotic tropical fruits such as durian, dragon fruit, mangosteen, star fruit, snake fruit, longan, litchi, and others, to encompass ample amounts of bioactive compounds (or phytochemicals). In addition, these fruits are rich in essential micro- and macro-nutrients as well as contain high levels of essential minerals and vitamins (A, C, and E) (Contreras-Calderón, Calderón-Jaimes, Guerra-Hernández, & García-Villanova, 2011; Gorinstein et al., 2011). The presence of natural bioactive compounds is of interest to the cosmetic, pharmaceutical and food industries. Of course, it is a well accepted fact that fruits based natural antioxidants can serve as natural protectants to prevent oxidative damage (from free radicals) and thus, slow down the occurrence of rancidity in foods.

* Corresponding author. Tel.: +60 4653 5212; fax: +60 4657 3678.
E-mail addresses: rajeevbhat1304@gmail.com, rajeevbhat@usm.my (R. Bhat).

http://dx.doi.org/10.1016/j.foodchem.2014.07.020
0308-8146/© 2014 Elsevier Ltd. All rights reserved.

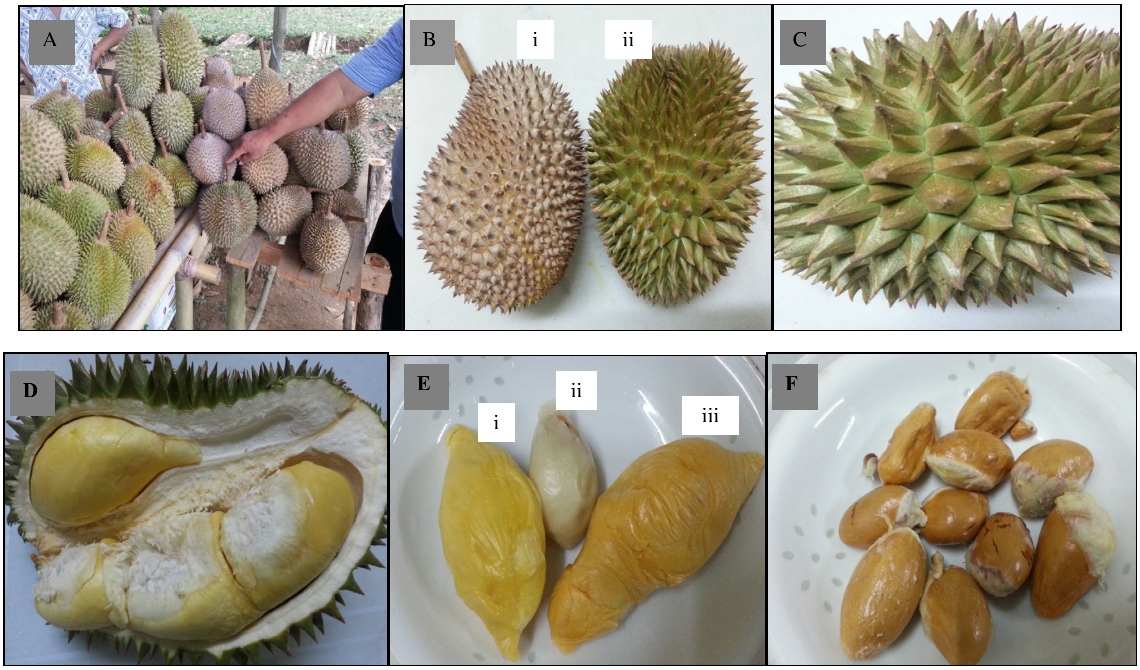

Fig. 1. (A and B) Different durian cultivars on sale in a local market; (C) close-up view of the thick and sharp hexagonal spines on the husk; (D) an malformed fruit with one large flesh on a locule (top), and well-developed locule with three flesh (bottom); (E) three creamy flesh with yellow (left), white (centre) and golden yellow (right) colours; (F) the hard seeds are covered with a thin and light-brown skin. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In this review, we are discuss the traditional values as well as on the potential uses of durian fruits and their waste (flesh, skin, and seed) for possible utilisation as a food additive (such as a preservative, thickening agent, antimicrobial agent) or for potential pharmaceutical applications. In addition, we have provided information on the nutritional composition, volatile/aroma producing compounds as well as toxicity of durian fruit consumption. It is envisaged that the details presented in this review will help to popularize as well as exploit the potentiality of this fruit at international market for food or pharmaceutical applications.

2. Durian fruit

Durian (Scientific name: *Durio zibethinus*; family: Bombacaceae; Genus: *Durio*) is a climacteric, seasonal tropical fruit of Southeast Asia (Malaysia, Thailand, Philippines and Indonesia). The ripe durian fruit owing to its unique taste and aroma, is considered locally as 'king of fruits' (Berry, 1979; Leontowicz et al., 2011; Srianta, Hendrawan, Kusumawati, & Blanc, 2012; Subhadrabandhu & Ketsa, 2001; Voon, Hamid, Rusul, Osman, & Quek, 2007b).

Tropical fruit frequently require some form of processing prior to consumption. For example: this can include, separating the edible (fleshy) parts from non-edible portions, separating the adherent waxy layer. Durian requires separating the skin from pulp, which can be comparable to that of jackfruits. Durian fruit is either oblong or round, with outer spiky skin being green to brown coloured (see Fig. 1A–D). The flesh, which is the edible part, is sweet in taste, and is either yellow, white, golden yellow or red in colour (see Fig. 1E). There are several popular durian cultivars with pleasant aroma and attractive flesh colour, which includes: Ang Heh (Red Prawn Durian), Chaer Phoy-15 (Green Skin Durian) and Khun Poh Durian (see Fig. 1 E, from left to right). Ang Heh durian has golden-chocolate coloured skin with round-shaped and shorter spines [Fig. 1B(i)] compared to Chaer Phoy-15 cultivar which is green skinned [Fig. 1B(ii)]. With regard to colour of the flesh, Ang Heh cultivar [Fig. 1E(i)] can be identified by their yellow to creamy flesh, Chaer Phoy-15 by their white to cream coloured flesh [Fig. 1E(ii)], and Khun Poh durian by their golden yellow coloured flesh [Fig. 1E(iii)]. In terms of mouth feel, Ang Heh durian flesh is moist with soft texture and has a fruity (highly aromatic) sweet taste, whilst, Chaer Phoy-15 flesh contains less moisture, and is not too sweet but tasty. Whilst, Khun Poh durian has a slightly bitter to sweet taste with a strong and intense aroma.

Seeds are present inside the edible flesh, and covered with a thin, light-brown coloured skin (see Fig. 1F) (Berry, 1979). It is reported that durian fruit cultivation generates nearly 67–70% of wastes in the form of seeds (20–25%), rind or shell, which are all non-edible (Amid & Mirhosseini, 2012). However, transforming durian wastes to useful products is possible (details of which are discussed later in this review) (Amin, Ahmad, Yin, Yahya, & Ibrahim, 2007; Amiza & Roslan, 2009; Chansiripornchai, Chansiripornchai, & Pongsamart, 2008; Lipipun, Nantawanit, & Pongsamart, 2002; Pongsamart & Panmuang, 1998; Tippayakul, Pongsamart, & Suksomtip, 2005).

3. Food value of durian

Durian fruit possesses high nutritional value and has rich bioactive properties. Generally, durian fruit pulp (flesh) is consumed directly or is eaten along with sticky rice (high in starch) or used as an ingredient in bakery product preparations (Tate, 1999; Wasnin, Abdul Karim, & Mohd Ghazali, 2012). As durian fruit supply is highly restricted in the market owing to its low shelf life (between 2 and 5 d at room temperature) the fruit needs to be consumed or processed within a limited time frame.

The over-ripened fruit are fermented to produce a food product 'tempoyak' (acid and salt-fermented durian), whereas 'lempok' is prepared by boiling durian flesh with coarse sugar (Amin, Jaafar, & Khim, 2004; Berry, 1979; Wasnin et al., 2012). The main intention of fermentation process is to retain high degree of characteristic sensory qualities of the durian. According Amin et al. (2004), 'tempoyak' can be prepared by placing a mixture of durian pulp with salt (1.3–3.0% w/v) in a covered jar for few weeks to allow spontaneous fermentation to occur. Fermented durian product has strong odour and are yellow coloured with a soft texture and sour tastes. 'Tempoyak' and 'lempok' are widely consumed in Malaysia and Indonesia, but are not yet completely commercialised. 'Dodol' is another popular traditional sweetmeat of Malaysia, Indonesia and Thailand, which is prepared by cooking pulp with sugar (Tate, 1999). The other traditional product, such as 'durian kuan' (pulp cooked with flour and sugar) or present bakery products such as jam, candy, toffees, ice cream, durian wine, and milkshakes are also widely processed in the food industries (Lim, 2012; Tate, 1999; The Straits Times., 2013). Moreover, unripe or partially ripe durian flesh can also be used in soup preparations. In addition, in certain instances, unripe fruits are boiled and are taken as a vegetable. Durian fruits can be dried to make 'leathers' or 'fruit bars' which can offer a convenient method of marketing the fruits (Che Man, Jaswir, Yusof, Selamat, & Sugisawa, 1997).

Durian juice is also consumed as a popular traditional drink. Reports are available wherein durian pulp was processed by treating with pectinase enzyme at different concentrations (0.025%, 0.05%, 0.075%, and 0.1%) (Norjana & Noor Aziah, 2011). As an outcome of the study, these researchers concluded that 0.1% pectinase added to durian juice and incubated for 3 h results in higher juice yield (an increase by 35%) compared to untreated durian pulp. However, sensory evaluation results had revealed that durian juice treated with 0.05% enzyme concentration had higher acceptance by panellists.

'Angkak' which is popular as '*Monascus*-fermented rice', is consumed by local population in Indonesia, China, Philippines, and Thailand. In the traditional method, 'Angkak' is prepared by employing solid-state fermentation technique (rice as a substrate for *Monascus* sp.) (Srianta et al., 2012). It is widely used as a food additive (colorant), dietary supplement, and traditional medicine to treat various types of diseases (anthrax, bruised muscles, diarrhoea, colic dyspepsia in children, and post-partum problems) (Lin & Demain, 1993; Pattanagul, Pinthong, Phianmongkhol, & Leksawasdi, 2007). However, recent studies have shown that 'Angkak' can also be produced by using durian seed as a novel substrate of *Monascus* sp. (Srianta et al., 2012).

Durian seeds are edible and are a good source of starch, thus can provide required energy. Seeds are often roasted or boiled and eaten as a snack (Berry, 1979; Tongdang, 2008). In Indonesia, seeds are roasted, cut into slices and coated with sugar and consumed as a candy, or are fried in spicy coconut oil and consumed as a dish with rice. Studies have shown starch derived from durian seeds to have small granules (mean diameter 4.0–4.9 μm; size range 3.0–22.0 μm) and posses' high swelling rate (60–100%), and are susceptible to hydrolysis under standard conditions (Oates & Powell, 1996). In an another related study, Tongdang (2008) tried to extract starch from three Thai aromatic fruit seeds, namely durian (*D. zibethinus* L.), jackfruit (*Artocarpus heterophyllus* L.), and chempedak (*Artocarpus integer*). The author reported that the yield of isolated durian seed starch to be 10% (dry weight), which was the lowest starch yield as compared to other isolated fruit seeds. Tongdang (2008) has also reported that the starch from durian seed to be uniform and have small starch granules compared to the rice. The author classified durian seed starch under low-gelatinization-temperature group, which indicates weak intermolecular bonding inside starch granules. This finding provides suffice knowledge on the starch properties extracted from durian seeds, thus opening up the potential of using it for food applications as a suitable replacer to other expensive commercial starch in the market. Fresh durian seeds contain mucilage, which has thickening characteristics.

Serawa, a durian product is produced by boiling pulp and seeds along with brown sugar and coconut milk. This thickening property is attributed to the presence of high starch content and other hydrocolloids in seeds (Amin et al., 2007). Based on the results generated, durian seed flour can be recommended to be suitable as a thickening agent. Amin et al. (2007) were successful in producing durian gum from seeds (yield of 18%). Further, purification of this yielded 1.2% of pure air-dried gum or 0.5% on freeze-drying. The authors reported durian seed gum to contain glucose, D-galactose, and rhamnose (9:1:3) with absence of galactomannan. The authors also found mineral content of processed durian seed gum to have similar amounts to commercial gum with the exception of microelement zinc, which was higher than in commercial gum. Later, Amid and Mirhosseini (2012) reported that the yield and physicochemical properties (solubility, volume-weight mean, span, water-holding capacity, and oil-holding capacity) of durian seed gum to be affected by extraction conditions (aqueous extraction ratio between water: seed, temperature, and pH). The study also revealed that high water-holding capacity (ranging from 139.5 to 274.0 g water/100 g gum) of durian seed gum can be used as a potential dietary source. The optimum conditions desired for the processing of durian seed gum is reported to be 35.5:1 (water: seed ratio) at 85 °C and alkaline pH (11.9) to produce a high extraction yield (56.4%) and solubility (27.9%). The authors claimed that the durian seed gum produced could be utilised as a commercial hydrocolloid source.

The enzyme β-galactosidase was successfully isolated from durian seeds by employing partial purification process (El-Tanboly, 2001). Accordingly, authors claimed that processing of β-galactosidase can solve problems concerning milk intolerance in sensitive consumers. Here the mechanism involves hydrolysing of lactose to galactose and glucose. In addition, authors concluded that the enzymes processed from durian seed can be explored in dairy industries for production of cheese, yogurt, ice cream, etc. In the later year, El-Hofi, Youssef, El-Desoki, Jalil, and El-Tanboly (2011) incorporated the prepared enzyme at various concentrations (12.3, 24.6, and 36.9 unit of β-galactosidase/mL) to prepare pasteurized milk to produce ice-milk. Their results showed β-galactosidase to enhance the sweetness in ice milk, but exhibited a decrease in the texture and appearance.

Recently, efforts have been made to commercialise processed durian flesh to prepare dried fruit powder (by freeze-drying and spray-drying processes) (Chin et al., 2008). However, of late, there have been major developments in processing value-added products from seeds and shells such as preparation of seed gums and polysaccharide gel, respectively (Amid & Mirhosseini, 2012; Amin et al., 2007; Chansiripornchai et al., 2008; Hokputsa et al., 2004).

Overall these reports indicate that both edible and non-edible portions of durian fruit to have potential to be explored for their food value. In addition, converting durian wastes can reduce environmental pollution in the durian farming region, as well as help in providing additional income to the farmers.

4. Composition and nutritional value

The importance of durian fruit as a nutraceutically valued source can be correlated to their composition and presence of bioactive antioxidant compounds (Arancibia-Avila et al., 2008; Haruenkit et al., 2010). Earlier, Devalaraja, Jain, and Yadav (2011) have excellently revived on durian fruit pulp, and have reported it to be a good source of protein (1.47%), fat (5.33%), fibre (3.1%) and carbohydrates (27%) (see Table 1). Gorinstein et al. (2011) reported fresh durian pulp to be rich in dietary fibre (soluble, insoluble and total dietary fibre) (see Table 1). Haruenkit et al. (2010) reported oleic and linoleic acids to be the major unsaturated fatty acids, whilst capric, myristic, palmitic, arachidic, and stearic acids are the major saturated fatty acids found in durian. In another

Table 1
Nutritional composition of durian flesh.

Compound	Amount
Proximate composition (on fresh weight basis; g/100 g)	
Water (Moisture)	64.99
Protein	1.47
Total lipids	5.33
Ash	1.12
Crude fibre	3.08
Carbohydrates	27.09
Dietary fibres (on fresh weight basis; g/100 g)	
Soluble dietary fibre	1.3 ± 0.1
Insoluble dietary fibre	1.9 ± 0.1
Total dietary fibre	3.2 ± 0.3
Energy (kcal)	147
pH	6.88–7.60
Titratable acidity	0.09–0.26
Minerals (dry weight basis; mg/kg)	
Sodium	220.2 ± 11.1
Potassium	15,942 ± 42
Magnesium	691.2 ± 29.7
Calcium	199.8 ± 10.1
Iron	6.71 ± 0.3
Manganese	8.26 ± 0.4
Zinc	4.92 ± 0.3
Copper	4.92 ± 0.3
Vitamins (on fresh weight basis; mg/100 g)	
Vitamin C	19.7
Thiamin	0.374
Riboflavin	0.2
Niacin	1.074
Pantothenic acid	0.23
Vitamin A, IU (IU)	44
Beta carotene (μg/100 g fresh weight)	23
Sugar content (g/kg)	
Sucrose	55.70–106.47
Glucose	7.34–27.70
Fructose	7.63–18.23
Total sugars	75.30–137.90
Citric acid	0.15–2.63
Malic acid	1.66–12.86
Succinic acid	0.81–3.17
Tartaric acid	0.00–0.76
Soluble solids concentration (%)	32.0–41.0

(Source: Devalaraja et al., 2011; Gorinstein et al., 2011; Voon et al., 2007b).

report, linoleic acid (2.20%), myristic acid (2.52%), oleic acid (4.68%), 10-octadecenoic acid (4.86%), palmitoleic acid (9.50%), palmitic acid (32.91%), and stearic acid (35.93%) have been stated to be major compounds (Phutdhawong, Kaewkong, & Buddhasukh, 2005).

Haruenkit et al. (2010) reported on the fatty acid composition of 'Mon Thong' durian cultivar. They recorded dominant fatty acids to be: linoleic acid (2.2%), myristic acid (2.5%), oleic acid (4.6%), palmitic acid (32.9%), and stearic acid (35.9%). The contents of fatty acids at different stages (immature, mature, ripe, and overripe) of durian fruit was identified by HPLC (Haruenkit et al., 2010). Palmitic (16:0), oleic (18:1), and linoleic (18:2) acids were the major fatty acids identified during maturation and ripening of durian fruits. The higher percent of n-3 fatty acids (polyunsaturated fatty acid) can be advantageous and may be linked to lowering of blood pressure, inflammation, plasma triacylglycerols and platelet aggregation (Breslow, 2006; Caterina, 2011; Mogilanski, 2013).

Srianta et al. (2012) found fresh durian seed contains 54.90% moisture, 3.40% protein, 1.58% ash, 1.32% fat, and 18.92% starch. This result is comparable to the report by Brown (1997), where fresh durian seed contained 51.5% moisture, 2.6% protein, and 43.6% carbohydrate. A study conducted by Amiza and Roslan (2009) showed whole durian seed flour to contain: 6.5% water, 6.0% protein, 3.1% ash, 0.4% fat, 10.1% crude fibre, and 73.9% carbohydrates. Further, proximate analysis of dehulled durian seed flour revealed that it contains: 6.6% moisture, 7.6% protein, 3.8% ash, 0.4% fat, 4.8% crude fibre and 76.8% carbohydrate. The whole durian seed flour contained 52.9% total dietary fibre. However, after being dehulled, seed flour showed 7.7% total dietary fibre (Amiza & Roslan, 2009). Durian seed flour can have potential in the food industry due to its high dietary fibre content.

With regard to durian fruit product, 100 g of the edible portion of 'tempoyak' has been reported (Saidin, 2000) to contain: moisture (71.1 g), protein (2.7 g), fat (2.6 g), carbohydrate (19.6 g), Ca (14 mg), P (35 mg), Fe (1.0 mg), Na (577 mg), K (470 mg), vitamin B_1 (0.20 mg), vitamin B_2 (0.40 mg), niacin (1.1 mg), vitamin C (0.0 mg), and carotene (69 μg). Tongdang (2008) reported that the starch extracted from durian seed to have high moisture (12.18%), ash (0.48%), amylose (22.76%), and resistant starch (4.53%) (on dry basis, respectively). The authors opined that amylose content of starch to affect the functional properties and can have multiple uses in the food industries.

The carbohydrate of the durian (*D. zibethinus* L.) fruit hull powder is reported to consist of a crude fraction (DFI) and purified fraction (DFII) (Pongsamart & Panmuang, 1998). DFI and DFII had 9.1% and 12.0% moisture, 9.2% and 9.5% glucose, 54.8% and 41.5% ash, respectively. However, crude fibre was not detected in both the fractions. DFI had four sugar components (arabinose, fructose, glucose, and rhamnose), whilst DFII had only three sugar components (arabinose, glucose, and rhamnose). The elemental analysis showed DFI and DFII to have 19.33% and 22.89% carbon, and 2.72% and 3.24% hydrogen, respectively. However, nitrogen was not detected in both the extracts. Authors have concluded that supplementation of 0.5% DFII powder in food formulations (such as in jelly) can produce highly stable and good quality products.

Recently Bai-Ngew, Therdthai, Dhamvithee, and Zhou (2014) evaluated the proximate composition of unripe and fully ripe durian pulp flour: carbohydrate was the major component (70.44% and 63.64% in unripe and fully ripe fruit, respectively) with no significant difference in moisture and protein contents (5.51% and 7.11% in fully ripe durian, respectively; 5.35% and 6.44% in unripe durian flour, respectively). Unripe and fully ripe durian fruit flour contained: 6.91% and 10.32% of fat, 8.20% and 10.14% of fibre and 2.66% and 3.27% of ash, respectively.

5. Volatile compounds

An wide array of plants are known to produce volatile compounds (at different concentration levels) that can immensely contribute to the overall aroma or flavour. In fruits, natural volatiles compounds originate mainly from aldehydes, alcohols, terpenes, and others. These volatile compounds are useful whilst preparing a wide range of products such as: bakery foods, beverages and cosmetics. In addition, volatiles are important from the organoleptic point of view and can influence consumers' acceptance of a product. Infact, flavour can be a blend of different volatile molecules. However, with regard to durian fruits, very few reports are available on the volatile constituents. See Table 2 for a summary of the volatile constituents in durian.

The edible flesh portion of different durian fruit cultivars is reported to have their own unique and strong aroma, attributed to esters and sulphur-containing volatiles (diethyl disulphide and propanethiol, ethyl 2-methylbutanoate) (Baldry, Dougan, & Howard, 1972; Nanthachai, 1994; Weenen, Koolhaas, & Apriyantono, 1996; Weenen et al., 1996; Yaacob & Subhadrabandhu, 1995). The report by Baldry et al. (1972) on volatile compounds in durian fruits revealed 26 volatiles in the distillate of durian fruits, which mainly consisted of 1 aromatic compound, 2 aldehydes, 4 alcohols, 7 sulphur compounds, and 12 aliphatic esters. The authors also observed

Table 2
Volatile compounds identified in durian (*D. zibethinus*).

Compound	Source
Esters	
Ethyl octanoate	***
Ethyl hexanoate	**, ***
Ethyl decanoate	***
Methyl propanoate	***
2-Methylheptyl propanoate	***
Methyl 9-(Z)-hexanoate	***
Ethyl 2-methylbutyrate	***
Ethyl 2-methyl butanoate	*, **
Hydroxyacetone	**
Ethyl isobutanoate	**
Octadecyl 9-(Z)-octadecenoic acid	***
2,3-Dihydroxy propyl 9, 12-(Z,Z),2,3,-octadecadienoate	***
Ethyl β-hydroxybutyrate	***
Methyl 15-(Z)-tetracosenoate	***
Methyl 2-methyl butanoate	**
Propyl 3-methyl butanoate	**
Sulphurous and nitrogenous compounds	
Ethyl n-propyl disulphide	***, ****
5-Ethyl 2-methyl pyridine	***
3,5-Dimethyl 1,2,4-trithiolane	**, ***
2-Hydroxyethyl propyl sulphide	***
3,6-Dimethyl 1,2,4,5 tetrathiocyclohexane	***
2-Ethyl 4-methyl 1-H imidazole	***
Diethyl disulphide	*, **, ****
Diethyl trisulphide	*, ****
3-Ethyl 1-2,4-dithiahexan-5-one	****
S-Ethyl thioacetate	**
Methyl ethyl disulphide	**
Ethyl 2-(methylthio)-acetate	**
2-Isopropyl-4-methylthiazole	**
Methyl thiohexanoate	**
Alcohols	
Ethanol	***
n-Butanol	***
p-Methan-8-ol	***
3-Hexanol	***
8-Methyl 1,8 nonanediol	***
Farnesol	***
1-Octadecanol	***
9-(Z)-Octadecen-1-ol	***
2-Methyl (S)-1-dodecanol	***
Acids	
2-Hydroxy decanoic acid	***
Hexadecanoic acid	***
Tetradecanoic acid	***
9-(Z)-Octadecanoic acid	***
2-Mβ butyric acid	***
9,12-(Z,Z)-Octadecanoic acid	***
Hydrocarbons	
Octyl cyclopropene	***
1,2,4-Trimethoxy butane	***
Cyclohexadecane	***
Octadecene	***
1,12 Tridecadience	***

(Source: *Moser et al., 1980; **Weenen et al., 1996; ***Jaswir et al., 2008; ****Zhang et al., 2008).

that durian of different regions to significantly influence mainly 2 volatile components (ethyl 2-methylbutanoate and 1-propanethiol), which are responsible for fruity and onion-like odour. The harvesting techniques can also play a vital role and can influence the aroma and overall taste of the fruit (Voon, Sheikh Abdul Hamid, Rusul, Osman, & Quek, 2006). Previously, Nanthachai (1994) have reported that those durian fruits collected after detaching naturally (natural fall) from the tree to have enhanced aroma compared to the fruits which are hand plucked or ripened artificially. According to Berry (1979), as soon as the fruit falls, very rapid chemical changes occur in the flesh and further storage can lead to rapid loss of flavour. In addition, research carried out by Moser, Duvel, and Greve (1980) showed that the concentrations of the major sulphur compounds to be enhanced during maturity stages.

Volatile compounds collected from headspace fractions of durian has been identified (Moser et al., 1980). Accordingly, sulphur compounds such as dialkyl polysulfides (diethyl trisulphide and diethyl disulphide) were predominant, whereas 1,1-diethoxyethane, ethyl acetate, and ethyl 2-methylbutanoate were identified to be present in the steam distillate of durian fruit. Durian from Malaysia has been identified to have 63 volatile compounds of which 16 were found to be sulphur compounds (Wong & Tie, 1995). Moreover, these authors reported the main volatile compounds to include: 3-hydroxy-2-butanone, ethyl propionate, and ethyl 2-methylbutanoate (32–33%, 20%, and 15–22%, respectively).

However, Weenen et al. (1996) could not detect ethyl propionate in their study. In addition, 18 sulphur compounds has also been identified in 3 different durian varieties (Cane, Koclak, and Boboko) origin of Indonesia. Accordingly, Cane variety had high number of sulphur compounds, and the odour of its extract was extremely sulphury. Amongst the sulphur compounds, *S*-ethyl thioacetate was at highest concentration in all the tested samples (0.8%, 0.7%, and <0.1% for Koclak, Cane, and Boboko, respectively). Amongst the non-sulphur compounds, the major components in the 3 durian extracts were 3-hydroxy-2-butanone, ethyl 2-methylbutanoate, and hexadecanol (Weenen et al., 1996).

The identification of volatile compounds in durian (*D. zibethinus* Murr.) from clone D24 is reported (Jaswir, Che Man, Selamat, Ahmad, & Sugisawa, 2008). The authors reported 38 volatile compounds in fresh durian flesh of which 11 were esters, 10 alcohols, 6 carboxylic acids, 6 sulfurous and nitrogenous compounds, and 5 hydrocarbons. In another report by Zhang, Zheng, Feng, Yu, and Zhang (2008), the volatile compounds of 'Jinzhen' durian fruit was determined by using thermal desorption cryo-trapping gas chromatography/mass spectrometry (TCT-GC/MS). Their results showed durian peel volatiles to be rich in esters (47.37% propanoic acid ethyl ester), whilst durian flesh volatiles were rich in sulphur compounds (8.03% diethyl disulphide, 2.24% diethyl trisulphide, 1.19% 3-ethyl-2,4-dithiahexan-5-one, and 0.06% ethyl n-propyl disulphide).

Nearly 40 volatile flavouring compounds in durian (D24 cultivar) fruit stored at 4 °C for 42 days were identified by Voon, Hamid, Rusul, Osman, and Quek (2007a). Amongst these, sulphur compounds, esters, and alcohols were found to be the major constituents. The majority of ester compounds were observed to have been decreased after 14 days of storage at 4 °C. After 1 week of storage, all the ester compounds, except for ethyl acetate decreased significantly. Moreover, both the isomers of 3,5-dimethyl 1,2,4-trithiolane, and ethanethiol and 1-propanethiol decreased significantly after 7 days of storage. Total sulphur contents in the fruit remained unchanged after 42 days of storage (Voon et al., 2007a).

The volatile compounds in spontaneous (without starter) fermented durian (or 'tempoyak') changed substantially during fermentation (Neti, Erlinda, & Virgilio, 2011). These authors reported 5 sulphur compounds such as 3,5-dimethyl 1,2,4-trithiolane (II), 3-(methylthio)-2-butanone, 1-1-bis (ethylthio) ethane II, ethyl ester propane (dithioic) acid, and N-methylthioacetamide to be generated in the fermented durian. Whereas, 16 non-sulphur compounds were detected in fermented durian. Moreover, 11 sulpuur compounds and 10 non-sulphur compounds disappeared after fermenting. These authors also reported several ester compounds, alcohol and carboxylic acids such as 1,3-butanediol, 2,3-butanediol, propyl ester acetic acid, and octanoic acid to be generated during fermentation.

Li, Schieberle, and Steinhaus (2012) by employing aroma extract dilution analysis detected 44 odour compounds in Thai durian, amongst which, 24 compounds were identified for the first time. So also, compounds such as 1-(propylsulphanyl) ethanethiol, 1-{[1-(methylsulphanyl)ethyl]sulphanyl}ethanethiol, and 1-{[1-(ethylsulphanyl)ethyl] sulphanyl} ethanethiol were detected in a natural product for first time.

However, there are still major gaps and research that can be pursued with regard to volatile/aroma compounds in durian fruits. Some of these includes: Understanding the actual kinetic scheme of flavour induction and aroma formation during different stages of fruit maturity, lipids or fatty acids oxidation or degradation on overall qualities, especially during post-harvest storage, identifying the actual role played by environmental conditions on inducing flavour and finally comparing the volatiles in raw and processed durian fruit products.

6. Phytochemicals

Daily consumption of fresh fruits are important as they contain health-promoting bioactive compounds such as anthocyanins, flavonoids, phenolics, vitamins (Gorinstein et al., 2011). It is well known that bioactive compounds (as antioxidants) have the potential to scavenge free radicals, and thus are able to reduce the level of oxidative stress. This in turn can retard the harmful reaction chains involved with risks of cancer and coronary heart diseases (Voon, Bhat, & Rusul, 2012). Reports available have shown durian (both flesh and hull) to encompass a wide array of bioactive compounds. These bioactive compounds possess high potential to be used as a therapeutic agent. They can be of help to treat patients suffering from diabetes mellitus (help in regulating secretion of insulin) as well as be of use to treat certain cardiovascular diseases (by reducing serum cholesterol) (Gorinstein et al., 2011; Haruenkit et al., 2010; Leontowicz et al., 2007, 2008, 2011; Roongpisuthipong, Banphotkasem, Komindr, & Tanphaichitr, 1991). Some of the major bioactive compounds such as anthocyanins, carotenoids, polyphenols, flavonoids, and others are reported to be present in ample amounts in durian fruit. However, different stages of ripening can influence their concentration levels and bioavailability (Gorinstein et al., 2011; Haruenkit et al., 2010; Jayakumar & Kanthimathi, 2011) (see Table 3). In Table 3, we provide details on the bioactive compounds and antioxidant activity detected in durian. In the following text, we are discussing in detail on some of the important works reported in this area.

6.1. Polyphenolic compounds

Different durian cultivars of same maturity and ripening stage are reported to possess varied concentrations of total polyphenols content and antioxidant capacities. Guan and Whiteman (2002) reported durian fruit extracts to be able to scavenge the $ABTS^+$ radical cation and the free radical DPPH. They observed that durian fruit extracts had 3.39 mM TEAC (result measured at 15 min point after addition of extract into reagent) and IC_{50} value determined to be 41.6 mg/mL (Guan & Whiteman, 2002). Furthermore, in a study by Toledo et al. (2008), a wide range of durian cultivars (Mon Thong, Chani, Kan Yao, Pung Manee and Kradum) were evaluated for their polyphenolics content and antioxidant capacities. Amongst these cultivars, 'Mon Thong' cultivar exhibited (on f.w. basis) significantly higher level of polyphenols (361.4 mg GAE/100 g), flavonoids (93.9 mg CE/100 g), flavanols (171.4 μg CE/100 g), and anthocyanins (427.3 μg cyaniding-3-glucoside equivalent/100 g). This was followed by Kradum cultivar (271.5 mg GAE/100 g and 69.2 mg CE/100 g for total polyphenols and flavonoids, respectively) and Kan Yao cultivars (283.2 mg GAE/100 g and 72.1 mg CE/100 g for polyphenols and flavonoids, respectively). In addition, Arancibia-Avila et al. (2008) have tried to identify phenolic compounds in durian extracts at different ripening stages by using HPLC/DAD method. Several bioactive compounds such as caffeic acid, *P*-coumaric acid, vanillic acid, hesperidin, quercetin, myricitin, apigenin, and campherol were identified in the durian flesh extracts. In addition, some of the compounds such as caffeic acid, quercetin, and apigenin were detected only during ripening or over-ripened stages, whilst some of them were not detected at same stage (*p*-coumaric acid, hesperidin, and quercetin) (Poovarodom et al., 2010).

In another report, durian varieties such as: Chaer Phoy (Green Skinned Durian), Yah Kang (Centipede Durian), D11, and Ang Jin (Red Yoke Durian) were evaluated for total phenolics, flavonoids, carotenoids, and vitamin C contents (Ashraf, Maah, Yusoff, Mahmood, & Wajid, 2011). Results showed Ang Jing variety to have highest amount of total phenolics (998.29 mg/L as GAE), and total

Table 3
Some of the bioactive compounds and antioxidants activity detected in durian.

Compounds (on fresh weight of durian pulp)	Value*		
Polyphenols (mg gallic acid/g)	2.58 ± 0.1		
Flavonoids (mg catechin/g)	1.523 ± 0.17		
Flavanols (μg catechin/g)	67.05 ± 3.1		
Anthocyanins (mg cyanidin-3-glucoside/g)	17.12 ± 1.1		
Tannin (mg catechin/g)	1.37 ± 0.1		
Vitamin C (mg ascorbic acid/g)	5.65 ± 0.2		
Total carotenoids (μg/g)	7.26 ± 0.4		
β-Carotenoids (μg/g)	4.94 ± 0.2		
Compounds (on fresh weight)	Based on maturity stage**		
	Ripe	Overripe	Mature
Total polyphenols (mg gallic acid/100 g)	374.4 ± 32.4	298.5 ± 24.4	231.4 ± 22.1
Free polyphenols (mg gallic acid/100 g)	45.4 ± 4.6	35.1 ± 3.4	27.3 ± 2.9
Total flavonoids (mg catechin/100 g)	97.9 ± 9.3	76.5 ± 6.9	57.3 ± 6.1
Free flavonoids (mg catechin/100 g)	23.9 ± 2.4	19.3 ± 1.9	14.7 ± 1.5
Anthocyanins (μg cyanidin-3-glucoside/100 g)	442.7 ± 33.3	393.1 ± 23.8	388.5 ± 41.1
Flavanols (μg catechin/100 g)	177.1 ± 16.3	163.8 ± 17.1	155.4 ± 15.7
Compound (on fresh weight)	Antioxidant value***		
Oxygen radical absorbance capacity (ORAC) (μmol Trolox equivalents/100 g)	1838		
Lipophilic antioxidants			
-Total carotenoids (mg of carotenoids/100 g)	306		
-Total vitamin E homologues (mg of vitamin E/100 g)	4800		

(Source: *Arancibia-Avila et al., 2008; **Gorinstein et al., 2011; ***Isabelle et al., 2012).

flavonoids (220.34 mg/L as CE). The authors reported total carotenoids to be in very low concentrations (0.05–0.08 mg/L as beta carotene equivalent). The highest amount of ascorbic acid was found in D11 variety (25.13 mg/L) and the lowest in Ang Jin variety (18.87 mg/L).

Haruenkit et al. (2010) have reported on the effects of different solvents (acetone, methanol and water) to influence the level of antioxidant compounds. The content of polyphenols extracted from Mon Thong cultivar using methanol (12.3 mg GAE/g d.w. basis) was higher than water and acetone extractions (10.3 and 7.2 mg GAE/g d.w. basis, respectively). Furthermore, authors reported that different stages of ripening possessed varied polyphenols content, with the overripe durian having highest level of polyphenols (4.3 mg GAE/g, d.w. basis), and with ripe durian having higher flavonoids content (2.2 mg CE/g on d.w. basis).

Poovarodom et al. (2010) reported durian fruit extracts of bioactive compounds vary according to the solvent. The results were (on dry weight basis): Total polyphenols: Methanol > water > acetone > hexane (3.65, 2.61, 1.66, and 0.47 mg GAE/g, respectively); Flavonoids: Acetone > Methanol > water > hexane (3.510, 2.571, 1.451, and 0.730 mg CE/g, respectively); Flavanols: Methanol > water > acetone > hexane (100.41, 67.05, 20.05, and 4.68, respectively), and Tannins: hexane > methanol > water, acetone (3.44, 0.87, 0.36, and 0.36 CE/g, respectively).

Gorinstein et al. (2010) reported the lyophilised 'Mon Thong' cultivar extracted using 1.2 M HCl in 50% methanol to contained 9.88 mg GAE/g of total polyphenols and 0.07 mg CE/g (d.w.) of flavanols. However, lower amounts of total polyphenols (0.75 mg GAE/g dry weight) and flavanols (0.004 mg CE/g dry weight) were recorded when non-hydrolysed method (50% methanol) was employed. Durian fruit extracts has also been reported to have a total phenolic content of 79.15 mg GAE/100 g, wherein myricitin, campherol, and cinnamic acid (1.01, 1.31, and 1.51 mg/100 g, respectively) were found to be the major compounds (Fu et al., 2011). The total polyphenols in durian shell (methanol extract) have also been reported as 33.77 mg GAE/g (Wang & Li, 2011). Whereas, in seed extracts, total polyphenols was recorded to be 3.67 mg GAE/g (Deng et al., 2012).

6.2. Antioxidant capacity

There are several reports available on determining the antioxidant capacity of durian fruit. In an *in vivo* study conducted by Leontowicz et al. (2007), nutritional and health properties of 'Mon Thong' durian cultivar collected during different stages of ripening was investigated. Results showed ripe durian to have high levels of antioxidant compounds (total polyphenols and flavonoids) compared to the mature and overripe durians. Moreover, the antioxidant capacity: 1,1-diphenyl-2-picrylhydrazyl radical (DPPH·) and $ABTS^+$ assays results showed the total polyphenol extracts of ripe durian possessed higher antioxidant capacity than the mature and overripe fruit.

Toledo et al. (2008) have reported on a wide array of antioxidants determined by various assays in durian. Accordingly, 'Mon Thong' durian cultivar had significantly higher ferric-reducing/antioxidant power, cupric reducing antioxidant capacity, and 2,2′-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) in the Trolox equivalent antioxidant capacity (TEAC) (260.89, 20.2, and 2352.79 mM Trolox equivalent/100 g on f.w. basis respectively) than the Kradum and Kan Yao durian cultivars. Moreover, the correlation coefficients between polyphenols, flavanols, flavonoids, and Ferric ion reducing antioxidant power (FRAP), Cupric reducing antioxidant capacity (CUPRAC) and TEAC capacities were shown to range between 0.89 and 0.98 (Toledo et al., 2008).

As detailed earlier, durian fruits are consumed during different stages of ripening. Differences in the levels of various antioxidant compounds and their activity at various ripening stages are reported (Arancibia-Avila et al., 2008). For example: effects of different ripening stages of durian (*D. zibethinus* Murr. cv. Mon Thong) were investigated on their antioxidant properties (Arancibia-Avila et al., 2008). Ripe durian extracts exhibited higher antioxidant capacity (FRAP: 270.4 μmol trolox equivalent/100 g; CUPRAC: 1112.7 μmol trolox equivalent/100 g; and β-carotene: 76.8% inhibition, f.w.), compared to overripe durian fruit extracts (FRAP: 257.5 and 217.4 μmol trolox equivalent/100 g; CUPRAC: 1091.2 and 1019.8 μmol trolox equivalent/100 g; β-carotene: 70.6% and 64.3% inhibition on fresh weight, respectively). In addition, Charoensiri, Kongkachuichai, Suknicom, and Sungpuag (2009) reported ripe durian fruits to be rich in beta-carotene (95.8 and 41.4 μg/100 g edible portion, respectively) and alpha-tocopherols (1.43 and 0.74 mg/100 g edible portion) in 'Chanee' and 'Mawntong' cultivars, respectively.

The hydrophilic oxygen radical absorbance capacity (H-ORAC) of durian fruit were found to be 1838 μmol Trolox equivalents/100 g (f.w.) of sample (Isabelle et al., 2012). In addition, total carotenoids (as obtained from the sum of lutein, zeaxanthin, β-cryptoxanthin, lycopene, α- and β-carotene) was recorded to be 306 μg carotenoids/100 g and 4800 μg vitamin E/100 g (f.w.).

Antioxidant activity of hydrolysed durian fruit extracts evaluated by CUPRAC and $ABTS^+$ assays was recorded to be 27.46 and 39.98 μM TEAC/g (d.w.), respectively. With regard to non-hydrolysed extracts, lower antioxidant activities were recorded from CUPRAC, $ABTS^+$, DPPH, and FRAP assays (3.58, 4.39, 3.27, and 2.48 μM TEAC/g d.w., respectively) (Gorinstein et al., 2010).

The antioxidant activities of durian fruit investigated by CUPRAC, FRAP, ABTS, and DPPH assays using different extracting solvents (such as methanol, water, acetone, and hexane) (Poovarodom et al., 2010) showed water extracts had high $ABTS^+$, FRAP, and DPPH values (39.41, 18.33, and 10.72 μM TEAC/g, d.w., respectively) compared to acetone, methanol and hexane extracts. However, results of CUPRAC assay indicated methanol fraction (21.98 μM TEAC/g dry weight) to have higher antioxidant activity compared to water, acetone, and hexane (20.40, 6.23, and 1.70 μM TEAC/g d.w., respectively).

Antioxidant activity in durian fruit wastes has been also reported. According to Wang and Li (2011) methanolic extracts of durian shell had IC_{50} values of 280.79, 154.67, 324.63, 770.52, 4.45, 102.37, 19.50, and 63.95 μg/mL for reducing power (Fe^{3+}), reducing power (Cu^{2+}), hydroxyl radical, superoxide anion radical, anti-lipid peroxidation, DPPH, $ABTS^+$, and ferrous ions (Fe^{2+}) chelating activity assays, respectively. Furthermore, Fu et al. (2011) on measuring the antioxidant capacities of durian fruit extracts reported an FRAP value of 741 μmol Fe(II)/100 g and 498 μmol TEAC/100 g from $ABTS^+$ assay.

Deng et al. (2012) evaluated the peel and seed residues of durian fruit for their antioxidant activity and reported neither the fat-soluble fraction of peel (extracted with tetrahydrofuran) nor the water-soluble fraction were able to reduce ferric tripyridyltriazine (Fe^{3+} TPTZ) to a ferrous form (Fe^{2+}) in the FRAP assay. However, some positive results were recorded for seed from fat-soluble fraction (2.90 μmol Fe(II)/g) and water-soluble fraction (4.95 μmol Fe(II)/g). Furthermore, seed extracts (fat-soluble fraction) was found to contain 27.35 μmol TEAC/g of free radical scavenging capacities in ABTS assay and 4.90 μmol TEAC/g in water-soluble fraction.

7. Traditional uses as medicine and pharmacological properties

The durian plant (fruits, hulls, leaves, and roots) has been used since long time to treat many types of diseases and common ailments in human. In Malaysia, traditional practitioners believe decoction prepared from leaves and root to possess an antipyretic effect. Here fresh juice are mixed with water for bathing the head of a patient suffering from high fever (Tate, 1999). The leaves are used in medicinal baths to treat patients suffering from jaundice (Tate, 1999). According to local folklore medicine, durian fruits cover/skin can be used externally to treat skin problems. In Malaysia and China, decoctions of leaves and roots are used as febrifuge, and treat phlegm and relieve colds, whilst decoction prepared from fruits and leaves are used to treat skin diseases and swelling (Tate, 1999). The ash obtained from burning of rinds is taken post-childbirth to supposedly improve sexual function (http://www.stuartxchange.com/Durian.html, assessed date: 13th March 2014). In India, decoctions prepared using durian seeds are believed (by some tribal sects) to enhance male sexual function, which is owed mainly to the putative aphrodisiacal properties of seeds (myth.html#.UwXu8GLNvIU assessed date: February 14 2014).

Durian flesh as well as its wastes (hull/skin) is reported to have abundance of therapeutic benefits such as: possessing anti-diabetic properties, anti-hyperlipidemic effects, anti-proliferative activity and antimicrobial activities (Chansiripornchai, Pongsamart, Nakchat, Pramatwinai, & Rangsipipat, 2005; Gorinstein et al., 2011; Haruenkit et al., 2010; Leontowicz et al., 2008, 2011; Pholdaeng & Pongsamart, 2010; Pongsamart, Lipipun, Jesadanont, & Pongwiwatana, 2006; Pongsamart, Lipipun, Nantawanit, & Lertchaiporn, 2005). Durian fruit consumption has also been reported to decrease metabolic syndromes, hyperlipidemia, hyperglycemia, cardiovascular diseases and inflammation including that of oxidative stress (Leontowicz et al., 2007; Roongpisuthipong et al., 1991).

A comparative study undertaken to examine the post-prandial glucose and insulin responses in non-insulin-dependent diabetes mellitus patients showed durian to produce significantly higher insulin response curve and insulin area compared to ingestion of other fruits, indicating improved glucose homeostasis. Daniel, Ismail, Winn, and Wolever (2008) conducted an *in vivo* study to examine the glycemic index of common tropical fruits. Their results revealed durian to have a significantly lower glycemic index than watermelon, papaya or pineapple.

The anti-hyperlipidemic effect of durian consumption (Gorinstein et al., 2011) by 'Wistar' rats fed with basal diets supplemented with 1% non-oxidised cholesterol in 5% of lyophilized durian fruit showed the fruit extracts decrease plasma antioxidant activity. In an another animal model study (Leontowicz et al., 2007), results showed rats fed with basal diet along with 1% of cholesterol and 5% of freeze-dried durian pulp powder to significantly hinder increase in plasma lipids. These reports suggest that durian fruit consumption could be beneficial for patients suffering from diabetes mellitus and hypercholesterolemia diseases.

Anti-atherosclerotic properties of durian has been reported (Leontowicz et al., 2008) in rat models. Rats fed with diets supplemented with Mon Thong > Chani > Kan Yao significantly hindered the rise in the plasma lipids: total cholesterol (16.1%, 10.3%, and 8.7%, respectively) with low density of lipoprotein (LDL) and cholesterol (31.3%, 23.5%, and 20.1%, respectively). On par with this report, another *in vivo* study by Leontowicz et al. (2011) showed rats fed with diet containing ripe durian to effectively decrease total cholesterol, low density lipoprotein cholesterol, and triacylglycerol (by 4.8%, 6.3%, and 26.3%, respectively).

With regard to anti-proliferative activity, Haruenkit et al. (2010) using the MTT assay was able to prove mature durian extract of 'Mon Thong' durian cultivar (concentration level of 2000 μg/mL) to exhibit anti-proliferative activity, which was able to suppress the growth of Calu-6 and SNU-601 by 86.8% and 88.5%, respectively. In addition, durian extracts is reported to possess inhibitory effect on nitric oxide induced cell proliferative activity in the breast cancer cell line (MCF-7) (Jayakumar & Kanthimathi, 2011).

Pongsamart et al. (2005) reported that the isolated polysaccharide gel of the durian rind has antibacterial and immuno-modulating properties. In addition, they reported polysaccharide gel (at 0.32%) obtained from durian hull to exhibit high antibacterial activity (minimal inhibitory concentration = 6.4 mg/mL) against *Bacillus subtilis*, *Escherichia coli*, *Staphylococcus epidermidis*, and *Micrococcus luteus*. Results of agar diffusion and broth dilution assay showed polysaccharide gel extracted from durian fruit rind to exhibit good inhibitory activity against two bacterial strains (*E. coli* and *Staphylococcus aureus*) and two yeast strains (*Candida abicans* and *Saccharomyces cerevisiae*) (Lipipun et al., 2002).

Durian seeds and rind (extracted in methanol) also exhibited higher inhibition against *E. coli* compared to control (Chloramphenicol) (Duazo, Bautista, & Teves, 2012). Polysaccharide gel obtained from the rind of *D. zibethinus* has also been reported to inhibit the growth of *Vibrio harveyi* 1526 (MIC = 6.3 and 12.5 mg/mL) in black tiger shrimps (Pholdaeng & Pongsamart, 2010). Polysaccharide gel film prepared using durian fruit hull had antibacterial properties when tested against some bacteria (Pongsamart et al., 2005). Chansiripornchai et al. (2005), used a film from durian fruit hull to improve a wound healing dressing. Non-alcoholic antiseptic hand lotion containing antimicrobial polysaccharide gel extracted from durian rind (concentration: 2.5% w/w) with combination of essential oils (1% w/w tea-tree oil or 0.5% w/w betel vine oil from *Piper betle* L. (Pongsamart et al., 2006) showed good inhibitory activity against *B. subtilis*, *E. coli*, *Propionibacterium acnes*, *Proteus vulgaris*, *S. aureus*, and *S. epidermidis* (MIC = 2.5% w/v). These result highlights the effectiveness of exploring durian hull wastes to prepare polysaccharide gel based films for commercialisation utilisation in food and pharmaceutical industries.

8. Toxicity studies

A combination of consuming durian fruit and alcohol drinks is reported to lead adverse effects in humans (Maninang, Lizada, & Gemma, 2009). Earlier, Croft (1981) reported on patients consuming durian and drinking alcohol simultaneously, which included deaths as well as cardiac arrest episodes. The symptoms included clinical manifestations such as: palpitation, vomiting, facial flushing, nausea, and drowsiness. In addition, physiological effects of drinking alcohol might also have major contribution on health effects. According to Kitson and Weiner (1996), component derived from ethanol is oxidised in liver by the action of aldehyde dehydrogenase (ALDH) enzyme. Disulfiram can retard ALDH activity resulting in the accumulation of alcohol-derived acetaldehyde. According to some researchers (Brien & Loomis, 1985), acetaldehyde contributes to the adverse reactions known as the disulfiram-ethanol reaction (DER). The inhibitory activities of sulphur-containing compounds obtained from natural resources on ALDH are well known (Kitson & Weiner, 1996). Several studies have shown durian to be abundant in sulphur compounds (Baldry et al., 1972; Moser et al., 1980; Voon et al., 2007b; Weenen et al., 1996; Wong & Tie, 1995).

Sub-chronic and acute toxicity examinations (through oral feeding) in rats and mice fed diets containing polysaccharide gel isolated from durian rind showed no toxic effects (Pongsamart, Sukrong, & Tawatsin, 2001; Pongsamart, Tawatsin, & Sukrong, 2002). Maninang et al. (2009) evaluated the effects of durian fruit extract on the inhibition of ALDH. The enzymatic assay demonstrated that yeast aldehyde dehydrogenase (yALDH) significantly lost enzymatic activity in the presence of durian fruit extract at all the tested concentrations (0.03, 0.07, 0.16, 0.33, 0.65, and 1.63 ppm). The intensity of inhibition increased with increase in the fruit extract concentration and was up to a maximum of 70% at 0.33 ppm extract. However, the inhibitory effect was observed to be low at the highest concentration (1.63 ppm) of the tested fruit extract. The non-polar organic constituents of the durian fruit extract gave positive results in the sulphur-test elicited significant inhibitory effects on yALDH. In addition, several studies reported that the diethyl disulphide to be the most abundant sulphur compound which contains a disulphide bridge in durian (Laohakunjit, Kerdchoechuen, Matta, Silva, & Holmes, 2007; Voon et al., 2007a). As the sulphur content of durian is reported to have inhibitory characteristic on ALDH activity and can be mortal in person who consume durian and drink alcohol simultaneously, further *in vivo* studies are warranted to provide more scientific evidence for better understanding to the consumers.

9. Conclusions and outlook

Durian fruit (flesh, rind, and seed) appear to have nutraceutical value. Investigating the edible portion of durian and its residues (hull and seed) can be useful for food, and pharmaceutical and cosmetic applications. Presence of antimicrobial activities can effective to replace synthetic chemicals. Though, durian fruit contains high amounts of bioactive compounds there is no literature reported on the actual mechanisms involved in the inhibition of tumours cell or antimicrobial activity.

Further studies are warranted to provide details on the functional properties of durian flour (pulp or rind) in order to identity their suitability as a functional food ingredient. As durian fruits are rich in dietary fibre, they can be incorporated to develop novel wheat or other cereal based bakery products. Another area to be explored is the potential use of durian seeds in food and pharmaceutical applications.

Conflict of interest

Authors declare there is no conflict of interest in this review. The authors are grateful to the referees and editor for their constructive suggestions, which were of immense help to upgrade the quality of this review.

References

Amid, B. T., & Mirhosseini, H. (2012). Optimization of aqueous extraction of gum from durian (*Durio zibethinus*) seed: A potential, low cost source of hydrocolloid. *Food Chemistry, 132*, 1258–1268.

Amin, A. M., Ahmad, A. S., Yin, Y. Y., Yahya, N., & Ibrahim, N. (2007). Extraction, purification and characterization of durian (*Durio zibethinus*) seed gum. *Food Hydrocolloids, 21*, 273–279.

Amin, A. M., Jaafar, Z., & Khim, L. N. (2004). Effect of salt on *tempoyak* fermentation and sensory evaluation. *Journal of Biological Sciences, 4*, 650–653.

Amiza, M. A., & Roslan, A. (2009). Proximate composition and pasting properties of durian (*Durio zibethinus*) seed flour. *International Journal of Postharvest Technology and Innovations, 1*, 367–375.

Arancibia-Avila, P., Toledo, F., Park, Y. S., Jung, S. J., Kang, S. K., Heo, B. K., et al. (2008). Antioxidant properties of durian fruit as influenced by ripening. *Food Science and Technology, 41*, 2118–2125.

Ashraf, M. A., Maah, M. J., Yusoff, I., Mahmood, K., & Wajid, A. (2011). Study of antioxidant potential of tropical fruit. *International Journal of Bioscience, Biochemistry and Bioinformatics, 1*(1), 53–57.

Bai-Ngew, S., Therdthai, N., Dhamvithee, P., & Zhou, W. (2014). A study of the effect of the drying process on the composition and physicochemical properties of flours obtained from durian fruits of two ripening stages. *International Journal of Food Science and Technology, 49*, 230–237.

Baldry, J., Dougan, J., & Howard, G. E. (1972). Volatile flavoring constituents of durian. *Phytochemistry, 11*, 2081–2084.

Berry, S. K. (1979). Cyclopropene fatty acids in some Malaysian edible seeds and nuts: 1. Durian (*Durio zibethinus*, Murr.). *Lipids, 15*, 452–455.

Breslow, J. L. (2006). A review n-3 fatty acids and cardiovascular disease. *American Journal of Clinical Nutrition, 83*(6), 1477S–1482S.

Brien, J. F., & Loomis, C. W. (1985). Aldehyde dehydrogenase inhibitors as alcohol sensitizing drugs: A pharmacological perspective. *Trends in Pharmacological Sciences, 6*, 477–480.

Brown, M. J. (1997). *Durio – A bibliographic review*. New Delhi: International Plant Genetic Resources Institute.

Caterina, R. D. (2011). Study shows omega-3 fatty acids extend life. *New England Journal of Medicine, 364*, 2439–2450.

Chansiripornchai, N., Chansiripornchai, P., & Pongsamart, S. (2008). A preliminary study of polysaccharide gel extracted from the fruit hulls of durian (*Durio zibethinus*) on immune responses and cholesterol reduction in chicken. *Acta Horticulture, 786*, 57–60.

Chansiripornchai, P., Pongsamart, S., Nakchat, O., Pramatwinai, C., & Rangsipipat, A. (2005). The efficiency of polysaccharide gel extracted from fruit-hulls of durian (*Durio zibethinus* L.) for wound healing in pig skin. *Acta Horticulture, 679*, 7–43.

Charoensiri, R., Kongkachuichai, R., Suknicom, S., & Sungpuag, P. (2009). Beta-carotene, lycopene, and alpha-tocopherol contents of selected Thai fruits. *Food Chemistry, 113*, 202–207.

Che Man, Y. B., Jaswir, I., Yusof, S., Selamat, J., & Sugisawa (1997). Effect of different dryers and drying conditions on acceptability and physico-chemical characteristics of durian leather. *Journal of Food Processing and Preservation, 21*, 425–441.

Chin, S. T., Hamid, N. S. A., Quek, S. Y., Che Man, Y. B., Rahman, R. A., & Hashim, D. M. (2008). Changes of volatiles attribute in durian pulp during freeze- and spray-drying process. *Food Science and Technology, 41*, 1899–1905.

Contreras-Calderón, J., Calderón-Jaimes, L., Guerra-Hernández, E., & García-Villanova, B. (2011). Antioxidant capacity, phenolic content and vitamin C in pulp, peel and seed from 24 exotic fruits from Colombia. *Food Research International, 44*, 2047–2053.

Croft, J. R. (1981). Bombacaceae. In E. E. Henty (Ed.), *Handbooks of the flora of Papua New Guinea* (pp. 4–18). Melbourne: Melbourne University Press.

Daniel, S. R., Ismail, A. A. S., Winn, T., & Wolever, T. (2008). Glycemic index of common Malaysian fruits. *Asia Pacific Journal of Clinical Nutrition, 17*, 35–39.

Deng, G.-F., Shen, C., Xu, X.-R., Kuang, R.-D., Guo, Y.-J., Zeng, L.-S., et al. (2012). Potential of fruit wastes as natural resources of bioactive compounds. *International Journal of Molecular Sciences, 13*, 8308–8323.

Devalaraja, S., Jain, S., & Yadav, H. (2011). Exotic fruits as therapeutic complements for diabetes, obesity and metabolic syndrome. *Food Research International, 44*, 1856–1865.

Duazo, N. O., Bautista, J. R., & Teves, F. G. (2012). Crude methanolic extract activity from rinds and seeds of native durian (*Durio zibethinus*) against *Escherichia coli* and *Staphylococcus aureus*. *African Journal of Microbiological Research, 6*, 6483–6486.

El-Hofi, M., Youssef, Y. B., El-Desoki, W., Jalil, R. A., & El-Tanboly, E. S. (2011). β-galactosidase from durian seeds (*Durio zibethinus*) and its utilization in ice milk production. *Internet Journal of Food Safety, 13*, 54–61.

El-Tanboly, E. E. (2001). The β-galactosidase system of a novel plant from durian seeds (*Durio zibethinus*) I. Isolation and partial characterization. *Pakistan Journal of Biological Sciences, 4*, 1531–1534.

Fu, L., Xu, B.-T., Xu, X.-R., Gan, R.-Y., Zhang, Y., Xia, E.-Q., et al. (2011). Antioxidant capacities and total phenolic contents of 62 fruits. *Food Chemistry, 129*, 345–350.

Gorinstein, S., Haruenkit, R., Poovarodom, S., Vearasilp, S., Ruamsuke, P., Namiesnik, J., et al. (2010). Some analytical assays for the determination of bioactivity of exotic fruits. *Phytochemical Analysis, 21*, 355–362.

Gorinstein, S., Poovarodom, S., Leontowicz, H., Leontowicz, M., Namiesnik, J., Vearasilp, S., et al. (2011). Antioxidant properties and bioactive constituents of some rare exotic Thai fruits and comparison with conventional fruits *in vitro* and *in vivo* studies. *Food Research International, 44*, 2222–2232.

Guan, T. T., & Whiteman, M. (2002). *Antioxidant activities of some tropical fruits*. URL <http://staff.science.nus.edu.sg/~scilooe/srp2002/sci_paper/Biochem/research_paper/Tan%20Tze%20Guan1.pdf>. Accessed 26.06.14.

Haruenkit, R., Poovarodom, S., Vearasilp, S., Namiesnik, J., Sliwka-Kaszynska, M., Park, Y. S., et al. (2010). Comparison of bioactive compounds, antioxidant and anti-proliferative activities of Mon Thong durian during ripening. *Food Chemistry, 118*, 540–547.

Hokputsa, S., Gerddit, W., Pongsamart, S., Inngjerdingen, K., Heinze, T., Koschella, A., et al. (2004). Water-soluble polysaccharides with pharmaceutical importance from durian rinds (*Durio zibethinus* Murr.): Isolation, fractionation, characterisation and bioactivity. *Carbohydrate Polymers, 56*, 471–481.

Isabelle, M., Lee, B. L., Lim, M. T., Koh, W.-P., Huang, D. J., & Ong, C.-N. (2012). Antioxidant activity and profiles of common fruits in Singapore. *Food Chemistry, 123*, 77–84.

Jaswir, I., Che Man, Y. B., Selamat, J., Ahmad, F., & Sugisawa, H. (2008). Retention of volatile components of durian fruit leather during processing and storage. *Journal of Food Processing and Preservation, 32*, 740–750.

Jayakumar, R., & Kanthimathi, M. S. (2011). Inhibitory effects of fruit extracts on nitric oxide-induced proliferation in MCF-7 cells. *Food Chemistry, 126*, 956–960.

Kitson, K. E., & Weiner, H. (1996). Ethanol and aldehyde metabolism: Past, present and future. *Alcohol. Clinical and Experimental Research, 20*(8), 82A–92A.

Laohakunjit, N., Kerdchoechuen, O., Matta, F. B., Silva, J. L., & Holmes, W. E. (2007). Postharvest survey of volatile compounds in five tropical fruits using headspace-solid phase microextraction (HS-SPME). *HortScience, 42*, 309–314.

Leontowicz, H., Leontowicz, M., Haruenkit, R., Poovarodom, S., Jastrzebski, Z., Drzewiecki, J., et al. (2008). Durian (*Durio zibethinus* Murr.) cultivars as nutritional supplementation to rat's diets. *Food and Chemical Toxicology, 46*, 581–589.

Leontowicz, M., Leontowicz, H., Jastrzebski, Z., Jesion, I., Haruenkit, R., Poovarodom, S., et al. (2007). The nutritional and metabolic indices in rats fed cholesterol containing diets supplemented with durian at different stages of ripening. *Biofactors, 29*, 123–136.

Leontowicz, H., Leontowicz, M., Jesion, I., Bielecki, W., Poovarodom, S., Vearasilp, S., et al. (2011). Positive effects of durian fruit at different stages of ripening on the hearts and livers of rats fed diets high in cholesterol. *European Journal of Integrated Medicine, 3*, 169–181.

Li, J.-X., Schieberle, P., & Steinhaus, M. (2012). Characterization of the major odor-active compounds in Thai durian (*Durio zibethinus* L. 'Monthong') by aroma extract dilution analysis and headspace gas chromatography–olfactometry. *Journal of Agriculture and Food Chemistry, 60*, 11253–11262.

Lim, T. K. (2012). *Edible medicinal and non-medicinal plants* (Vol. 1). Dordrecht Heidolberg, New York: Springer.

Lin, T. F., & Demain, A. L. (1993). Resting cell studies on formation of water-soluble red pigments by *Monascus* sp. *Journal of Industrial Microbiology, 162*, 114–119.

Lipipun, V., Nantawanit, N., & Pongsamart, S. (2002). Antimicrobial activity (*in vitro*) of polysaccharide gel from durian fruit-hulls. *Songklanakarin Journal of Science and Technology, 24*, 31–38.

Maninang, J. S., Lizada, M. C. C., & Gemma, H. (2009). Inhibition of aldehyde dehydrogenase enzyme by durian (*Durio zibethinus* Murray) fruit extract. *Food Chemistry, 117*, 352–355.

Mogilanski, L. J. (2013). *Study shows Omaga-3 fatty acids extend life*. Available from: <http://www.thecrimson.com/article/2013/4/9/fish-omega-science-hsph/> Assess date: 14.12.13).

Moser, R., Duvel, D., & Greve, D. (1980). Volatile constituents of durian (*Durio zibethinus* Murr.). *Phytochemistry, 19*, 79–81.

Nanthachai, S. (1994). *Durian: Fruit development, postharvest physiology, handling and marketing in ASEAN*. Kuala Lumpur, Malaysia: ASEAN Food Handling Bureau.

Neti, Y., Erlinda, I. D., & Virgilio, V. G. (2011). The effect of spontaneous fermentation on the volatile flavor constituents of durian. *International Food Research Journal, 18*, 635–641.

Norjana, I., & Noor Aziah, A. A. (2011). Quality attributes of durian (*Durio zibethinus* Murr) juice after pectinase enzyme treatment. *International Food Research Journal, 18*, 1117–1122.

Oates, C. G., & Powell, A. D. (1996). Bioavailability in of carbohydrate material stored tropical fruit seeds. *Food Chemistry, 56*, 405–414.

Pattanagul, P., Pinthong, R., Phianmongkhol, A., & Leksawasdi, N. (2007). Review of angkak production (*Monascus purpureus*). *Chiang Mai Journal of Science, 34*, 319–328.

Pholdaeng, K., & Pongsamart, S. (2010). Studies on the immuno-modulatory effect of polysaccharide gel extracted from *Durio zibethinus* in *Penaeus monodon* shrimp against *Vibrio harveyi* and WSSV. *Fish Shellfish Immunology, 28*, 555–561.

Phutdhawong, W., Kaewkong, S., & Buddhasukh, D. (2005). GC–MS analysis of fatty acids in Thai durian aril. *Chiang Mai Journal of Science, 32*, 155–158.

Pongsamart, S., Lipipun, V., Jesadanont, S., & Pongwiwatana, U. (2006). Antimicrobial polysaccharide of durian-rinds and natural essential oils combination in an effective non-alcoholic antiseptic lotion for hands. *Planta Medica (Congress abstract), 72*, P043.

Pongsamart, S., Lipipun, V., Nantawanit, N., & Lertchaiporn, J. (2005). Novel water soluble antibacterial dressing of durian polysaccharide gel. *Acta Horticuture, 678*, 65–73.

Pongsamart, S., & Panmuang, T. (1998). Isolation of polysaccharide from fruit-hulls of durian (*Durio zibethinus* L.). *Songklanakarin Journal of Science and Technology, 20*, 323–332.

Pongsamart, S., Sukrong, S., & Tawatsin, A. (2001). The determination of toxic effects at a high oral dose of polysaccharide gel extracts from fruit-hulls of durian (*Durio zibethinus* L.) in mice and rats. *Songklanakarin Journal of Science and Technology, 23*, 55–62.

Pongsamart, S., Tawatsin, A., & Sukrong, S. (2002). Long-term consumption of polysaccharide gel from durian fruit-hulls in mice. *Songklanakarin Journal of Science and Technology, 24*, 649–661.

Poovarodom, S., Haruenkit, R., Vearasilp, S., Namiesnik, J., Cvikrová, M., Martincová, O., et al. (2010). Comparative characterisation of durian, mango and avocado. *International Journal of Food Science and Technology, 45*, 921–929.

Roongpisuthipong, C., Banphotkasem, S., Komindr, S., & Tanphaichitr, V. (1991). Postprandial glucose and insulin responses to various tropical fruits of equivalent carbohydrate content in non-insulin-dependent diabetes mellitus. *Diabetes Research and Clinical Practice, 14*, 123–131.

Saidin, I. (2000). *Sayuran tradisional ulam and penyedap rasa*. Kuala Lumpur: Penerbit Universiti Kebangsaan Malaysia.

Srianta, I., Hendrawan, B., Kusumawati, N., & Blanc, P. J. (2012). Study on durian seed as a new substrate for angkak production. *International Food Research Journal, 19*, 941–945.

Subhadrabandhu, S., & Ketsa, S. (2001). *Durian-king of tropical fruit*. New Zealand: CABI Publishing.

Tate, D. (1999). *Tropical fruit*. Singapore: Tien Wah Press.

The Straits Times. (2013). *Durian wine, anyone*? Available from http://newshub.nus.edu.sg/news/1307/PDF/DURIAN-st-11jul-pB10.pdf (Assess date 13.03.14).

Tippayakul, C., Pongsamart, S., & Suksomtip, M. (2005). Lipid entrapment property of polysaccharide gel (PG) extracted from fruit-hulls of durian (*Durio zibethinus* Murr cv. Mon-Thong). *Songklanakarin Journal of Science and Technology, 27*, 291–300.

Toledo, F., Arancibia-Avila, P., Park, Y. S., Jung, S. T., Kang, S. G., Heo, B. G., et al. (2008). Screening of the antioxidant and nutritional properties, phenolic contents and proteins of five durian cultivars. *International Journal of Food Science and Nutrition, 59*, 415–427.

Tongdang, T. (2008). Some properties of starch extracted from three Thai aromatic fruit seeds. *Starch/Stärke, 60*, 199–207.

Voon, H. C., Bhat, R., & Rusul, G. (2012). Flower extracts and their essential oils as potential antimicrobial agents for food uses and pharmaceutical applications. *Comprehensive Review In Food Science and Food Safety, 11*(1), 34–55.

Voon, Y. Y., Hamid, N. S. A., Rusul, G., Osman, A., & Quek, S. Y. (2007a). Volatile flavour compounds and sensory properties of minimally processed durian (*Durio zibethinus* cv. D24) fruit during storage at 4°C. *Postharvest Biology and Technology, 46*, 76–85.

Voon, Y. Y., Hamid, N. S. A., Rusul, G., Osman, A., & Quek, S. Y. (2007b). Characterization of Malaysian durian (*Durio zibethinus* Murr.) cultivars: Relationship of physicochemical and flavour properties with sensory properties. *Food Chemistry, 103*, 1217–1227.

Voon, Y. Y., Sheikh Abdul Hamid, N., Rusul, G., Osman, A., & Quek, S. Y. (2006). Physicochemical, microbial and sensory changes of minimally processed durian (*Durio zibethinus* cv. D24) during storage at 4 and 28 °C. *Postharvest Biology and Technology, 42*, 168–175.

Wang, L., & Li, X. (2011). Antioxidant activity of durian (*Durio zibethinus* Murr.) shell in vitro. *Asian Journal of Pharmaceutical and Biological Research, 1*(4), 542–551.

Wasnin, R. M., Abdul Karim, M. S., & Mohd Ghazali, H. M. (2012). Effect of temperature-controlled fermentation on physico-chemical properties and lactic acid bacterial count of durian (*Durio zibethinus* Murr.) pulp. *Journal of Food Science and Technology* (in press). http://dx.doi.org/10.1007/s13197-012-0869-7).

Weenen, H., Koolhaas, W. E., & Apriyantono, A. (1996). Sulfur containing volatiles of durian fruits (*Durio zibethinus*). *Journal of Agricultural and Food Chemistry, 4*, 3291–3293.

Wong, K. C., & Tie, D. Y. (1995). Volatile constituents of durian (*Durio zibethinus* Murr.). *Flavour and Fragrance Journal, 10*, 79–83.

Yaacob, O., & Subhadrabandhu, S. (1995). *The production of economic fruits in South-East Asia*. Kuala Lumpur: Oxford University Press.

Zhang, H., Zheng, H., Feng, Y., Yu, L. S., & Zhang, R. G. (2008). Analysis of volatile components of 'Jinzhen' durian fruit by TCT-GC/MS. *Food Science (Shipin Kexue), 29*, 517–519.