



Nutritional, Phytochemical and Pharmacological Properties of *Canarium odontophyllum* Miq. (Dabai) Fruit

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Abstract – *Canarium odontophyllum* Miq. fruit, popularly recognized as dabai fruit in Sarawak, is a seasonal fruit found in the tropical rainforest of East Malaysia. A dabai fruit can be divided into several anatomical parts, and different parts of the fruit have different valuable phytochemicals. Due to the lack of promotion, dabai fruit is viewed as nutritionally inferior fruit by the public. On the contrary, the fruit is rich in nutrients such as protein, fat, carbohydrates, sodium, calcium and iron. Many phytochemicals have been detected from different parts of dabai fruit, and these molecules have been linked to beneficial properties such as hypolipidemic, anti-atherosclerotic, anti-cholinesterase, antimicrobial and potentially anti-diabetic. The aim of this article is to review research studies on this fruit in order to provide adequate baseline information for commercial exploitation as well as for future studies.

Keywords: *Canarium odontophyllum*, dabai, phytochemical, pharmacological

Introduction

Canarium odontophyllum Miq. fruit, commonly known as dabai fruit in Sarawak, is a *Canarium* species from the Burseraceae family. There are approximately 18 genera and 700 species under the Burseraceae family. The family is distributed tropically across a wide range of frost-free and low-elevation habitats such as rainforest, deserts and dry deciduous forest (Weeks, Daly & Simpson, 2005). This family contains 3 tribes, namely Canariceae, Protieae and Burserae. The Burseraceae family is well known in producing resins of medicinal, economic and cultural values including myrrh, frankincense and copal (Paparozzi, 2005).

Approximately 100 species of *Canarium* genus are distributed in Asia and Pacific Islands. Around 55 species indigenous to the Southeast Asia tropics are valuable for their edible oil-rich kernels, fragrant resins and lumber (McGregor, 1991). Among these species, Chinese olive (*Canarium album*), Galip (*Canarium indicum*), Pili (*Canarium ovatum*) and African black olive (*Canarium Schweinfurthi*) are the most common studied species. Dabai (*Canarium odontophyllum* Miq.) fruit becomes the most sought after species due to its nutritional, phytochemical and pharmacological properties.

In local communities of Sarawak, dabai fruit is immersed in lukewarm water for 5 to 10 minutes prior to consuming it together with sugar and soy sauce. As the economic potential has not been fully explored due to the lack of promotion, dabai fruit is classified as an underutilized fruit. Since 1985, numerous studies on the conservation, collection, improvement and documentation of dabai fruit have been conducted by the Agriculture Department of Sarawak (Chai et al., 2008). Lately, dabai fruit has been promoted by the Agriculture Department of Sarawak as a specialty fruit due to its high nutritional quality (Kunding, 2007; Lau, 2009).

Dabai trees can grow up to 36 metres high and the leaves are thin, large and odd-pinnate (Lim, 2012). The biennial fruit-bearing season of dabai trees can be found in the tropical rainforests of East Malaysia (Sarawak and Sabah). The trees are distributed along the riverbanks of Sarawak, particularly in the Kapit, Sarikei, Limbang and Sibu divisions. The fruiting season for dabai fruit is from October to January and the storage period of dabai fruit is about two days after harvest. Dabai fruits may shrivel, shrink and loose its quality when stored at 27 °C for two days (Ding & Yahia, 2011). The short shelf life of dabai fruit is probably caused by its high respiration rate. With the advancement of postharvest technologies, a new freezing technique has been developed by the Agriculture Department of Sarawak. This freezing technique can prolong the shelf life of dabai fruit up to one year if stored in cold storage (Lau & Fatimah, 2007).



Figure 1: Dabai fruit.

In Sarawak, dabai fruit is also known as Sarawak olive or Sibu olive because the physical appearance, flavour and texture of dabai fruit (Figure 1) is almost similar to olive. Dabai fruit is ovoid drupe, 2.2 – 3.0 cm in diameter, 3.0 – 4.0 cm in length and weighing 10.0 -18.0 g (Chew et al., 2011a). The immature dabai fruit is white in colour and it turns to purplish-black when fully ripe. Dabai fruit contains large single three-angled seed with a thick, hard endocarp (1.6 - 2.0 cm in diameter and 2.5 - 3.5 cm in length) (Chew et al., 2011a). Unlike the usual purplish-black, a rare type of red dabai fruit is available in Sarikei, Sarawak. The red dabai fruit is also known as red dabai by the local people. A dabai fruit can be divided into several anatomical origins, namely peel, seed and pulp. Different parts of the dabai fruit have different valuable compounds. Generally, a dabai fruit contains 61.4 % of pulp, 37.0 % of seed and 5.6 % of peel (Azrina et al., 2010a). The edible portions of dabai fruit are the purplish-black peel and the pale yellow pulp whereas the blackish seed is non-edible and usually is discarded even though it contains kernel. According to Lau (2009), a good quality of dabai fruit should be large in size (the weight is approximately 18 g), fine texture, nutty flavour and thick aril. The Agriculture Department of Sarawak has been utilising the dabai fruit to produce recipes for its use in ice-cream, mayonnaise, fried rice, pizza, chips, salad sauce, maki, mixed vegetables and pickles (Lim, 2012).

Nutritional values of dabai fruit

Dabai fruit is nutritious and delicious, and different parts of the fruit have different valuable compounds. Due to the lack of promotion, dabai fruit is viewed as nutritionally inferior by the public.

Proximate compositions

A 100 g of dabai fruit contains 339 kcal energy, 26.2 g fat, 22.1 g carbohydrate and 3.8 g protein (Voon & Kueh, 1999). The amount of fat in this fruit is greater than other high fat fruits, such as olive (23 g/100g) and avocado (25 g/100g) (Shakirin et al., 2010). Factors that may affect the nutrient values of dabai fruit are cultural practice, climate, cultivar, growing region and maturity. Kapit, Kanowit, Song and Sarikei are the four main districts of dabai fruit production in Sarawak. The red dabai fruit found in Sarikei is different compared to the usual purplish-black dabai fruit, r. The ash,

moisture and fat contents of dabai fruit are unaffected by the growing region, but the carbohydrate and protein contents of dabai fruit vary by growing regions (Chew et al., 2011a). Besides, the carbohydrate content of dabai fruit collected from Sarikei (9.16 %) and Song (8.97 %) were almost two folds greater than Kanowit (4.45 %) and Kapit (5.07 %), whereas only a slight difference in its protein content of dabai fruit obtained from different locations of Sarawak (Chew et al., 2011a). The main macronutrient in dabai fruit is fat, and the contents are unaffected by the difference in growing regions. In contrast with the purple variety, the red dabai fruit variety obtained from Song, Kapit and Kanowit is a good source of carbohydrate, but with lesser protein contents.

Different fruit genotypes affect the antioxidant capacities and phenolic contents (Scalzo et al., 2005), and the six common genotypes of dabai fruit are *Besar*, *Biasa*, *Jernah*, *Bujur*, *Seluang* and *Bulat*. Previous studies show dabai fruit collected from various locations in Sarawak have an impact on the nutritional values (Chew et al., 2011a). Hence, genotypes of dabai fruit may affect the nutritional compositions. The edible portions (peel, pulp and kernel) of six common dabai fruits were investigated, and dabai peel was reported to be high in ash and moisture content whereas the part of dabai fruit with the highest percentage of fat and protein was the dabai kernel (Chua et al., 2015).

Dietary fibre is the edible portion of plants that is resistant to enzymatic digestion and absorption by the intestinal tract. Dietary fibre can be categorized according to its digestibility in the small intestine into soluble and insoluble dietary fibre. All genotypes of dabai fruit studied by Chua et al. (2015) demonstrated a very low level of soluble dietary fibre (0.00-0.16 g/100g) and a high level of insoluble dietary fibre (9.29-22.98 g/100g).

Fatty acid and amino acid compositions

Fatty acid compositions affect the nutritional value, physical properties and stability of fat (Sikorski & Kolakowska, 2010). The fatty acid compositions of dabai pulp and kernel oils are shown in Table 1. Generally, the main active fatty acids for dabai pulp and kernel oils are palmitic (16:0), oleic (18:1) and linoleic (18:2) acids. Azrina et al. (2010b) investigated the fatty acid compositions of olive oil, palm oil and dabai (pulp and kernel) oils, and they observed the fatty acid compositions of palm oil and dabai pulp oil were similar. Both types of oils (palm and dabai pulp oils) have approximately 40% SFAs and MUFAs as well as about 12-13 % of PUFAs. The similar trend was also observed by Shakirin et al. (2012b). The high amount of SFAs and MUFAs in palm oil makes it suitable to be used as cooking oil as it provides oxidative stability and prominent frying quality (Ong & Goh, 2000). This suggests that dabai pulp oil could be developed as cooking oil. The fat content of dabai fruit is greater than olive and avocado, but the MUFAs of dabai pulp oil (42%) reported by both studies (Azrina et al., 2010b; Shakirin et al., 2012b) were much lower compared to olive (56–86%) (Milosevic et al., 2002) and avocado (65-68%) oils (Takenaga et al., 2008). On the other hand, the PUFAs of dabai pulp oil, 12 – 14% (Azrina et al., 2010b; Shakirin et al., 2012b) were the same with avocados oil, 12–14% (Takenaga et al., 2008), but different with olive oil, 3.5-21.5% (Milosevic et al., 2002).

Based on the fatty acid compositions displayed in *Table 1*, dabai kernel oil can be classified as saturated fat-rich oil as its SFAs (56-60%) was higher than MUFAs and PUFAs, but the amount of SFAs was lesser than coconut oil, 70% (Azrina et al., 2010b; Shakirin et al., 2012b). Unlike coconut oil, dabai kernel oil contains less dangerous SFA such as myristic acid (14:0). At room temperature, dabai kernel oil has a high possibility to stay solid. As reported by Azrina et al. (2010b), the amount of MUFAs in dabai kernel oil was higher than corn oil (26.5%) and soybean oil (22%) whereas the fatty acid compositions of dabai kernel oil was comparable with cocoa butter (SFAs: 60%, MUFAs: 36-37% and PUFAs: 3%). Cocoa butter is a vegetable fat extracted from the cocoa bean and it is usually used in baking biscuits. Thus, dabai kernel oil could be developed as a replacement oil for cocoa butter used in baking biscuits.

Table 1: The fatty acid compositions detected from dabai pulp and kernel oils

Fatty acids	Azrina et al. (2010)		Shakirin et al. (2012b)	
	Pulp	Kernel	Pulp	Kernel
SFAs	44.3 ± 0.07	60.84 ± 0.04	43.42 ± 0.05	56.2 ± 0.04
C14:0	5.78 ± 0.02	9.30 ± 0.02	0.31 ± 0.04	0.10 ± 0.01
C15:0	0.18 ± 0.00	0.14 ± 0.09	ND	ND
C16:0	36.05 ± 0.05	43.36 ± 0.03	40.31 ± 0.01	50.22 ± 0.74
C18:0	2.15 ± 0.01	4.86 ± 0.02	2.19 ± 1.04	5.88 ± 0.76
C20: 0	0.27 ± 0.14	0.18 ± 0.01	0.61 ± 0.07	ND
MUFAs	42.82 ± 0.06	35.58 ± 0.04	42.53 ± 0.06	39.84 ± 0.04
C16:1	1.37 ± 0.01	0.47 ± 0.00	0.63 ± 0.08	0.28 ± 0.05
C18:1	41.54 ± 0.06	35.11 ± 0.04	41.9 ± 0.02	39.56 ± 0.48
PUFAs	12.76 ± 0.03	3.78 ± 0.25	14.05 ± 0.09	3.96 ± 0.04
C18:2	0.50 ± 0.01	0.73 ± 0.25	ND	ND
C18:2 n6	11.75 ± 0.02	2.82 ± 0.01	14.05 ± 1.96	3.73 ± 0.41
C18:3 n3	0.51 ± 0.01	0.23 ± 0.01	ND	0.23 ± 0.04

ND: Non-detectable, SFAs: Saturated fatty acids, MUFAs: Monounsaturated fatty acids, PUFAs: Polyunsaturated fatty acids

The difference in fatty acid compositions among six different genotypes of dabai fruit were investigated by Chua et al. (2015). From the study, they found dabai pulp oil was rich in PUFAs such as linoleic (18:2) and linolenic (18:3) acids. Meanwhile, dabai kernel oil contained high amount of SFAs and low amount PUFAs for all genotypes studied except *Bulat* genotype, which showed superior high PUFAs (29.54%) and MUFAs (48.58%) values compared to SFAs (21.89%) value (Chua et al., 2015). The SFAs of dabai kernel oil reported by Azrina et al. (2010b) and Shakirin et al. (2012b) were almost three folds greater than the SFAs of *Bulat* genotype. Hence, future research should focus on the kernel of *Bulat* genotype as it may be able to develop as natural fruit oil for pharmaceutical and food industries.

Amino acids can be classified into essential and nonessential. Human body is unable to synthesis essential amino acids and it must be obtained via diet. Contrarily, nonessential amino acids can be synthesised by the human body. Seventeen amino acids exist in dabai fruit, in which seven are essential (methionine, lysine, isoleucine, threonine phenylalanine, leucine, and valine) and ten are nonessential (glutamic acid, aspartic acid, tyrosine, arginine, alanine, histidine, cystine, glycine, proline, and serine) (Chew et al., 2011a). Generally, the concentrations of essential amino acids are lower compared to nonessential amino acids, and dabai fruit is high in glutamic and aspartic acids. The amount of amino acids present in dabai fruit is affected by location difference and varieties.

Minerals and vitamins composition

Minerals and vitamins are micronutrients needed to maintain body physiology well-being. Dabai fruit is rich in minerals with a 100 g of edible dabai fruit contained 810 mg potassium, 200 mg calcium, 106 mg magnesium, 65 mg phosphorus, 1.3 mg iron, 8 µg manganese, 7 µg copper and 4.7 µg zinc (Voon & Kueh, 1999). Previous studies reported conflicting results on the influence of geographic regions on the fruit mineral compositions. Some studies stated geographic regions strongly affected the mineral compositions of fruit (for example, Forster et al., 2002), whereas other studies reported no effect of geographic regions on the mineral compositions of fruit (for example, Wall, 2006). The mineral composition of dabai fruit is strongly affected by the varieties and locations of cultivation, in which calcium (28.47-43.72 mg/100g), sodium (5.02-6.93 mg/100g) and potassium (5.02-6.93 mg/100g) were the major minerals in dabai fruit whereas iron (2.10-3.14 mg/100g), zinc (0.77-0.92 mg/100g) and copper (0.21-0.47 mg/100g) were the minor minerals (Chew et al., 2011a). Among the four types of samples examined, the purple dabai fruit variety obtained from the Kapit district has the

greatest amount of potassium, sodium and iron whereas the red variety collected from the Sarikei district has the least amount of potassium and copper.

Vitamin C serves as an antioxidant to defend against free radicals and protect tissues from oxidative stress. The vitamin C content in dabai fruit was the same as olive and the amount of vitamin C in dabai peel and pulp were 5.85 mg/100g and 2.59 mg/100g, respectively (Alina & Azrina, 2008). Vitamin E contains four tocopherols and four tocotrienols. All the tocopherol and tocotrienol compounds in vitamin E are potent membrane-soluble antioxidants especially the α -tocopherol, which plays an important role as an antioxidant to stop the chain reaction of free radicals in lipoproteins and membranes. High intake of dietary α -tocopherol was associated with a reduction of CVD and cancers (Schwartz et al., 2008). Vitamin E was not detected in dabai pulp oil, but α -tocopherol (1.03 mg/100g) and γ -tocopherol (11.01 mg/100g) were detected in dabai kernel oil (Azrina et al., 2010b). The γ -tocopherol value obtained in dabai kernel oil was greater than cashew nut (5.1 mg/100 g) and almond (3.1 mg/100 g) oils (Kornsteiner et al., 2006). Meanwhile, the vitamin E in dabai kernel oil was significantly greater than olive oil (1.04 mg/100g) (Azrina et al., 2010b).

Phytochemical properties of dabai fruit

The phytochemicals of various parts of dabai fruit have been investigated using different extraction media such as methanol, water, butanol and ethyl acetate. Results show dabai fruit is high in phenolic contents, in which the greatest total phenolics was found in the peel of dabai fruit (387.5 ± 33.23 mg GAE/100 g), followed by pulp (267.0 ± 4.24 mg GAE/100 g) and kernel (51.0 ± 0.01 mg GAE/100 g) (Azrina et al., 2010a). Several phytochemicals have been detected from dabai fruit extracts, and majority of the identified phytochemicals are phenolic compounds such as phenolic acids, flavonoids anthocyanins and anthocyanidins. Based on assays such as β -carotene bleaching, ferric reducing antioxidant power (FRAP) and free radical scavenging, these phenolic compounds were proven for their high antioxidant properties (Prasad et al., 2010; Azrina et al., 2010a; Shakirin et al., 2010; Ali-Hassan, 2013). Different parts of the fruit namely the peel, pulp without the peel, pulp with the peel and kernel, had been used for the antioxidant assays, whereby the order of antioxidant activity were peel > pulp with the peel > pulp without the peel > kernel (Shakirin et al., 2010). *Table 2* lists the identified phytochemicals.

The antioxidant capacities of different parts of dabai fruit (peel, pulp without the peel and seed) using various extraction media (butanol, ethyl-acetate and water) were investigated by Parasad et al. (2010). Ethyl-acetate dabai peel extract showed the greatest total flavonoid, total phenolic and antioxidant capacities as compared to other parts of dabai fruit and extraction media examined. This study showed dabai peel has high potential to be utilized as a natural antioxidant agent. Eight carotenoid compounds were detected from the pulp, peel and seed extracts of dabai fruit. All-trans- β -carotene exhibited large quantity in the peel (69.52 mg/kg), pulp (31.1 mg/kg) as well as the seed (15.1 mg/kg) extracts of dabai fruit (Parasad et al., 2011). Meanwhile, other main carotenoid compounds found in dabai fruit extracts (pulp, peel and seed) includes 9-cis- β -carotene, 15-cis- β -carotene and 13-cis- β -carotenes.

On the other hand, geographic regions and varieties are factors affecting the phenolic compounds of dabai fruit (Chew et al., 2011b). Dabai fruit varieties significantly affected the contents of anthocyanins and anthocyanidins, but had little or no effect on the contents of flavonoids and phenolic acids. Catechin was the main phenolic compound detected in dabai pulp. The amount of catechin in the purple variety of dabai fruit (3.01-4.00 mg/g DW) was significantly higher than the red variety of dabai fruit (0.33 mg/g DW). Anthocyanins, which contribute purple, red or blue pigments to fruits and vegetables, were detected in dabai fruit. The main anthocyanin extracted from dabai pulp was cyanidin-3-*O*-rutinoside and the amount of anthocyanin in the purple variety of dabai fruit was about 16-26 folds more than the red variety of dabai fruit. Generally, dabai fruit collected from the Kapit district, a place with fewer pollutants exposure, had the greatest amount of identified phenolic compounds (anthocyanin, anthocyanidins, flavonoids and phenolic acids).

Table 2: Phytochemicals identified from dabai fruit extracts

Author/year	Chemical classification	Phytochemical identified	Fruit parts
Prasad et al. (2011)	Carotenoids	all- <i>trans</i> - β -carotene, all- <i>trans</i> -lutein, 13- <i>cis</i> - β -carotene, 15- <i>cis</i> - β -carotene, 13- <i>cis</i> -lutein, 9- <i>cis</i> - β -carotene, 9- <i>cis</i> -lutein and di- <i>cis</i> - β -carotene	Peel, pulp, seed
Chew et al. (2011b)	Phenolics acids	Vanillic acid and ellagic acid	Pulp
	Flavonoids	Catechin, apigenin, epicatechin gallate, epigallocatechin gallate and epicatechin	
	Anthocyanidins	Delphinidin, cyanidin and pelargonidin	
	Anthocyanins	Peonidin-3- <i>O</i> -glucoside, cyanidin-3- <i>O</i> -rutinoside, cyanidin-3- <i>O</i> -glucoside and malvidin-3,5-di- <i>O</i> -glucoside,	
Khoo et al. (2012a)	Phenolics acids	Vanillic acid, ellagic acid and protocatechuic acid	Defatted (pulp, peel, pulp without the peel)
	Flavonoids	Catechin, apigenin, epicatechin gallate, epigallocatechin, epicatechin and methyl gallate	
	Anthocyanidins	Delphinidin, cyanidin and pelargonidin	
Khoo et al. (2012b)	Flavonoids	Apigenin, apigenin 8- <i>C</i> -glucoside, apigenin 6- <i>C</i> -glucoside, hesperetin 7- <i>O</i> -glucoside, methyl 4,5-dicaffeoylquinic acid and quercetin 3- <i>O</i> - α -darabinopyranoside	Defatted (pulp, peel)
	Anthocyanins	Cyanidin 3- <i>O</i> -arabinoside, cyanidin 3- <i>O</i> -galactoside, cyanidin 3- <i>O</i> -glucoside, malvidin 3- <i>O</i> -glucoside, delphinidin 3- <i>O</i> -glucoside, delphinidin 3- <i>O</i> -galactoside, delphinidin 3- <i>O</i> -arabinoside, cyanidin 3- <i>O</i> -rutinoside, cyanidin 3- <i>O</i> -sophoroside and hirsutidin 3- <i>O</i> -glucoside	
	Saponins		
Khoo et al. (2013)	Anthocyanins	Cyanidin-3-arabinoside, cyanidin-3-galactoside, cyanidin-3-glucoside, pelargonidin-3-glucoside, malvidin-3-glucoside and peonidin-3-glucoside	Defatted (peel, pericarp)
Mokiran et al (2014)	Phenolics acids	Vanillic acid, ferulic acid and 4-hydroxybenzoic acid	Defatted pulp
	Flavonoids	Catechin, , apigenin, epicatechin and ethyl gallate	

By-products produced from fruit processing have the potential to be developed as new value added-products. Dabai fruit is rich in nutritional values and antioxidants. Hence, the by-products of dabai oil processing such as defatted dabai pulp and peel, should be fully explored. Defatted dabai peel and pulp were rich in phenolic compounds with potent antioxidant capacities (Khoo et al., 2012a). The trend of anthocyanidin and phenolic peaks in various parts of defatted dabai fruit were similar to the dabai pulp as reported by Chew et al. (2011b). Extraction media influence the antioxidant capacities

and phenolic contents of defatted dabai fruit (Khoo et al., 2012a). The main phenolic compounds detected in methanol extract of defatted dabai peel were epigallocatechin and catechin, whereas ellagic acid was the major phenolic compound found in different parts (pulp and pulp without the peel) of defatted dabai fruit extracts (water, ethanol, acetone and ethyl acetate) studied. As compared to other defatted dabai fruit extracts (water, ethanol, acetone and ethyl acetate), methanol extracted defatted dabai peel exhibited the greatest total phenolics (total anthocyanin content, total phenolic content and total flavonoid content). Apart from that, another study from Khoo et al. (2013) showed the main anthocyanin in extracts of defatted dabai pericarp and peel was cyanidin-3-glucoside.

Pharmacological properties of dabai fruit

Lately, the exploitation of indigenous fruits becomes the interest of scientists. Indigenous fruits are the food source and supplementary income of rural communities. The commercial demand for indigenous fruits is gradually increasing because of the awareness of public to use natural products as functional foods, nutraceuticals or dietary supplements to treat diseases and maintain health. The preference of consumers over natural synthetic products is increasing because of the downsides of chemically synthetic medications. Hence, numerous scientific studies on pharmacological of dabai fruit have been conducted lately.

Hypolipidemic effect

Hyperlipidemia is a metabolic disease characterized by the elevation of total cholesterol (TC) and triglyceride (TG) levels in blood. Meanwhile, hypercholesterolemia is associated with a reduction of high density lipoprotein cholesterol (HDL-C) and/or an elevation of low density lipoprotein cholesterol (LDL-C). Hypertriglyceridemia and hypercholesterolemia are the prominent risk factors for CVD development, and the relative contribution of hypercholesterolemia to CVD development is more significant than insulin resistance (Ray et al., 2009). Statins are common hypolipidemic drugs used to inhibit the rate-limiting step in cholesterol biosynthesis, which is HMG-CoA reductase. The possible side effects of using statins are myopathy and elevation of liver transaminases (Bellosta et al., 2004).

Dabai fruit is rich in phenolic compounds and this contributes to the hypolipidemic effect. Five flavonoids, four anthocyanins, three anthocyanidins and two phenolic acids were identified from dabai pulp extract (Chew et al., 2012b). These phenolic compounds have been proven spectrophotometrically for high antioxidant activities (Shakirin et al., 2010; Prasad et al., 2010; Azrina et al., 2010a; Ali-Hassan, 2013) and antioxidants are essential in combating reactive oxygen species (ROS). ROS are unstable yet highly reactive molecules which are able to induce deleterious and irreversible reactions with biological macromolecules. Hence, excessive ROS production may contribute to pathologic cellular alterations and inducing lipid peroxidation. Meanwhile, ROS are linked to the initiation of various types of diseases such as hypercholesterolemia, diabetes mellitus, heart disease and Alzheimer's disease (Giordano, 2005).

Apart from that, the best natural source of saturated fatty acids are palmitic (16:0) and stearic (18:0) acids (Hayes, 2002). The high palmitic and stearic acids in dabai pulp oil (16:0 = 36%, 18:0 = 2%) and dabai kernel oil (16:0 = 46%, 18:0 = 4%) make the oils suitable to be used as vegetable oils (Azrina et al., 2010b). Hypercholesterolemia effect was not present when linoleic acid (18:2) was consumed with palmitic acid above 4.5 % (Ng et al., 1991). Hence, dabai pulp oil (16:0 = 36%, 18:2 = 12%) and dabai kernel oil (16:0 = 46%, 18:0 = 3%) have the potential to be produced as new supplementary oil to combat against hypercholesterolemia.

The effect of dabai (kernel and pulp) oil supplementation on lipid profiles of healthy rabbits was tested by Shakirin et al. (2012a). After 4 weeks of the experimental period, the supplementation of dabai pulp oil at a dosage of 2 % in the diet had exhibited significant increment of TC and HDL-C values as well as significant reduction of LDL-C and TG values. The elevation of TC value did not conclude that dabai pulp oil promotes CVD development because the HDL-C value was increasing at the same time. The explanation was based on the fact that there was a negative relationship between CVDs development and HDL-C value (Gonzalez-Santiago et al., 2006; Basu et al., 2007). Besides,

the supplementation of kernel oil at a dosage of 2 % in the diet appeared to have a significant reduction of TC value, but no significant effect on LDL-C, HDL-C and TG values. This study showed that dabai pulp oil is more effective in improving the lipid profile of healthy rabbits compared to dabai kernel oil.

On the other hand, the effect of dabai fruit supplementation on rabbits fed with high cholesterol diet was also investigated by Shakirin et al. (2012b). Significant reduction of TC and LDL-C values were observed in hypercholesterolemic rabbits supplemented with 50 g kg⁻¹ defatted pulp into their high cholesterol diet. This suggests hypocholesterolemic properties of defatted dabai pulp on hypercholesterolemic rabbits.

The hypocholesterolemic effect of dabai fruit has also been evaluated by Mokiran et al (2014) on obese-diabetic rats. As compared with untreated obese-diabetic rats, 600 mg dabai extract/kg/day significantly increased the plasma HDL-C (47 %) and reduced the plasma cholesterol (19.1 %) and LDL-C (42 %) after 4 weeks of treatment. The results from this study indicated 600 mg dabai extract/kg/day possesses hypocholesterolemic effect.

Anti-atherosclerotic effect

Oxidative damage is a leading factor to the cardiovascular pathologies progression, such as atherosclerosis (Chisolm & Steinberg, 2000). Based on oxidative-modification hypothesis, excessive LDL-C in the blood contributes to the development of atherosclerotic plaques in the inner walls of the arteries, thereby causing narrowing and lead to atherosclerosis (Virmani et al., 2000). When LDL-C oxidized, it will become a lipoprotein species that is particularly atherogenic as the oxidized LDL (oxLDL) is able to accumulate within the arterial wall (Stocker & Kearney, 2004). A Higher level of circulating oxLDL was observed in coronary heart disease patients (Toshima et al., 2000). Contrarily, HDL-C exhibited an anti-atherosclerotic effect in many in-vivo studies (Barter et al., 2004; Assmann & Gotto, 2004). The hypocholesterolemic effect of dabai fruit has been discussed earlier on and it is hard to identify the CVD risk factor according to levels of TC, TG, HDL-C and LDL-C. Alternatively, an atherogenic index (TC to HDL-C ratio) is a good marker to detect the CVD risk (Leudu et al., 2006). A higher reading of atherogenic index reflects the greater risk of having CVD. The supplementation of 50 g kg⁻¹ defatted pulp and full fat pulp of dabai fruit reduced the atherogenic index by 93% and 36%, respectively (Shakirin et al., 2012b).

Oxidative stress is produced when there is an imbalance between antioxidants and endogenous oxidants. Oxidative stress will generate ROS, and this can induce oxidative damage to lipids, nucleic acids and proteins. As a result, DNA oxidative damage occurs. DNA oxidative damage has been linked to the occurrence of atherosclerosis. Hence, there is a dynamic relationship between antioxidants and ROS. Superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx) are antioxidant enzymes found in liver and plasma which contribute to the antioxidant defence system to defend against oxidative injury (Lee et al., 2002). Besides, the major final product of lipid peroxidation, malondialdehyde (MDA), is a biomarker used to determine oxidative damage.

Defatted dabai fruit was found to be rich in phenolic compounds such as anthocyanidin, catechin, ellagic acid and epigallocatechin (Khoo et al., 2012a; Khoo et al., 2012b). By using hypercholesterolemic induced New Zealand white rabbits, Azrina et al. (2013) proved that defatted dabai pulp produced a better effect than simvastatin drug in reducing free radicals. They observed an increment of MDA and reduction of SOD levels, both significantly, on hypercholesterolemic rabbits fed with simvastatin after 8 weeks of treatment. Meanwhile, they also observed a reduction in total antioxidant status (TAS) of hypercholesterolemic rabbits fed with simvastatin. Contrarily, supplementation of 50g kg⁻¹ defatted dabai pulp produced an increment of TAS and SOD significantly, but a reduction of MDA, after 8 weeks of treatment. Their study indicated defatted dabai pulp has the potential to be developed as a new hypolipidemic drug to reduce hypercholesterolemia and the risk of CVD.

Hypoglycemic and anti-diabetic effects

Diabetes mellitus (DM) is a complex metabolic disorder characterized by insulin resistance (insulin action impairment) or insulin deficiency (lack of insulin secreted by the pancreatic islet β -cell), or both. There are numerous types of DM, and the most common form is type 2 diabetes mellitus (T2DM). T2DM causes hyperglycemia and disturbs the metabolism of carbohydrate, protein and fat in the body (Basu et al., 2005). There are a variety of synthetic medications used to manage hyperglycaemia, but the side effects associated with those medications remain concerns. For example, long term consumption of thiazolidinedione (an oral anti-diabetic drug) associates with side effects such as anaemia, weight gain, oedema and risk of cardiovascular diseases (Lipscombe, 2009).

In human, obesity is closely related to T2DM. The anti-hyperglycaemic effect of dabai fruit on obese-diabetic rats was tested and results showed 600 mg dabai extract/kg/day reduced plasma glucose by 30 % after 4 weeks of treatment (Mokiran et al., 2014). Both dosages (300 mg/kg/day and 600 mg/kg/day) groups showed an increase in insulin sensitivity, but a reduction in insulin level and insulin resistance (HOMA-IR index) after 4 weeks of supplementation. Although the results were not significantly different, but the inverse relationship between insulin sensitivity and HOMA-IR index suggests that dabai fruit consumptions may be able to sensitize the insulin binding action for cellular glucose uptake. In addition, the reduction of insulin level in obese-diabetic rats after consuming dabai extract indicates that the extract may be less effective in improving the condition of pancreatic islet β -cell (Mokiran et al, 2014).

Anti-cholinesterase effect

Alzheimer's disease is age-related dementia characterized by impairment of cognitive functions and memory. Approximately 50-60 % of the age-related dementia cases accounted by Alzheimer's disease and it mainly affects individuals above the age of 65 years (Kar et al., 2004). Enzyme acetylcholinesterase (AChE) is needed to terminate the transmission of the nerve impulse at cholinergic synapses. In Alzheimer's disease, the enzyme AChE is decreased because of the reduction activity of cholinergic projections to the cortex and hippocampus (Perry et al., 1999). Hence, the ability of dabai fruit extracts in preventing or treating Alzheimer's disease can be done by measuring the AChE activity, and it is based on the yellow intensity formed when thiocholine (a product from acetylthiocholine) reacts with dithiobisnitrobenzoate ion (Vinutha et al., 2007). An anti-cholinesterase drug is the most common medication used in treating Alzheimer's disease.

In Sabah, *Canarium odontophyllum* Miq. fruit is widely known as kembayau fruit instead of dabai fruit (Lim, 2012; Ali-Hassan, 2013). The anti-cholinesterase ability of seed and pulp of dabai fruit (Kembayau fruit) obtained from Sabah was studied by Ali-Hassan et al. (2013) using two extracting media, namely 80% methanol and water. From their study, 80% methanol extracted dabai seed and pulp showed anti-cholinesterase activity, whereas water extracted dabai seed and pulp displayed low or no anti-cholinesterase activity. The AChE activity was inhibited by 80% methanol extracted from dabai seed and pulp in a concentration-dependent (0-100 μ g/ml) manner. They reported the anti-cholinesterase activity of 80% methanol extracted from dabai seed and pulp was 18.6 and 22.4%, respectively at a concentration of 100 μ g/ml.

Antioxidants are essential in combating reactive oxygen species (ROS) and ROS are linked to the initiation of diseases such as Alzheimer and hypercholesterolemia (Giordano, 2005). The anti-cholinesterase activity in dabai fruit showed moderately positive correlation with ABTS and FRAPS assays, but a strong positive correlation with DPPH assay (Ali-Hassan et al., 2013).

The study by Ali-Hassan et al. (2013) demonstrated positive correlations between the anti-cholinesterase activity of dabai fruit with chemical assays (ABTS, FRAPS and DPPH assays). However, there is no information available on the anti-cholinesterase activity of dabai fruit with bioassays that mimic human vascular system such as haemoglobin oxidation assay and linoleic acid oxidation system assay. Future studies on these aspects are highly warranted.

Antimicrobial activities

Many diseases arise from pathogenic microorganisms. One of the contributing factors to morbidity and mortality in hospitalized patients is nosocomial infection, in the forms of urinary tract infection, surgical wound infection, lower respiratory tract infection or fungal infectious diseases (Samuel et al., 2010; Bereket et al., 2012). Long term usage of commercial antimicrobial medicines such as antibiotic promotes the development of resistance towards the medicines. Hence, the search of an alternative phytotherapeutic agent to combat microbially induced diseases becomes the interest of researchers. Among the *Canarium* species, African black olive (*Canarium schweinfurthii*) has been proven high in antimicrobial properties (Obame et al., 2007).

Basri et al. (2014a) evaluated antimicrobial activities of various dabai pulp extracts (acetone, hexane, water and methanol) at 25, 50, 75 and 100 mg/ml using agar well diffusion method. All extracts from dabai pulp did not show anti-bacteria and anti-fungus activities, but acetone and hexane extracts from dabai pulp showed moderate anti-yeast effect against *Candida glabrata*. Their study showed dabai pulp has the potential as an alternative phytotherapeutic agent against yeast infections.

In the same year, Basri et al. (2014b) conducted another study on dabai fruit, but this time, they focused on the antibacterial activities of various shell extracts (acetone, methanol and acetyl acetate) from dabai seed. As compared with other extracts studied, acetone shell extract from dabai seed showed significantly stronger antibacterial activities on most bacteria species examined, in which the strongest antibacterial activities were observed on *Proteus mirabilis* and *Acinetobacterbaumannii*. Their study also revealed the presence of tannin and flavonoid in acetone shell extract of dabai seed whereas the ethyl acetate shell extract of dabai seed contained tannin and flavonoid.

Both in-vitro studies pointed out the potential usage of dabai fruit as anti-yeast and antibacterial agents. However, there is no information available on the possible anti-yeast and antibacterial of dabai fruit in vivo. Future studies are warranted on these aspects.

Future of dabai fruit as potential source of functional ingredients

Functional ingredients are natural ingredients with health-promoting benefits. Several researchers have studied the beneficial effects of dabai fruit on disease prevention or reduction. Based on the available literature, it can be concluded that dabai fruit has many therapeutic potentials and can be explored further for commercial purposes. The oils produced from this fruit, either from the pulp or the kernel, have lower viscosities compared to saturated fats. Hence, dabai pulp and kernel oils have potential to be used in designing new butter and margarine formulations to improve the physical properties such as spreadability of the product. Besides, palm oil is widely used as cooking oil because of its high amount of SFAs and PUFAs. The fatty acid compositions of dabai pulp oil and palm oil were proved to be the same. Therefore, dabai pulp oil is suitable to be developed as cooking oil. On the other hand, cocoa butter is a type of vegetable fat obtained from the cocoa bean. The fatty acid compositions of oil extracted from dabai kernel are comparable with cocoa butter. Thus, dabai kernel oil has the potential to be developed as an alternative for cocoa butter. Meanwhile, the high phytochemicals contents found in this fruit makes it suitable to be developed as a fruit sauce. Based on a consumer acceptance survey conducted by Rahman & Thajudin (2015), they found the marketing potential of dabai fruit sauce. Through their survey, 68% of respondents would consider purchasing dabai fruit sauce if it was available in the market. Apart from that, defatted dabai pulp has the potential to be developed as a new hypolipidemic drug as Azrina et al. (2013) proved defatted dabai pulp produced a better effect than simvastatin drug in reducing free radicals.

Conclusion

This article reviews the nutritional, phytochemicals and pharmacological prospects of dabai fruit. In Malaysia, dabai fruit is exclusively planted in Sarawak and Sabah. Due to the lack of promotion, dabai fruit is rarely known by the public. Dabai fruit is rich in nutrients such as protein, fat, carbohydrates, sodium, calcium and iron. Many phytochemicals have been detected from different parts of dabai fruit and these phytochemicals have been linked to beneficial properties such as hypolipidemic, anti-atherosclerotic, anti-cholinesterase, antimicrobial and potentially anti-diabetic.

Based on the available literature, it is evident that dabai fruit possesses many therapeutic effects and can be explored further for commercial purposes. Due to quality and safety concerns, it is crucial to employ solvent free techniques in extracting this fruit. Also, current scientific reports on dabai fruit are based on animal models. As the genetics and molecular biology of animals and humans are different, it is important to conduct human trials. Further research on the pharmacological properties of dabai fruit should focus on human trials as these data are able to provide better insights into the long-term safety concerns of consuming the fruit extract.

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