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REVIEW ARTICLE

Artocarpus altilis and *Pandanus tectorius*: Two important fruits of Oceania with medicinal values

Shigeyuki Baba[1], Hung Tuck Chan[1], Mio Kezuka[1], Tomomi Inoue[2], Eric Wei Chiang Chan[3]*

[1]Secretariat, International Society for Mangrove Ecosystems (ISME), Faculty of Agriculture, University of the Ryukyus, Okinawa, 903-0129 Japan, [2]Centre for Environmental Biology and Ecosystem Studies, National Institute for Environmental Studies, Onogawa, Tsukuba 305-0053, Japan, [3]Faculty of Applied Sciences, UCSI University, 56000 Cheras, Kuala Lumpur, Malaysia

ABSTRACT

Artocarpus altilis (breadfruit) and *Pandanus tectorius* (screw pine) are two cultural icons of Oceania. Fruits of both species are rich in carbohydrates, and contain proteins, vitamins and minerals. Endowed with triterpenes, flavonoids, stilbenes, arylbenzofurans and sterols as chemical constituents, fruits of *A. altilis* possess antioxidant, antimicrobial, anticancer and anti-hyperglycemic properties. With phenolic compounds such as flavonoids and caffeoylquinic acids, fruits of *P. tectorius* possess antioxidant, antibacterial, anti-diabetic, α-glucosidase inhibitory and antidiarrheal properties. In comparison, more bioactivities have been reported in other plant parts such as leaves, bark, wood and root of these two species. Nevertheless, the scientific evidence is convincing that the regular consumption of fruits of *A. altilis* and *P. tectorius* by the islanders of the Pacific does have both nutritive and medicinal values.

Keywords: Breadfruit; Screw pine; Phytochemistry; Pharmacology

INTRODUCTION

Inspired by the books The Fruits We Eat (SPC, 2001), Fruits of Oceania (Walter and Sam, 2002) and Gardens of Oceania (Walter and Lebot, 2007), and by our regular visits to Kiribati, Fiji, Tuvalu and Samoa in the past decade, we opted to review the medicinal properties of fruits of *Artocarpus altilis* and *Pandanus tectorius*. They are two important fruit crops that are cultural icons of Oceania (Melanesia, Micronesia and Polynesia). Other major fruit crops include avocado, banana, plantain, citrus, coconut, mango, papaya and pineapple (SPC, 2001).

Grown in 86 countries worldwide, *A. altilis* is an important staple crop in Oceania that has been cultivated for more than 3000 years (Ragone, 2006, 2011). Islanders have selected, grown and named hundreds of cultivars that can be distinguished by their fruits (shape, size, weight, seasonality, skin texture, flesh colour and presence or absence of seeds) and leaves (shape, size and colour). In Vanuatu alone, more than 500 cultivars of *A. altilis* have been identified (Labouisse, 2016).

In the Pacific, the different varieties of *P. tectorius* are identified by their appearance, and the size, shape and colour of fruit bunches and individual phalanges (SPC, 2001). Other features include flavour, water content and ease of detachment from the bunch. In the Marshall Islands, some 150 indigenous varieties of *P. tectorius* have been identified. About 60 varieties have been reported in the Federated States of Micronesia (Englberger et al., 2003a).

To date, there are at least six reviews on *A. altilis* (Ragone, 2006; Deivanai and Subhash, 2010; Jones et al., 2011; Sikarwar et al., 2014; Mohanty and Pradhan, 2015; Turi et al., 2015) and three reviews on *P. tectorius* (Thomson et al., 2006; Lim, 2012; Adkar and Bhaskar, 2014). Breadfruit has also been reviewed under the genus *Artocarpus* (Hakim, 2010; Jagtap and Bapat, 2010; Hari et al., 2014). These reviews entail the botany, ecology, silviculture, uses, phytochemistry and pharmacology of *A. altilis* and *P. tectorius*. Unlike previous articles that describe all plant parts, this review focuses on the phytochemistry and pharmacology of the edible fruits of *A. altilis* and *P. tectorius*.

***Corresponding author:**
Eric Wei Chiang Chan, Faculty of Applied Sciences, UCSI University, 56000 Cheras, Kuala Lumpur, Malaysia.
E-mail: chanwc@ucsiuniversity.edu.my; erchan@yahoo.com

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ARTOCARPUS ALTILIS

Botany and uses

Artocarpus altilis (Parkinson) Fosberg (breadfruit) belongs to the family Moraceae. Synonyms of *A. altilis* are *A. communis* and *A. incisus* (The Plant List, 2013a). In Oceania, the tree is deciduous, fast-growing and can reach heights of 12-15 m (Ragone, 2006, 2011). All parts of the tree produce white latex. The bark is greyish and the trunk can grow to 30-100 cm in diameter, often with buttresses. Leaves are alternate, thick, leathery, and can range from almost entire to deeply dissected, with a pointed apex (Fig. 1). The upper leaf surface is dark green with distinct yellowish veins. The species is monoecious with male and female inflorescences present on the same tree. Male inflorescences are elongated and club-shaped while female inflorescences are rounded. They each consist of a spongy core with many tiny flowers. Trees start to bear fruits after 3-5 years. Fruits are compound, round or oval with a greenish-yellow skin, patterned with hexagonal markings. Depending on the variety, the flesh is creamy white or pale yellow, seedless or containing many seeds. Seedless cultivars are common in Micronesia and Polynesia. Seeds are brown, shiny, rounded, irregularly compressed. Propagation is by raising basal shoots or root cuttings.

Breadfruit is an important staple food that is eaten raw, boiled, steamed or roasted (Ragone, 2006, 2011; Labouisse, 2016). Most of the trees are grown for subsistence with small quantities of the fruits sold in town markets. Fruits generally weigh 1-2 kg and the edible portion is 70-75% of the fruit (Jones et al., 2011). Edible and dry weight fruit yields of 6 t/ha have been reported.

In Oceania, the light hardwood of *A. altilis* is used for building houses and canoes, and is often carved into ornaments and utensils (Ragone, 2011; Labouisse, 2016). Old trees are felled for firewood. The inner bark was formerly used to make bark cloth (tapa). Leaves are used to wrap food for cooking in a pit stove with heated rocks. The latex has been used as chewing gum and adhesive. Dried male flowers can be burned in the evening to distract mosquitoes and other insects (Jones et al., 2012).

Fig 1. Leaves (left), bark (middle) and fruits (right) of *Artocarpus altilis.*

Islanders use the latex of *A. altilis* to treat skin diseases, stomach ache, diarrhoea and dysentery (Ragone, 2006). Crushed leaves are used to treat skin, ear and eye infections. Other medicinal uses include the roots as stringent, purgative and poultice for skin ailments, and the bark for treating headache.

Nutrient content of fruits

Fruits of breadfruit are nutritious and are consumed as starchy staple when mature (Ragone, 2006, 2011). They are rich in carbohydrates, and contain vitamins and minerals. A fruit quality evaluation of 20 breadfruit cultivars sampled from the National Tropical Botanical Garden in Hawaii showed significant differences in aroma, texture, colour, flavour, sweetness, starchiness, moistness, stringiness and firmness (Ragone and Cavaletto, 2006). The greatest differences were in colour and texture. Nutrient analyses showed that the pulp of mature fruits of *A. altilis* (100 g) contained 69% of water, 1.0 g of protein, 29 g of carbohydrate, 5.2 g of dietary fibre, 22 mg of sodium, 24 mg of magnesium, 32 mg of phosphorous, 350 mg of potassium and 20 mg of calcium on the average. The content of vitamin C, β-carotene and lutein was 3.8 mg, 13 μg and 72 μg, respectively. Breadfruit is a good source of vitamin C, thiamin, riboflavin and niacin (Englberger et al., 2003a). Nutritionally, breadfruit is comparable or superior to other staple food commonly consumed in Oceania e.g., taro, plantain, cassava, sweet potato and rice (Dignan et al., 2004).

Phytochemistry and pharmacology of fruits

Early chemical analysis of fruits of *A. altilis* led to the isolation of triterpenes of cycloartenol, cycloart-23-ene-3β,25-diol, cycloart-25-ene-3β,24-diol and α-amyrin (Altman and Zito, 1976). Volatile chemicals of fresh and cooked fruits of *A. altilis* have been studied (Iwaoka et al., 1994). In fresh breadfruit, 40 volatile compounds were identified with *cis*-3-hexenol (36%) being the major constituent. Out of 43 volatile compounds identified in breadfruit boiled for 10 min, the main component was ethyl acetate (38%). From the methanol and ethyl acetate fruit extracts of *A. altilis*, arylbenzofuran of moracin M; stilbenes of oxyresveratrol and artoindonesianin F; flavonoids of norartocarpanone, norartocarpetin and isoartocarpesin; triterpenes of 3β-acetoxyolean-12-en-11-one and cycloartenyl acetate; and sterols of sitosterol β-D-glucopyranoside and sitosterol have been isolated (Amarasinghe et al., 2008).

Fruits of *A. altilis* have been reported to possess antioxidant and antimicrobial activities. A comparative study has been conducted on the antioxidant properties of the pulp, peel and whole fruit of *A. altilis* extracted with hexane, dichloromethane and methanol (Jalal et al., 2015). Results showed that the highest values were from the methanol pulp extract with total phenolic content of 780 mg GAE/g, total flavonoid content of 6210 mg QE/g, DPPH radical scavenging IC_{50} of 55 μg/ml and β-carotene bleaching ability of 88%. Against pathogenic microorganisms of *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Bacillus cereus*, *Salmonella typhimurium*, *Escherichia coli*, *Klebsiella pneumonia* and *Candida albicans*, the methanol fruit pulp extract of *A. altilis* had the largest zone of inhibition and the lowest minimum inhibitory concentration (MIC). The methanol and ethyl acetate fruit extracts against *S. aureus*, *Pseudomonas aeruginosa*, *Streptococcus mutans* and *Enterococcus faecalis* (Pradhan et al., 2013). MIC values of the methanol fruit extract were 0.9 mg for *S. aureus* and *S. mutans*, and 0.6 mg for *E. faecalis*. The ethyl acetate fruit extract inhibited *S. aureus*, *P. aeruginosa* and *E. faecalis* with MIC values of 0.6 mg, 0.9 mg and 1.2 mg, respectively.

From the methanol fruit extract of *A. altilis*, two new geranyl flavonoid derivatives together with four known compounds were isolated (Hsu et al., 2011). They were arcommunol A [1], arcommunol B [2], lespeol [3], 3'-geranyl-2',3,4,4'-tetrahydroxychalcone [4], xanthoangelol [5] and 8-geranyl-3',4',7-trihydroxyflavone [6]. When tested against a panel of human cancer cells based on inhibitory activity (IC_{50}), strongest inhibition was displayed by [1] against SK-Hep-1 cells (2.1 μM), by [4] against Hep3B (7.8 μM), and by [6] against HepG2 (4.4 μM) and PLC5 (9.2 μM) cells. Against SK-Hep-1 cells, [1] induced apoptosis possibly through up-regulation of p53, death-receptor signalling, loss of mitochondrial trans-membrane potential, followed by activation of caspases.

Fruits of *A. altilis* have been reported to possess anti-hyperglycemic properties. The hypoglycemic effects of the aqueous fruit extract and powder were demonstrated *via* the inhibitory activity of α-amylase, α-glucosidase and sucrase, and by the enhancement of glucose uptake by yeast cells (Sairam and Urooj, 2013). Values were however not as strong as those of leaf and bark extracts. The possible mode of action of *A. altilis* as a hypoglycemic agent against diabetes is by glucose adsorption, carbohydrate metabolizing enzyme inhibition and glucose diffusion facilitation through the cell membrane.

A geranyl flavonoid derivative (5,7,4'-trihydroxy-6-geranylflavanone) isolated from fruits of *A. altilis* was reported to possess anti-inflammatory properties (Lin et al., 2011). The compound attenuated S100B-induced inflammatory response in human monocytes by decreasing reactive oxygen species and pro-inflammatory cytokines, and by inhibiting advanced glycation end-products (RAGE)-dependent signalling.

In comparison to fruits, more bioactivities have been reported in the other plant parts of *A. altilis* (Table 1). Leaves possess properties which include anti-inflammatory, anti-atherosclerotic, cytotoxic, hypotensive, skin lightening, hypoglycemic, anti-malarial, renal improvement and hedgehog signalling inhibitory activities. The bark has been reported to be antioxidative, antimicrobial, anti-atherogenic, hypocholestrolemic, hypoglycemic, hepatoprotective, arginase inhibitory and renal protective. The heartwood possesses depigmenting, anti-tyrosinase and anticancer properties while antioxidant, antiplatelet, antitubercular, antiplasmodial, anticancer and UV protective activities have been reported in the root cortex.

PANDANUS TECTORIUS

Botany and uses

Pandanus tectorius Parkinson ex Du Roi (screw pine or beach pandan) belongs to the family Pandanaceae. Previously treated as a distinct species, *Pandanus odoratissimus* L. is now a synonym of *P. tectorius* (The Plant List, 2013b). Growing up to 15 m in height, *P. tectorius* is a stout, branching and multi-stemmed plant (Thomson et al., 2006). Stems are greyish- or reddish-brown, smooth or flaky, ringed by leaf scars and produce prop roots at the base. Leaves are spirally arranged in three rows, sword-like with spiny margins and midribs, and apices with flagella. In the afternoon, plants have a characteristic drooping appearance with the leaves hanging downwards. The species is dioecious with male and female flowers occurring in separate plants. Male flowers are tiny, pendulous and fragrant with white spathes. Female flowers are single spikes with yellow spathes. Resembling pineapples, fruits are globular and contain tightly bunched, wedge-shaped fleshy keys (Fig. 2). They are green when young turning orange-red when ripe. Seeds are obovoid, ellipsoid, or oblong, reddish-brown outside and whitish gelatinous inside. Propagation is by raising branch cuttings.

The distribution of *P. tectorius* stretches from the coast of South and Southeast Asia eastward through Papua New Guinea and tropical northern Australia, and extends into the Pacific islands of Oceania (Lim, 2012). In Oceania, *P. tectorius* is an important fruit crop that occurs in Marshall Islands, Kiribati, Papua New Guinea, New Caledonia, Fiji and most of Polynesia (SPC, 2001).

Throughout the Pacific, the fleshy fruit keys of *P. tectorius* are consumed fresh or processed into various preserved foods (Thomson et al., 2006). Fruits are green when young, turning to yellow and then orange or orange-red when mature. *Pandanus* fruits can be eaten when the green heads of the keys separate out, displaying the bright orange colour and emitting a characteristic sweet smell (Fig. 2). The fibrous and fleshy basal mesocarp is the portion of the key

Table 1: Bioactivities of other plant parts of *Artocarpus altilis*

Plant part and bioactivity	Reference
Leaf	
Flavonoids with anti-inflammatory properties	Wei et al. (2005)
Phytochemicals with anti-atherosclerotic properties	Wang et al. (2006)
Cytotoxic activity against murine P-388 leukaemia cells	Lotulung et al. (2008)
Cytotoxic effects of new geranyl chalcone derivatives against SW 872	Fang et al. (2008)
human liposarcoma cells	Hsu et al. (2012)
Anti-inflammatory activity of isolated geranyl flavonoid derivatives	Nwokocha et al. (2012)
Hypotensive effects on rats	Rao et al. (2013)
Skin lightening activity by inhibition of melanocyte dendrite elongation	Sairam and Urooj (2013)
In-vitro and *ex-vivo* hypoglycemic activity	Arai et al. (2015)
Hedgehog signalling pathway inhibition	Fakhrudin et al. (2015)
Anti-inflammatory effect on carrageenan-induced paw oedema in rats	Nguyen et al. (2014)
Cytotoxic activity of the extract and isolated compounds against human PANC-1 pancreatic cancer cells	Mozef et al. (2015)
Protective effect against atherosclerosis	Jeon et al. (2015)
Extract and geranyl dihydrochalcone inhibited STAT3 activity in prostate cancer DU145 cells	Hafid et al. (2016)
Good to moderate *in-vitro* and *in-vivo* antimalarial activity against	Safitri et al. (2016)
Plasmodium falciparum and *P. berghei*	
Improves kidney function in rats with renal failure	
Bark	
Hypoglycemic effect of the root bark on STZ-treated diabetic rats	Adewole and Ojewole (2007a, 2007b)
Antimicrobial activity of the stem bark extract and isolated compounds	Kuete et al. (2011)
In-vitro and *ex-vivo* hypoglycemic activity	Sairam and Urooj (2013)
Anti-atherogenic and hypocholestrolemic activities of the stem bark in hypercholestrolemic rats	Adaramoye and Akanni (2014)
Antioxidative and arginase inhibitory activities of the stem bark	Akanni et al. (2014)
Protective effect of the stem bark against Cd-induced liver and kidney dysfunction in rats	Adaramoye and Akanni (2016)
Heartwood	
Compounds isolated from the heartwood with inhibitory effects on	Shimizu et al. (1998, 2000)
5α-reductase and melanin biosynthesis	Donsing et al. (2008)
Melanogenesis and tyrosinase inhibitory activities of the heartwood	Arung et al. (2009)
extract and isolated atrocarpin	Buranajaree et al. (2011)
Anticancer activity by inducing sub-G1 apoptosis in human T47D	Lan et al. (2013)
breast cancer cells	Tzeng et al. (2014)
Depigmenting effects of the heartwood on UVB-induced hyper-	Fu et al. (2014)
pigmentation in C57BL/6 mice	Tiraravesit et al. (2015)
Antioxidant and anti-tyrosinase activities, and inhibition of melanin	
production of isolated prenylated flavonoids isolated from heartwood	
Anticancer activity toward human HepG2 and PLC/PRF/5 hepatoma cancer cells of the heartwood extract and fractions rich in artocarpin	
Heartwood extract inhibits melanogenesis through activation of ERK and JNK signalling pathways	
Protective effect of the heartwood on UVB-exposed skin in mice	
Root cortex	
Antiplatelet effect of flavonoids isolated from the root cortex on human platelet-rich plasma	Weng et al. (2006)
Antitubercular, antiplasmodial and anticancer activities	Boonphong et al. (2007)
Antioxidant activity of prenylflavonoids isolated from the root cortex	Lin et al. (2009)
Attenuation of UVA-induced damaged human keratinocytes and fibroblasts by prenylated phenols isolated from the root cortex	Lin et al. (2015)

that is chewed and eaten. In Micronesia, adults consume more than 20 fresh keys daily during the fruiting season. Chewing fresh keys between meals is a pleasurable and highly social activity.

Not all fruits are edible with some cultivars having oxalate crystals, which cause mouth irritation (Thomson et al., 2006). Fruits of different varieties are distinct in size, shape, colour, flavour and juiciness. They are rich in vitamin C and carotenoids, including β-carotene (Dignan et al., 2004; Englberger et al., 2003a). Varieties with soft keys can be eaten raw while those with fibrous keys are processed into paste and flour before consumption or sold as chips (SPC, 2001; Ragone, 2011).

Fig 2. Yellow (left) and orange (middle) fruits, and fruit keys (right) of *Pandanus tectorius*. The photo on fruit keys is from Thomson et al. (2006).

In Oceania, *P. tectorius* is an important source of wood for buildings and crafts (SPC, 2001; Thomson et al., 2006). The dried leaves are used for thatching traditional houses. The green leaves are processed and woven into mats, baskets, fans, hats and other handicrafts. The womenfolk in Marshall Islands are considered the finest weavers known for their quality mats with patterns created by combining natural and dyed strips of leaves (Baba et al., 2013). Elsewhere, the womenfolk of the Mah Meri aboriginal tribe on Carey Island in Selangor, Malaysia are also renowned for their exquisite purses and pouches woven from leaves of *P. tectorius*.

The species is also an important medicinal plant (Thomson et al., 2006). In Kiribati, the leaves are used as remedy for cold, influenza, hepatitis, dysuria, asthma, boils and cancer, while the roots are used to treat haemorrhoids. In Hawaii, fruits, male flowers and aerial roots are used to treat digestive and respiratory disorders. In Palau, roots and leaves are used to alleviate stomach cramps and vomiting, respectively. Roots are also known for their use in traditional medicine in Pohnpei.

Nutrient content of fruits

The keys of *P. tectorius* fruits (100 g) contain 80% of water, 1.3 g of protein, 17 g of carbohydrate, 3.5 g of dietary fibre, 70 mg of sodium, 17 mg of magnesium, 236 mg of potassium, 88 mg of calcium, 60 μg of β-carotene, 5.0 μg of vitamin A and 5.2 mg of vitamin C (Dignan et al., 2004). Five cultivars of *P. tectorius* collected from the Federated States of Micronesia and analysed for α- and β-carotene showed that cultivars with yellow fruit coloration contained low levels of carotenoids (Englberger et al., 2013b). Cultivars with orange fruits, which are preferred by the islanders, contained higher levels of up to 190 mg/100 g of α-carotene and 393 mg/100 g of β-carotene.

Phytochemistry and pharmacology of fruits

From the fruit of *P. tectorius*, 15 compounds including 10 phenolic compounds and five flavonoids were isolated for the first time (Zhang et al., 2012). The compounds were vanillin, *trans*-ethyl caffeate, *cis*-ethyl caffeate, ethyl coumarate, trans-3,4-dihydroxycinnamaldehyde, sinapaldehyde, dihydroconiferyl alcohol, coniferyl alcohol, 3-hydroxy-1-(4-hydroxy-3-methoxyphenyl)propan-1-one, salicylaldehyde, tangeretin, sakuranetin, chrysin, naringenin and 5,8-dihydroxy-7-methoxy-flavone. Soon after, the same group of scientists isolated two new phenolic compounds, named pandanusphenols A and B (Zhang et al., 2013a). Some of these compounds have been reported to possess useful pharmacological properties. Vanillin is known to be a potent antioxidant and inhibits tyrosinase. Tangeretin and naringenin have cholesterol-lowering ability while ethyl caffeate has anti-inflammatory properties.

From fruits of *P. tectorius*, one new and six known aldehyde compounds were isolated and identified (Mai et al., 2015). They were (*Z*)-4-hydroxy-3-(4-hydroxy-3-methylbut-2-en-1-yl) benzaldehyde, *p*-hydroxybenzaldehyde, syringaldehyde, (*E*)-ferulaldehyde, (*E*)-sinapinaldehyde, vanillin and 5-hydroxymethylfurfual. When tested for α-glucosidase inhibitory activity, the compounds (IC_{50} of 37-192 μM) showed better activity than the standard drug of acarbose (IC_{50} of 215 μM).

Recently, fruits of *P. tectorius* have been reported to be rich in caffeoylquinic acids (CQAs). From the *n*-butanol fraction of the ethanol fruit extract, 15 types of CQAs were identified (Liu et al., 2013; Zhang et al., 2013b). They comprised four CQAs (1-CQA, 3-CQA, 4-CQA and 5-CQA), eight di-CQAs, two methyl esters of di-CQAs and one tri-CQA. Major components were 1,4-CQA, 3,4-CQA and 3,5-CQA. Besides antioxidant properties, studies have shown that CQAs display diverse bioactivities such as antimicrobial, anti-inflammatory, analgesic, antipyretic, anti-hyperlipidemia, anti-hyperglycemia, anti-skin aging and cytotoxic properties (Wong et al., 2014).

Analysis of the essential oil extracted from ripe fruits of *P. tectorius* showed that the major components were geranyl acetate (28%), 3-methyl-3-buten-1-yl cinnamate (17%), 3-methyl-3-buten-1-yl acetate (10%) and ethyl cinnamate (10%) (Vahirua-Lechet et al., 1996). Major essential oil components of fruits of P. tectorius sampled from Hainan were alkenes of docosene (15%) and hexacosene (11%), and alkanes of 1,2-diethyl-cyclohexa-decane (18%) and cyclotetracosane (12%) (Wang et al., 2011).

A study on some bioactivities of the hexane, ethyl acetate and methanol extracts of keys and cores of *P. tectorius* fruits has been conducted in Malaysia (Adriani et al., 2015). The results showed that the ethyl acetate core extract had the highest phenolic content and antioxidant capacity, while the ethyl acetate key extract displayed the highest antibacterial activity with inhibition zones of 10–15 mm against Gram-positive (*Bacillus subtilis* and *S. aureus*) and Gram-negative (*E. coli* and *P. aeruginosa*) bacteria. All the six extracts did not have any cytotoxic activity against selected normal cells (RAW and L-6) and cancer cell lines (HeLa, HepG2 and MCF-7).

Earlier, fruits of *P. tectorius* have been reported to possess anti-diabetic properties. The anti-hyperlipidemic effects and possible mechanisms of action of the fruit extract on hamsters fed with a high fat-diet were investigated (Zhang et al., 2013b). Administration of the CQA-rich *n*-butanol fraction of the ethanol fruit extract of *P. tectorius* for a month effectively reduced retroperitoneal fat, and serum and hepatic cholesterol and triglycerides. Treatment with the fruit extract significantly stimulated the activity of AMP-activated protein kinase (AMPK) as well as those of serum and hepatic lipoprotein lipase (LPL). The results suggested that the fruit fraction moderated hyperlipidemia and improved the liver lipid profile. These effects were attributed to increasing the expression of peroxisome proliferator-activated receptor alpha (PPARα) associated genes, and to up-regulating LPL and AMPK activities. Of the CQAs isolated from fruits of *P. tectorius*, the same group of scientists also reported that 3-CQA, 3,4-CQA and 4,5-CQA significantly inhibited lipid accumulation and reduced the intracellular content of total cholesterol and triglyceride in HepG2 hepatoma cells (Liu et al., 2013; Wu et al., 2015). The mechanism of actions involves up-regulating the expression of lipid oxidative genes and down-regulating the expression of lipogenic genes.

Further work on the hypoglycemic and hypolipidemic effects of the CQA-rich fraction of the fruit extract of *P. tectorius* was investigated in diabetic db/db mice (Wu et al., 2014). Treatment with the extract at 200 mg/kg significantly reduced body weight and fasting glucose level, and alleviated high blood insulin and hyperlipidemia. The elevated levels of serum pro-inflammatory cytokines and islet hypertrophy in db/db mice were markedly attenuated. Biochemical analysis showed that the extract stimulated AMPK and AS160, and enhanced the expression and translocation of glucose transporter type 4 (GLUT4) in skeletal muscles. Overall, the extract was found to benefit the treatment of diabetes by alleviating hyperglycemia and dyslipidemia *via* the activation of AMPK-AS160-GLUT4 pathway in skeletal muscles, and the inhibition of gluconeogenesis and lipogenesis in the liver.

The antidiarrheal effects of fruits of *P. tectorius* have been reported. Based on defecation, intestinal transit and intestinal fluid accumulation (IFA), antidiarrheal activities were evaluated in rats with castor oil-induced diarrhoea (Rahman et al., 2014). Oral administration of the *P. tectorius* fruit extract, at 200 and 400 mg/kg, exhibited significant and dose-dependent antidiarrheal effects. The diarrheal episode was reduced by 35% and 47%, respectively. In addition, the fruit extract significantly inhibited IFA by reducing both the weight and volume of intestinal content and also decreased intestinal transit. Comparable results were obtained with loperamide at 5.0 mg/kg (standard drug) and with the leaf extract at the same dosage.

In comparison with fruits, more bioactivities have been reported in other plant parts of *P. tectorius* (Table 2). Leaves possess properties which include antitubercular, antibacterial, anti-inflammatory, hepatoprotective, CNS depressant, antidiarrheal, anticonvulsant, diuretic and neuroprotective activities. Steroids isolated from the stem bark have been reported to be cytotoxic and roots have anti-hyperglycemic and hepatoprotective activities.

CONCLUSION

Fruits of *A. altilis* and *P. tectorius* are rich in carbohydrates, and are a good source of proteins, vitamins and

Table 2: Bioactivities of other plant parts of *Pandanus tectorius*

Plant part and bioactivity	Reference
Leaf	
Antitubercular activity of isolated triterpenes and phytosterols	Tan et al. (2008)
Growth inhibition of Gram-positive bacteria but not Gram-negative bacteria and yeast	Kumar et al. (2010)
Anti-inflammatory effect against carrageenan-induced acute and formalin-induced	Londonkar et al. (2010)
chronic paw oedema in mice	Londonkar et al. (2011)
Hepatoprotective effect against CCl_4-induced liver injury in rats	
CNS depressant effects on albino mice	Raju et al. (2011)
Antidiarrheal activity against castor oil-induced diarrhoea in rats	Rahman et al. (2014)
Anticonvulsant activity against epileptic mice	Adkar et al. (2014)
Diuretic activity of extract and isolated squalene	Tan et al. (2014)
Neuroprotective activity in mice model with Parkinson's disease	Sitepu et al. (2016)
Stem bark	
Cytotoxic steroids isolated from the stem bark	Carver and Truscott (1993); Hoa et al. (2014)
Root	
Anti-hyperglycemic activity in alloxan-induced diabetic rats	Madhavan et al. (2008)
Protective effects on paracetamol-induced hepatotoxicity in rats	Mishra et al. (2015)
Strong antioxidant activity of isolated compounds	Jong and Chau (1998)

minerals. Endowed with triterpenes, flavonoids, stilbenes, arylbenzofurans and sterols as chemical constituents, fruits of *A. altilis* possess antioxidant, antimicrobial, anticancer and anti-hyperglycemic properties. With phenolic compounds such as flavonoids and caffeoylquinic acids, fruits of *P. tectorius* possess antioxidant, antibacterial, anti-diabetic, α-glucosidase inhibitory and antidiarrheal properties. Although more bioactivities have been reported in other plant parts, there is scientific evidence that the regular consumption of fruits of *A. altilis* and *P. tectorius* by the islanders does have both nutritive and medicinal values. With multiple uses, both species are truly the two cultural icons of Oceania.

Author contributions

During their expeditions to Oceania, S. Baba (the lead scientist), T. Inoue and M. Kezuka took notes and photographs of *A. altilis* and *P. tectorius*, and related their experiences. Based on available literature, H.T. Chan drafted the review with comments by S. Baba. Being the natural product chemist in the team, Eric Chan (the corresponding author) was responsible for the phytochemistry and pharmacology sections.

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