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Research article

Nutritional composition of conserved *Kadsura* spp. plants in Northern Thailand

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ABSTRACT

The genus *Kadsura* comprises woody vine plants belonging to the family *Schisandraceae*. Species are found mostly in Northern Thailand and widely consumed by the local population. Occurrences of these wild fruits are rare as they only grow naturally in forest areas. Nutritive values of *Kadsura* spp. remain unclear, leading to improper management for food applications. Nutritional composition of *Kadsura* spp. was evaluated to promote sustainable conservation. Nutritive values in different fruits parts (exocarp, mesocarp, seed and core) of two *Kadsura* species as *Kadsura coccinea* (Lem.) A.C. Sm. and *Kadsura heteroclita* (Roxb.) Craib, from Chiang Rai Province, Thailand were assessed. When comparing nutritional contents based on per 100 g dry weight, results suggested that *K. coccinea* exhibited higher carbohydrate (1–2 times), sugar (1–2 times) and vitamin C (3–4 times) contents than *K. heteroclita*, while the latter possessed higher fat (1–2 times), protein (1.6–1.9 times), and dietary fiber (1.5–1.8 times) contents. Considering each fruit part, the mesocarp (the only edible fruit part) and exocarp of both species provided high dietary fiber (11.6–20.9% recommended dietary fiber) and vitamin C (as high as 73% recommended per day) but were low in energy (30–40 kcal/100 g fresh weight), protein (0.6–1.2% recommended per day), fat (0.5–1.8% recommended per day) and sugar (2.4–5.4% recommended per day). Interestingly, seed contained higher energy (1–2 times), protein (2–3 times) and fat (4–50 times) than the other fruit parts. Results support the potential consumption of *Kadsura* spp. as a healthy fruit that can be used for future food applications. Seed and exocarp from *Kadsura* spp. also showed potential for new product development.

1. Introduction

The genus *Kadsura*, in the family *Schisandraceae*, is a woody vine plant found in evergreen forest. It has ovate-elliptic shaped leaves, solitarily unisexual flowers and large globose fruits ($14–20 \times 10^{-2}$ m in diameter) with hexagonal structured skin developed by each carpel and 1 to 3 flat seeds in each mericarp (Trisonthi and Trisonthi, 1999). However, color, shape and size of fruits and leaves vary among *Kadsura* species. *Kadsura* spp. are indigenous fruits found mostly in Southern China and consumed by the local population as fresh fruit, juice and wine (Sun et al., 2011). *Kadsura* spp. are also used as ingredients in folk medicine. The stem and root of *K. coccinea* can relieve rheumatic pain in the bones, chronic enteritis, acute gastritis (Ban et al., 2009; Mulyaningsih et al., 2010) and immunologic hepatic fibrosis (Pu et al., 2008). The stem of *K. heteroclita* is used to prevent and treat rheumatic and arthritic diseases, with anti-nociceptive and anti-inflammatory effects (Corona et al., 2011; Yao et al., 2013; Xiang et al., 2016).

In Thailand, *Kadsura* spp. (or noi-na-kreua in Thai) were first reported in Northern Thailand in 1972 (Keng, 1972). It is found mostly in forests located near villages in Mae-jedi-mai sub-district, Weing-pa-pao district, Chiang Rai Province. *Kadsura coccinea* (Lem.) A.C. Sm. (*K. coccinea*) and *Kadsura heteroclita* (Roxb.) Craib (*K. heteroclita*) are the two species growing naturally in these forests. *K. coccinea* is harvested between October to November, whereas *K. heteroclita* is harvested between December and January. The fruit of *Kadsura* spp. is consumed by villagers as fresh fruit or fermented with rice whisky and sugar. The leaflets can be boiled or blanched and consumed with chili paste. Unlike *Kadsura* spp. found in China, usage of *Kadsura* spp. as a folk medicine has not been reported widely in Thailand.

Unlike other ubiquitous fruits in Thailand, *Kadsura* spp. are not well-known and recognized by foreigners. This rare wild fruit only grows naturally in forested areas, with reproduction occurring at a very low growth rate. Thus, the genus *Kadsura* is listed as the conservative plant under the Plant Genetic Conservation Project under the

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royal initiation of Her Royal Highness Princess Maha Chakri Sirindhorn (RSPG) in an attempt to increase awareness of its status as nearly extinct as well as achieve sustainable conservation and allocation of plant resources for beneficial utilization as a source of nutrients. To date, only one previous literature by Sun et al. (2011) has reported on the nutritive values of *K. coccinea* harvested in China (Sun et al., 2011), while no information is available on *K. coccinea* and *K. heteroclita* growing naturally in Thailand. Therefore, the aim of this study was to evaluate the nutritional composition of *Kadsura* spp. to ensure sustainable conservation. This is the first report comparing the nutritional contents in different fruit parts of *K. coccinea* and *K. heteroclita*. These species are almost extinct in the wild due to limited information on food applications and agricultural management. Results detailing the qualitative and quantitative nutrients of these conservative plants will promote their consumption as healthy fruits and can be used for future food applications, eventually leading to sustainable plant conservation. All parts of the fruits including the exocarp, mesocarp, seed and core were investigated to reduce waste products from food consumption.

2. Materials and methods

2.1. Materials

The specimens were identified by RSPG experts (led by Assist. Prof. Dr. Chunthana Suwanthada and Assoc. Prof. Dr. Chusri Trisonthi from the board of the RSPG) according to their characteristics (Keng, 1972; Trisonthi and Trisonthi, 1999). *K. coccinea* was collected in October, 2017, while *K. heteroclita* was collected in January, 2018. These plants can be harvested only once a year; therefore, the closest periods to collect both specimens were chosen. The fruits (around 15–20 kg of each species) of both specimens were collected from forest areas near Hui-Nam-Guen village, Mae-jedi-mai sub-district, Weing-pa-pao district, Chiang Rai Province, Thailand (19°11′58.3″N and 99°31′00.7″E) within a range of 4 km (around 5–7 plants). Average rainfall in year 2017 was 2244.7 mm (Chiang Rai rice research center). Soil type is river delta soil with layers, in which the upper layer is clay loam soil with gravel, and the lower layer is clay soil with more gravel (Soil Resources Survey and Research Division).

2.2. Sample preparation

Fresh samples were cleaned with deionized water and separated as exocarp, mesocarp, core and seed. The fruit diameters of both samples were measured using a Mitutoyo 530-119 Vernier caliper (0–300 x 10^{-3} m, Mitutoyo Asia Pacific Pte. Ltd., Singapore). The samples were cut to 0.3 x 10^{-2} m thickness before freeze drying using a freeze dryer (Heto Powerdry PL9000, Heto Lab Equipment, Allerod, Denmark) for 3 days. Dry samples were ground into a fine powder using a grinder (Philips 600W series, Philips Electronics Co., Ltd., Jakarta, Indonesia), packed in vacuum aluminum foil bags, and kept at 253 K in a freezer until required for further analysis.

Colors of both fresh and dry samples were measured using a spectrophotometer (ColorFlex EZ, Hunter Associates Laboratory, Virginia, USA) and expressed as CIELAB L*a*b* units, including L* representing dark (0) to white (100) colors, a* representing green (-) to red (+) colors and b* representing blue (-) to yellow (+) colors. Moisture contents of powdery samples were analyzed using a Halogen moisture analyzer (HE53 series, Mettler-Toledo AG, Greifensee, Switzerland).

2.3. Analyses of nutritive values

Fresh samples were weighted and analyzed for nutritive values using the standard protocols of the Association of Official Analytical Chemists (AOAC) (Latimer, 2016) at the Institute of Nutrition, Mahidol University (conformed to ISO/IEC 17025:2005, the international standard for laboratory quality systems). Milli-Q water with resistivity of 18.2 MΩ cm at 298.15 K (Millipore RiOs-DITM134, Millipore Corporation, Massachusetts, USA) and HPLC grade solvents were used for HPLC analysis. Nutritive values including energy, moisture content, protein, fat, ash, total dietary fiber, carbohydrate, energy, vitamin C and minerals as Ca, P, Na, K, Mg, Fe and Zn were determined as follows.

2.3.1. Moisture content

Moisture content was determined by the drying method using a hot air oven (Memmert Model UNE 500, Memmert GmbH + Co. KG, Schwabach, Germany) at a temperature of 373 ± 5 K with heat-dispersed material until sample weight was constant. The missing weight was calculated as moisture content (AOAC 930.04, 934.01).

2.3.2. Protein

Protein was determined according to the Kjeldahl method (Bradstreet, 1954). Protein was hydrolyzed by concentrated sulfuric acid to generate ammonia (nitrogen containing compound) (BUCHI Model K-435 and B-324, BUCHI Corporation, St. Gallen, Switzerland). The amount of detected nitrogen was multiplied by 6.25, the converting factor for general foods, to obtain protein content (AOAC 992.23).

2.3.3. Fat

Fat was determined using acid hydrolysis and petroleum ether extraction (AOAC 948.15, 945.16). The extracted solution was washed-out by deionized water through Whatman™ qualitative filter paper (125 mm, GE Healthcare UK Limited, Buckinghamshire, UK), then dried and extracted using a Soxhlet system (Model HT1043, Tecator, Höganäs, Sweden) with petroleum ether at 313.15–333.15 K.

2.3.4. Dietary fiber

Total dietary fiber was determined utilizing the enzymatic-gravimetric method (AOAC 991.42 and 991.43). The sample was digested with α-amylase, amyloglucosidase and protease. Soluble and insoluble dietary fibers were determined separately, and total dietary fiber was calculated by the sum of both dietary fibers (AOAC 985.29).

2.3.5. Ash content

Ash content was calculated by incineration in a muffle furnace (CWF 1100, Carbolite Gero Ltd., UK) at 823.15 K, then weighing the remaining ash residue (AOAC 930.30, 945.46).

2.3.6. Carbohydrate and energy

Total carbohydrate was calculated from the information of moisture, protein, fat and ash using the following equation;

$$\text{Total carbohydrate (g)} = [100 - \text{moisture content (g)} - \text{protein (g)} - \text{fat (g)} - \text{ash (g)}]. \quad (1)$$

Energy was calculated using the Atwater factor (kcal/g) following the equation;

$$\text{Energy (kcal)} = [\text{protein (g) x 4}] + [\text{carbohydrate (g) x 4}] + [\text{fat (g) x 9}]. \quad (2)$$

2.3.7. Sugars

Disaccharides including fructose, glucose and sucrose were determined utilizing a premium ultra-fast liquid chromatography (UFLC) system (Shimadzu Corporation, Kyoto, Japan) with an ELSD detector (Alltech® model with 800 ELSD detector, BUCHI Corporation, Delaware, USA) and a 5μ Shodex Asahi Pak NH2P-50 4E column (250 × 4.6 mm, Shodex Group, Kanagawa, Japan). The sample was analyzed under an isocratic solvent system (76% (v/v) acetonitrile) with a flow rate of 1.0 mL/min.

2.3.8. Vitamin C

Vitamin C analysis was performed according to the protocol in the ASEAN manual of Food Analysis (2011) (Puwastien et al., 2011). Vitamin C was extracted by 10% (v/v) metaphosphoric acid (MPA) (Merck, Darmstadt, Germany) before subjection to an HPLC system with a pump (Waters 515 pump, Waters Corporation, Massachusetts, USA) and a UV/Vis detector (UV-975, JASCO International Co., Ltd., Tokyo, Japan). Vitamin C was separated by a 5μm Zorbax original ODS column (250 × 4.6 × 10^{-3} m, Agilent Technologies, California, USA) under isocratic solvent system (0.5% (v/v) KH_2PO_4, adjusted pH to 2.5 with H_3PO_4) with a flow rate of 0.8 mL/min. The presence of vitamin C was monitored at 254 nm (Odriozola-Serrano et al., 2007; Kongkachuichai et al., 2015).

2.3.9. Minerals

Ash residue was used to determine the presence of some minerals including calcium, sodium, potassium and phosphorus. An Atomic Absorption Spectrometer (AAS) (S Series, Thermo Electron Corporation, Cambridge, UK) was used for calcium, sodium and potassium determinations (AOAC 985.35), while the gravimetric method was employed for phosphorus determination (Kolthoff et al., 1969). A fresh sample digested by HNO_3:H_2O_2 (5:1) was used to determine magnesium, iron and zinc, utilizing an Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES) (Optima 4200DV, PerkinElmer®, Massachusetts, USA) (AOAC 984.27).

2.4. Statistical analysis

All experiments were carried out in triplicate (n = 3) and expressed as mean ± standard deviation (SD). One-way Analysis of Variance (ANOVA) followed by Duncan's multiple comparison tests and the Student *t*-test were performed to determine significant differences between values with $p \leq 0.05$ using SPSS™ software for Windows version 19 (SPSS Inc., Illinois, USA).

3. Results

3.1. Sample characteristics

K. coccinea was 10–16 x 10^{-2} m in diameter, larger than *K. heteroclita* at 7 to 12 x 10^{-2} m (Figure 1). The whole fruit was separated as exocarp, mesocarp (edible part), seed and core. After the freeze drying process, the exocarp, mesocarp and core were ground to a fine powder, while the texture of the ground seed was oilier and clustered.

Colors of fresh and dry samples are shown in Table 1. Comparing the fresh samples, almost all parts of *K. heteroclita* exhibited higher a* values but lower b* values than of *K. coccinea*, suggesting that the color of *K. heteroclita* was redder, while the color of *K. coccinea* was more greenish-yellow. Comparing between the fresh and dry samples, dry exocarp, mesocarp and core tended to possess higher L* values than their corresponded fresh fruit parts, suggesting that the colors of these samples were lighter after the freeze drying process. However, the color of seed was darker after freeze drying, indicated by a significantly lower L* value. Most fruit parts of dry *K. coccinea* and *K. heteroclita* tended to possess lower a* and b* values than their corresponding fresh samples, indicating that the red and yellow colors of fresh samples became lighter after the freeze drying process.

3.2. Nutritional contents

Nutritional contents including energy, protein, fat, ash, total dietary fiber, carbohydrate, energy, vitamin C and minerals were reported as per 100 g dry weight (DW) to accurately compare results among the different fruits parts (exocarp, mesocarp, seed and core) and between species (*K. coccinea* and *K. heteroclita*) without concern for moisture contents (Table 3 and Table 4). Moisture contents altered the interpretation of the comparison of nutritional contents and were reported separately as percentages for both fresh and dry samples.

3.2.1. Moisture content

Moisture contents of fresh exocarp, mesocarp and core ranged from 88 to 91%, while seed had lower moisture content in the range of 46–54% (Table 2). Moisture contents detected in both *K. coccinea* and *K. heteroclita* followed similar trends. Highest moisture contents were detected in exocarp (90.77% in *K. coccinea* and 88.63% in *K. heteroclita*) and mesocarp (91.46% in *K. coccinea* and 89.98% in *K. heteroclita*), followed by core (89.80% in *K. coccinea* and 87.79% in *K. heteroclita*). However, seed recorded significantly lowest moisture contents (53.56% in *K. coccinea* and 46.36% in *K. heteroclita*). Comparing between species, all fruit parts of *K. coccinea* possessed significantly higher moisture contents than those of *K. heteroclita*.

Moisture contents of all dry fruit parts in *K. coccinea* ranged from 5.15 to 6.31%, while those of *K. heteroclita* were 5.36–12.24% (Table 2).

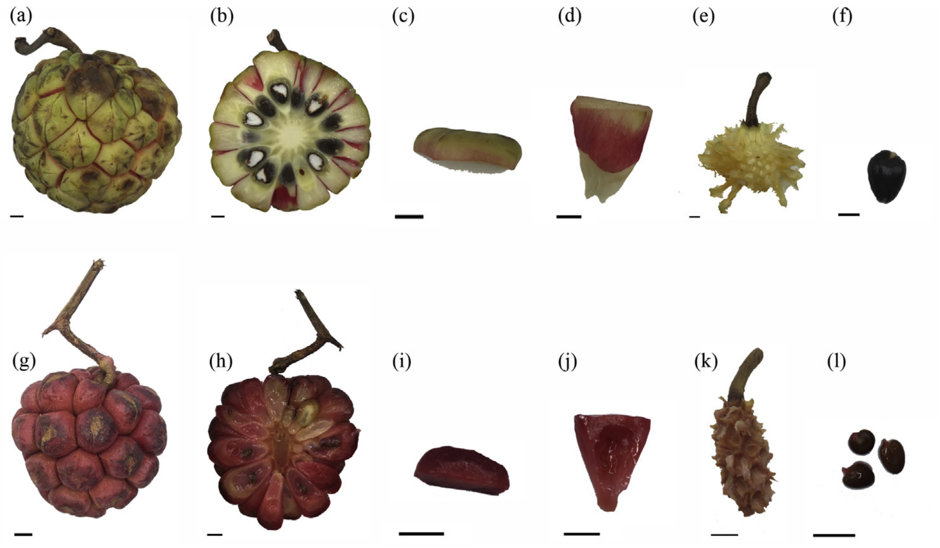

Figure 1. *K. coccinea* in (a) whole fruit, (b) sectioned fruit, (c) exocarp, (d) mesocarp, (e) core, and (f) seed, and *K. heteroclita* in (g) whole fruit, (h) sectioned fruit, (i) exocarp, (j) mesocarp, (k) core, and (l) seed. The line indicates the scale of 1 cm.

Table 1. Color values of fresh and dry exocarp, mesocarp, core and seed of *K. coccinea* and *K. heteroclita.*

Parts	Color values					
	Fresh samples			Dry samples		
	L*	a*	b*	L*	a*	b*
K. coccinea						
Exo	$33.93 \pm 2.76^{c,*}$	$3.90 \pm 0.94^{c,*}$	25.30 ± 1.22^{b}	65.78 ± 0.67^{c}	6.16 ± 0.36^{a}	24.46 ± 1.57^{a}
Meso	$42.76 \pm 1.36^{a,*}$	$29.17 \pm 4.80^{a,*}$	$19.41 \pm 1.47^{c,*}$	72.45 ± 0.85^{b}	6.75 ± 0.54^{a}	14.13 ± 0.37^{c}
Seed	$21.17 \pm 0.63^{d,*}$	$6.59 \pm 0.29^{c,*}$	$8.64 \pm 0.88^{d,*}$	14.73 ± 0.29^{d}	2.74 ± 0.10^{b}	4.17 ± 0.11^{d}
Core	$37.51 \pm 0.12^{b,*}$	$15.98 \pm 0.36^{b,*}$	$33.82 \pm 0.30^{a,*}$	75.70 ± 0.06^{a}	6.28 ± 0.08^{a}	18.81 ± 0.26^{b}
K. heteroclita						
Exo	$26.30 \pm 5.96^{b,*}$	$19.71 \pm 3.48^{b,**}$	$14.66 \pm 1.61^{b,*,**}$	$35.51 \pm 0.63^{b,**}$	$15.28 \pm 0.27^{a,**}$	$6.05 \pm 0.41^{c,**}$
Meso	$33.17 \pm 3.86^{b,*,**}$	$27.88 \pm 3.95^{a,*}$	$13.97 \pm 2.45^{b,**}$	$45.68 \pm 1.04^{a,**}$	$8.69 \pm 0.08^{b,**}$	$10.99 \pm 0.45^{b,**}$
Seed	$28.27 \pm 2.75^{b,*,**}$	$12.48 \pm 0.44^{c,*,**}$	$15.73 \pm 1.40^{b,*,**}$	$16.14 \pm 0.58^{c,**}$	$4.99 \pm 0.02^{d,**}$	$6.47 \pm 0.29^{c,**}$
Core	$46.39 \pm 0.55^{a,**}$	$11.37 \pm 0.27^{c,*,**}$	$19.49 \pm 0.19^{a,*,**}$	$45.98 \pm 0.01^{a,**}$	$7.74 \pm 0.01^{c,**}$	$14.99 \pm 0.02^{a,**}$

All data were expressed as mean ± SD of triplicate experiments. Exo: Exocarp; Meso: Mesocarp.

The colors were analyzed using a ColorFlex EZ spectrophotometer and expressed as CIELAB L*a*b* units, including L (darkness to lightness), a (green to red) and b (blue to yellow).

$^{a\text{-}d}$showed significant difference ($p \leq 0.05$) of each part within the same sample using one way ANOVA and Duncan's *post hoc* test.

*showed significant difference ($p \leq 0.05$) between fresh and dry samples within the same species using unpaired sample t-test.

**showed significant difference ($p \leq 0.05$) between *Kadsura coccinea* (Lem.) A.C. Sm. and *Kadsura heteroclita* (Roxb.) Craib using unpaired sample t-test.

Table 2. Moisture contents of fresh and dry exocarp, mesocarp, core and seed parts of *K. coccinea* and *K. heteroclita.*

Species	Parts	Moisture contents (%)	
		Fresh samples	Dry samples
K. coccinea	Exocarp	$90.77 \pm 0.24^{ab,*}$	5.91 ± 0.13^{a}
	Mesocarp	$91.46 \pm 0.23^{a,*}$	6.24 ± 0.44^{a}
	Seed	$53.56 \pm 1.00^{c,*}$	$5.15 \pm 0.05^{b,*}$
	Core	$89.80 \pm 0.44^{b,*}$	6.31 ± 0.44^{a}
K. heteroclita	Exocarp	88.63 ± 0.30^{ab}	6.27 ± 0.36^{b}
	Mesocarp	89.98 ± 0.25^{a}	5.36 ± 0.60^{c}
	Seed	46.36 ± 1.39^{c}	12.24 ± 0.35^{a}
	Core	87.79 ± 0.29^{b}	6.76 ± 0.29^{b}

The data of exocarp, mesocarp and seed were expressed as mean ± SD of triplicate experiments.

$^{a\text{-}d}$showed significant difference ($p \leq 0.05$) of each part within the same sample using one way ANOVA and Duncan's *post hoc* test.

*showed significant difference ($p \leq 0.05$) in the same fruit parts but different species using unpaired sample t-test.

These results were used to calculate other nutritional contents to compare values among different fruit parts and between species as per 100 g DW.

3.2.2. Protein

Protein content in the exocarp, mesocarp and core of *K. coccinea* ranged at 3.83–4.13 g, while seed exhibited significantly higher protein content of 10.96 g (Table 3). Similar results were observed in *K. heteroclita* (Table 4), with protein contents in exocarp, mesocarp and core ranging from 6.03 to 7.83 g. The seed exhibited significantly highest protein content at 17.74 g. Overall, *K. heteroclita* possessed significantly higher protein contents in all fruit parts than *K. coccinea*.

3.2.3. Fat

The exocarp, mesocarp and core of *K. coccinea* contained fat contents in the range of 0.84–7.20 g, and significantly lower than seed at 26.39 g (Table 3). Similarly, exocarp and mesocarp of *K. heteroclita* possessed fat contents of 2.91 and 13.53 g, respectively, while seed exhibited significantly highest content of 49.51 g (Table 4). However, fat was not detected in its core. When comparing different species, mesocarp and seed of *K. heteroclita* possessed significantly higher fat contents than *K. coccinea*, while the latter contained significantly higher fat content in the exocarp than the former species.

3.2.4. Dietary fiber

Total dietary fiber in seed of *K. coccinea* (66.99 g) was significantly higher than core (44.56 g) and exocarp (40.75 g), while mesocarp exhibited the lowest content (36.67 g) (Table 3). Interestingly, the content of insoluble dietary fiber was 1–3 times higher than soluble dietary fiber in exocarp, mesocarp and core, and up to 13 times higher in seed. Likewise, total dietary fiber in *K. heteroclita* was found to be significantly highest in core (81.458 g), followed by exocarp (61.58 g), mesocarp (58.84 g) and seed (34.04 g) (Table 4). Insoluble dietary fiber contents were 4–10 times higher than the soluble form. Comparing between species, exocarp, mesocarp and core of *K. heteroclita* possessed significantly higher total dietary fiber than those of *K. coccinea*, while the opposite result was observed in seed. Soluble fiber contents in the mesocarp and core of *K. coccinea* were significantly higher than in *K. heteroclita*, while no significant differences in exocarp and seed were observed. However, insoluble dietary fiber contents in the exocarp, mesocarp and core of *K. heteroclita* were significantly higher than those of *K. coccinea*. The opposite result was observed in seed, where *K. heteroclita* contained significantly lower insoluble dietary fiber content than *K. coccinea*.

3.2.5. Ash content

A powdery residue remaining after burning (ash) was detected in small amounts in all fruit parts. Ash contents in *K. coccinea* ranged

Table 3. Nutrient compositions of *Kadsura coccinea* (Lem.) A.C. Sm (per 100 g dry weight).

Nutrients	Nutritive values (per 100 g dry weight)			
	Exocarp	Mesocarp	Seed	Core
Energy (kcal)	401.68 ± 1.93^{c}	410.98 ± 0.26^{b}	520.81 ± 3.14^{a}	389.00 ± 0.32^{d}
Protein (g)	3.83 ± 0.26^{c}	$4.04 \pm 0.07b^{c}$	10.96 ± 0.00^{a}	4.13 ± 0.10^{b}
Fat (g)	6.67 ± 0.29^{b}	7.20 ± 0.32^{b}	26.39 ± 0.64^{a}	0.84 ± 0.05^{c}
Carbohydrate (g)	81.59 ± 0.75^{b}	82.51 ± 0.71^{b}	59.87 ± 0.66^{c}	91.23 ± 0.13^{a}
Total dietary fiber (g)	40.75 ± 2.17^{c}	36.67 ± 1.91^{d}	66.99 ± 2.25^{a}	44.56 ± 0.27^{b}
- SDF (g)	12.90 ± 0.72^{b}	16.21 ± 1.01^{a}	4.64 ± 0.50^{c}	12.78 ± 0.45^{b}
- IDF (g)	27.85 ± 1.48^{c}	20.45 ± 0.89^{d}	62.35 ± 1.95^{a}	31.77 ± 0.18^{b}
Total sugar (g)	15.75 ± 0.61^{c}	34.35 ± 1.74^{a}	3.25 ± 0.04^{d}	25.74 ± 0.27^{b}
- Fructose (g)	10.07 ± 0.24^{c}	15.50 ± 1.21^{a}	1.61 ± 0.03^{d}	12.23 ± 0.33^{b}
- Glucose (g)	5.67 ± 0.37^{b}	13.16 ± 0.55^{a}	1.40 ± 0.01^{c}	13.51 ± 0.06^{a}
- Sucrose (g)	ND^{b}	5.69 ± 0.37^{a}	0.24 ± 0.01^{b}	ND^{b}
Ash (g)	7.92 ± 0.37^{a}	6.25 ± 0.34^{b}	2.79 ± 0.02^{d}	3.80 ± 0.01^{c}
Vitamin				
- Vitamin C (mg)	923.80 ± 72.03^{a}	550.09 ± 15.27^{b}	ND^{d}	400.30 ± 7.32^{c}
Minerals				
- Ca (mg)	127.86 ± 0.54^{b}	81.62 ± 2.43^{d}	94.45 ± 0.05^{c}	151.14 ± 0.47^{a}
- P (mg)	447.57 ± 18.21^{b}	369.88 ± 29.31^{c}	414.14 ± 17.87^{b}	722.00 ± 21.69^{a}
- Na (mg)	265.34 ± 3.45^{a}	208.35 ± 12.01^{b}	100.60 ± 0.47^{d}	147.19 ± 10.85^{c}
- K (mg)	2406.76 ± 108.05^{a}	1673.02 ± 57.30^{c}	621.44 ± 4.15^{d}	2236.86 ± 18.45^{b}
- Mg (mg)	258.51 ± 12.48^{b}	347.12 ± 13.00^{a}	381.87 ± 27.83^{a}	358.17 ± 16.70^{a}
- Fe (mg)	2.80 ± 0.08^{a}	0.76 ± 0.16^{b}	3.02 ± 0.19^{a}	0.67 ± 0.00^{b}
- Zn (mg)	0.33 ± 0.06^{b}	0.44 ± 0.08^{b}	1.41 ± 0.11^{a}	0.34 ± 0.00^{b}

All data were expressed as mean ± standard deviation (SD) of triplicate experiments. SDF: soluble dietary fiber; IDF: insoluble dietary fiber; ND: not detected.
$^{a\text{-}d}$showed significant difference ($p \leq 0.05$) of each part within the same sample using one way ANOVA and Duncan's *post hoc* test.

Table 4. Nutrient compositions of *Kadsura heteroclita* (Roxb.) Craib (per 100 g dry weight).

Nutrients	Nutritive values (per 100 g dry weight)			
	Exocarp	Mesocarp	Seed	Core
Energy (kcal)	$385.50 \pm 3.46^{c,*}$	$448.46 \pm 2.39^{b,*}$	$636.98 \pm 1.09^{a,*}$	$368.23 \pm 5.45^{d,*}$
Protein (g)	$6.03 \pm 0.29^{c,*}$	$6.73 \pm 0.14^{bc,*}$	$17.74 \pm 0.06^{a,*}$	$7.83 \pm 1.24^{b,*}$
Fat (g)	$2.91 \pm 0.07^{c,*}$	$13.53 \pm 0.36^{b,*}$	$49.51 \pm 0.19^{a,*}$	ND
Carbohydrate (g)	$83.80 \pm 1.16^{a,*}$	$74.94 \pm 0.73^{b,*}$	$30.11 \pm 0.08^{c,*}$	$84.23 \pm 2.61^{a,*}$
Total dietary fiber (g)	$61.58 \pm 4.22^{b,*}$	$58.84 \pm 1.69^{b,*}$	$34.04 \pm 0.11^{c,*}$	$81.45 \pm 13.53^{a,*}$
- SDF (g)	13.05 ± 0.77^{a}	$13.15 \pm 0.87^{a,*}$	4.57 ± 0.05^{c}	$7.51 \pm 1.09^{b,*}$
- IDF (g)	$48.53 \pm 3.45^{b,*}$	$45.69 \pm 1.03^{b,*}$	$29.47 \pm 0.06^{c,*}$	$73.94 \pm 12.44^{a,*}$
Total sugar (g)	16.28 ± 0.82^{a}	$16.82 \pm 0.75^{a,*}$	$2.05 \pm 0.03^{c,*}$	$11.56 \pm 2.04^{b,*}$
- Fructose (g)	$8.95 \pm 0.18^{a,*}$	$9.59 \pm 0.39^{a,*}$	$0.89 \pm 0.00^{c,*}$	$5.69 \pm 0.88^{b,*}$
- Glucose (g)	$7.32 \pm 0.67^{a,*}$	$7.22 \pm 0.37^{a,*}$	$0.94 \pm 0.01^{c,*}$	$5.87 \pm 1.16^{b,*}$
- Sucrose (g)	ND	ND	0.23 ± 0.01^{a}	ND
Ash (g)	7.26 ± 0.87^{a}	$4.80 \pm 0.44^{b,*}$	$2.64 \pm 0.04^{c,*}$	$7.94 \pm 1.36^{a,*}$
Vitamin				
- Vitamin C (mg)	$237.19 \pm 11.60^{a,*}$	$197.17 \pm 5.18^{b,*}$	ND	$147.46 \pm 21.16^{c,*}$
Minerals				
- Ca (mg)	$234.80 \pm 6.43^{b,*}$	$230.84 \pm 9.60^{b,*}$	$117.33 \pm 0.59^{c,*}$	$604.08 \pm 57.23^{a,*}$
- P (mg)	413.88 ± 45.01^{b}	416.56 ± 21.54^{b}	$494.30 \pm 17.79^{b,*}$	597.91 ± 78.85^{a}
- Na (mg)	$124.94 \pm 8.14^{ab,*}$	$133.59 \pm 4.14^{a,*}$	$86.78 \pm 2.89^{c,*}$	$111.28 \pm 15.19^{b,*}$
- K (mg)	$1706.05 \pm 225.01^{b,*}$	$2118.86 \pm 132.44^{a,*}$	$470.80 \pm 8.43^{d,*}$	$1313.16 \pm 192.34^{c,*}$
- Mg (mg)	290.52 ± 55.46^{b}	$235.59 \pm 10.45^{b,*}$	$993.27 \pm 77.40^{a,*}$	$83.51 \pm 13.63^{c,*}$
- Fe (mg)	$1.78 \pm 0.05^{b,*}$	0.73 ± 0.08^{d}	$4.58 \pm 0.16^{a,*}$	$1.22 \pm 0.21^{c,*}$
- Zn (mg)	$0.99 \pm 0.05^{b,*}$	$0.85 \pm 0.06^{c,*}$	$3.37 \pm 0.02^{a,*}$	$0.71 \pm 0.12^{c,*}$

All data were expressed as mean ± standard deviation (SD) of triplicate experiments. SDF: soluble dietary fiber; IDF: insoluble dietary fiber; ND: not detected.
$^{a\text{-}d}$showed significant difference ($p \leq 0.05$) of each part within the same sample using one way ANOVA and Duncan's *post hoc* test.
*showed significant difference ($p \leq 0.05$) between *Kadsura coccinea* (Lem.) A.C. Sm. and *Kadsura heteroclita* (Roxb.) Craib (Table 3) using unpaired sample t-test.

2.79–7.92 g (Table 3), while *K. heteroclita* contained 2.64–7.94 g (Table 4). In *K. coccinea*, the exocarp (7.92 g) contained significantly higher ash contents than the mesocarp (6.25 g), core (3.80 g) and seed (2.79 g), respectively. However, results in different fruit parts of *K. heteroclita* suggested that the exocarp (7.26 g) and core (7.94 g) contained significantly highest ash contents, followed by mesocarp (4.80 g) and seed (2.64 g). When comparing between species, the mesocarp and seed of *K. coccinea* contained significantly higher ash contents than in *K. heteroclita*; however, the latter contained significantly higher ash content in core than the former. Nevertheless, no significant differences in ash contents in the exocarp were observed in both species.

3.2.6. Carbohydrate and energy

Energy content of the seed of *K. coccinea* (520.81 kcal) was significantly higher than the mesocarp (410.98 kcal) and exocarp (401.68 kcal), while the core exhibited significantly lowest energy (389.00 kcal) (Table 3). Similar results were observed in different fruit parts of *K. heteroclita*, in which seed exhibited significantly highest energy (636.98 kcal), followed by mesocarp (448.46 kcal), exocarp (385.50 kcal) and core (368.23 kcal) (Table 4). Comparing between species, the exocarp and core of *K. coccinea* possessed significantly higher energy than in *K. heteroclita*. Opposite results were observed in mesocarp and seed, whereby fruit parts of *K. coccinea* possessed significantly lower energy than those of *K. heteroclita.*

Due to low protein and fat contents, the energy in *Kadsura* spp. mainly resulted from carbohydrate. In *K. coccinea*, the core contained significantly higher carbohydrate content (91.23 g) than the exocarp and mesocarp (81.59 and 82.51 g, respectively), while seed contained significantly lowest content (59.87 g). Likewise, exocarp and core of *K. heteroclita* contained significantly higher carbohydrate contents (83.80 and 84.23 g, respectively) than mesocarp (74.94 g) and seed (30.11 g). Additionally, mesocarp, core and seed of *K. coccinea* exhibited significantly higher carbohydrate contents than those of *K. heteroclita*, while the latter contained significantly higher carbohydrate content in the exocarp than the former.

3.2.7. Sugars

Total sugar contents in *K. coccinea* were significantly highest in mesocarp (34.35 g), followed by core (25.74 g), exocarp (15.75 g), and seed (3.25 g) (Table 3). Likewise, exocarp (16.28 g) and mesocarp (16.82 g) of *K. heteroclita* possessed significantly highest total sugar contents, followed by core (11.56 g) and seed (2.05 g) (Table 4). Comparing between the two species, mesocarp, core and seed of *K. coccinea* exhibited significantly higher total sugar contents than *K. heteroclita*, while their exocarps recorded similar contents.

Types of sugar detected in *Kadsura* spp. were fructose, glucose and sucrose. Only fructose and glucose were detected in all fruit parts, while only sucrose was detected in seed. Fructose content in the mesocarp of *K. coccinea* (15.50 g) was significantly higher than in the core (12.23 g), exocarp (10.07 g) and seed (1.61 g). Similar results were observed for glucose, in which mesocarp (13.16 g) and core (13.51 g) exhibited significantly higher contents than exocarp (5.67 g) and seed (1.40 g). Sucrose in *K. coccinea* was detected only in the mesocarp (5.69 g) and seed (0.24 g). On the other hand, mesocarp (9.59 g) and exocarp (8.95 g) of *K. heteroclita* exhibited significantly higher fructose contents than core (5.69 g) and seed (0.89 g). Similar results were observed for glucose contents, whereby mesocarp (7.22 g) and exocarp (7.32 g) exhibited significantly higher contents than core (5.87 g) and seed (0.94 g). Sucrose in *K. heteroclita* was detected only in the seed (0.23 g).

3.2.8. Vitamin C

Water-soluble vitamin C in the exocarp of *K. coccinea* (923.80 mg) was significantly higher than in the mesocarp (550.09 mg) and core (400.39 mg), while none was detected in the seed (Table 3). Similar results were observed in *K. heteroclita,* in which exocarp exhibited significantly highest vitamin C content (237.19 mg), followed by mesocarp (197.17 mg) and core (147.46 mg) (Table 4). Again, none was detected in the seed. Comparing between species, all fruit parts (with the exception of the seed) in *K. coccinea* exhibited significantly higher vitamin C contents than those in *K. heteroclita*.

3.2.9. Minerals

All major minerals (K, P, Mg, Na and Ca) were detected in *K. coccinea* (Table 3 and Table 4). Potassium was found at the highest contents. The exocarp of *K. coccinea* exhibited significantly higher K content (2,406.76 mg) than core (2,236.86 mg), mesocarp (1,673.02 mg) and seed (621.44 mg). However, the mesocarp of *K. heteroclita* exhibited significantly highest K content (2,118.86 mg) than the exocarp (1,706.05 mg), core (1,313.16 mg) and seed (470.80 mg). Comparing between species, the exocarp, seed and core of *K. coccinea* exhibited significantly higher K contents than those of *K. heteroclita.* However, the mesocarp of *K. coccinea* exhibited significantly lower K content than that of *K. heteroclita.*

The second most abundant mineral was phosphorus. The core of *K. coccinea* exhibited significantly highest content at 722.00 mg, followed by exocarp (447.57 mg) and seed (414.14 mg), while the mesocarp exhibited the lowest content at 369.88 mg. Likewise, the core of *K. heteroclita* exhibited significantly higher P content (597.91 mg) than the other fruit parts (413.88–494.30 mg). Comparing between species, the P content in seed of *K. heteroclita* was significantly higher than that of *K. coccinea*, while other fruits parts contained comparable amounts.

The third most abundant mineral as magnesium was found at the highest content in the mesocarp, core and seed of *K. coccinea* (347.12–381.87 mg), while the exocarp exhibited significantly lowest content (258.51 mg). *K. heteroclita* seed contained significantly highest Mg content (993.27 mg), followed by exocarp and mesocarp (235.59–290.52 mg), while the core exhibited the lowest (83.51 mg). Comparing between species, mesocarp and core of *K. coccinea* contained significantly higher Mg contents than those of *K. heteroclita*, while the seed of the latter exhibited significantly higher content than the former. Exocarp Mg contents were similar in both species.

The sodium content in *K. coccinea* suggested that the exocarp (265.34 mg) possessed the highest amount, followed by the mesocarp (208.35 mg), core (147.19 mg) and seed (100.60 mg). However, Na content in the mesocarp of *K. heteroclita* (133.59 mg) was higher than in the exocarp (124.94 mg), core (111.28 mg) and seed (86.78 mg). All fruit parts in *K. coccinea* exhibited significantly higher Na contents than those of *K. heteroclita*.

Interestingly, the calcium content was found to be highest in the core of *K. coccinea* (151.14 mg), followed by the exocarp (127.86 mg), seed (94.45 mg) and mesocarp (81.62 mg). The core of *K. heteroclita* also contained highest Ca content (604.08 mg), followed by exocarp and mesocarp (230.84–234.80 mg), while the seed contained the lowest content (117.33 mg). Interestingly, all fruit parts of *K. heteroclita* exhibited significantly higher Ca contents than those of *K. coccinea.*

Trace elements including iron and zinc were detected in low amounts. The Fe contents in *K. coccinea* ranged 0.67–3.02 mg, while those of *K. heteroclita* were 0.73–4.58 mg. Likewise, the Zn contents in *K. coccinea* ranged 0.33–1.41 mg, while *K. heteroclita* contained 0.85–3.37 mg. The Zn contents in *K. heteroclita* were significantly higher than those in *K. coccinea,* while the Fe contents varied depending on fruit parts.

4. Discussion

Two different *Kadsura* spp. in Thailand, as *K. coccinea* producing larger fruits and *K. heteroclita* producing smaller fruits, exhibited different nutritional contents in each fruit part. Results for nutritional contents suggested that (i) the edible part as the mesocarp contained high contents of dietary fiber and vitamin C but was low in sugar, Na, P, and K, (ii) when comparing the edible part as the mesocarp, *K. coccinea* provided higher sugar and vitamin C than *K. heteroclita*, while the latter contained higher contents of other nutritional elements than the former, (iii) the

Table 5. Nutrient compositions of *Kadsura coccinea* (Lem.) A.C. Sm. (per 100 g fresh weight).

Nutrients	Nutritive values (per 100 g fresh weight)			
	Exocarp	Mesocarp	Seed	Core
Energy (kcal)	30.13 ± 0.95^{d}	32.59 ± 1.39^{c}	247.67 ± 1.00^{a}	34.84 ± 0.16^{b}
Protein (g)	0.29 ± 0.01^{d}	0.32 ± 0.01^{c}	5.21 ± 0.01^{a}	0.37 ± 0.01^{b}
Fat (g)	0.50 ± 0.02^{b}	0.57 ± 0.00^{b}	12.55 ± 0.28^{a}	0.08 ± 0.01^{d}
Carbohydrate (g)	6.12 ± 0.24^{c}	6.55 ± 0.34^{c}	28.47 ± 0.37^{a}	8.17 ± 0.02^{b}
Total dietary fiber (g)	3.05 ± 0.08^{bc}	2.90 ± 0.03^{c}	31.86 ± 1.01^{a}	3.99 ± 0.04^{b}
- SDF (g)	0.97 ± 0.03^{c}	1.28 ± 0.02^{b}	2.21 ± 0.24^{a}	1.15 ± 0.04^{bc}
- IDF (g)	2.09 ± 0.06^{bc}	1.62 ± 0.01^{c}	29.65 ± 0.87^{a}	2.85 ± 0.01^{b}
Total sugar (g)	1.18 ± 0.01^{d}	2.72 ± 0.02^{a}	1.55 ± 0.02^{c}	2.31 ± 0.02^{b}
- Fructose (g)	0.76 ± 0.01^{c}	1.23 ± 0.05^{a}	0.77 ± 0.02^{c}	1.10 ± 0.03^{b}
- Glucose (g)	0.43 ± 0.02^{d}	1.04 ± 0.05^{b}	0.67 ± 0.01^{c}	1.21 ± 0.01^{a}
- Sucrose (g)	ND	0.45 ± 0.01^{a}	0.12 ± 0.01^{b}	ND
Ash (g)	0.59 ± 0.02^{b}	0.50 ± 0.01^{c}	1.33 ± 0.01^{a}	0.34 ± 0.00^{d}
Vitamin				
- Vitamin C (mg)	69.18 ± 3.35^{a}	43.60 ± 1.35^{b}	ND	35.85 ± 0.52^{c}
Minerals				
- Ca (mg)	9.59 ± 0.31^{c}	6.48 ± 0.45^{d}	44.92 ± 0.12^{a}	13.54 ± 0.10^{b}
- P (mg)	33.54 ± 0.36^{c}	29.27 ± 1.05^{c}	196.94 ± 8.10^{a}	64.65 ± 1.69^{b}
- Na (mg)	19.90 ± 0.34^{b}	16.51 ± 0.77^{c}	47.84 ± 0.32^{a}	13.18 ± 1.00^{d}
- K (mg)	180.43 ± 7.37^{c}	132.54 ± 1.42^{d}	295.53 ± 1.39^{a}	200.32 ± 2.44^{b}
- Mg (mg)	19.39 ± 1.21^{b}	27.50 ± 0.19^{b}	181.58 ± 12.87^{a}	32.07 ± 1.37^{b}
- Fe (mg)	0.21 ± 0.00^{b}	0.06 ± 0.01^{c}	1.44 ± 0.09^{a}	0.06 ± 0.00^{c}
- Zn (mg)	0.03 ± 0.01^{b}	0.04 ± 0.01^{b}	0.67 ± 0.05^{a}	0.03 ± 0.00^{b}

All data were expressed as mean ± standard deviation (SD) of triplicate experiments.
$^{a\text{-}d}$showed significant difference ($p \leq 0.05$) of each part within the same sample using one way ANOVA and Duncan's *post hoc* test.
SDF: soluble dietary fiber; IDF: insoluble dietary fiber; ND: not detected.

Table 6. Nutrient compositions of *Kadsura heteroclita* (Roxb.) Craib (per 100 g fresh weight).

Nutrients	Nutritive values (per 100 g fresh weight)			
	Exocarp	Mesocarp	Seed	Core
Energy (kcal)	$39.08 \pm 2.22^{b,*}$	$39.78 \pm 1.59^{b,*}$	$322.38 \pm 0.47^{a,*}$	36.94 ± 6.78^{b}
Protein (g)	$0.61 \pm 0.01^{c,*}$	$0.60 \pm 0.02^{c,*}$	$8.98 \pm 0.06^{a,*}$	$0.77 \pm 0.01^{b,*}$
Fat (g)	$0.30 \pm 0.02^{c,*}$	$1.20 \pm 0.04^{b,*}$	$25.06 \pm 0.02^{a,*}$	ND
Carbohydrate (g)	$8.50 \pm 0.52^{b,*}$	6.65 ± 0.32^{c}	$15.24 \pm 0.09^{a,*}$	8.46 ± 1.69^{b}
Total dietary fiber (g)	$6.23 \pm 0.16^{c,*}$	$5.22 \pm 0.06^{d,*}$	$17.23 \pm 0.11^{a,*}$	$8.01 \pm 0.05^{b,*}$
- SDF (g)	$1.32 \pm 0.02^{b,*}$	$1.17 \pm 0.05^{c,*}$	2.32 ± 0.04^{a}	$0.74 \pm 0.02^{d,*}$
- IDF (g)	$4.91 \pm 0.14^{c,*}$	$4.05 \pm 0.07^{d,*}$	$14.92 \pm 0.08^{a,*}$	$7.27 \pm 0.02^{b,*}$
Total sugar (g)	$1.65 \pm 0.01^{a,*}$	$1.49 \pm 0.03+$	$1.04 \pm 0.01^{d,*}$	$1.14 \pm 0.01^{c,*}$
- Fructose (g)	$0.91 \pm 0.03^{a,*}$	$0.85 \pm 0.02^{b,*}$	$0.45 \pm 0.00^{d,*}$	$0.56 \pm 0.01^{c,*}$
- Glucose (g)	$0.74 \pm 0.03^{a,*}$	$0.64 \pm 0.01^{b,*}$	$0.48 \pm 0.01^{d,*}$	$0.58 \pm 0.02^{c,*}$
- Sucrose (g)	ND	ND	0.12 ± 0.01^{a}	ND
Ash (g)	$0.73 \pm 0.06^{b,*}$	$0.43 \pm 0.03^{c,*}$	1.34 ± 0.03^{a}	$0.78 \pm 0.00^{b,*}$
Vitamin				
- Vitamin C (mg)	$24.05 \pm 1.87^{a,*}$	$17.49 \pm 0.74^{b,*}$	ND	$14.53 \pm 0.41^{c,*}$
Minerals				
- Ca (mg)	$23.78 \pm 0.70^{b,*}$	$20.47 \pm 1.02^{b,*}$	$59.38 \pm 0.11^{a,*}$	$60.18 \pm 9.15^{a,*}$
- P (mg)	$41.83 \pm 3.27^{c,*}$	$36.94 \pm 2.27^{c,*}$	$250.19 \pm 9.80^{a,*}$	$59.00 \pm 2.40^{b,*}$
- Na (mg)	$12.64 \pm 0.27^{b,*}$	$11.84 \pm 0.14^{b,*}$	$43.92 \pm 1.60^{a,*}$	11.02 ± 1.29^{b}
- K (mg)	172.16 ± 15.20^{b}	$187.67 \pm 5.59^{b,*}$	$238.28 \pm 5.02^{a,*}$	$129.35 \pm 3.27^{c,*}$
- Mg (mg)	$29.28 \pm 4.45^{b,*}$	$20.92 \pm 1.65^{b,*}$	$502.65 \pm 38.29^{a,*}$	$8.21 \pm 0.07^{b,*}$
- Fe (mg)	$0.18 \pm 0.01^{b,*}$	0.07 ± 0.01^{c}	$2.32 \pm 0.09^{a,*}$	$0.12 \pm 0.00^{bc,*}$
- Zn (mg)	$0.10 \pm 0.00^{b,*}$	$0.08 \pm 0.01^{c,*}$	$1.71 \pm 0.01^{a,*}$	$0.07 \pm 0.00^{c,*}$

All data were expressed as mean ± standard deviation (SD) of triplicate experiments. SDF: soluble dietary fiber; IDF: insoluble dietary fiber; ND: not detected.
$^{a\text{-}d}$showed significant difference ($p \leq 0.05$) of each part within the same sample using one way ANOVA and Duncan's *post hoc* test.
*showed significant difference ($p \leq 0.05$) between *Kadsura coccinea* (Lem.) A.C. Sm. and *Kadsura heteroclita* (Roxb.) Craib (Table 5) using unpaired sample t-test.

exocarp provided lower sugar but higher vitamin C and dietary fiber contents than the mesocarp, and (iv) the seed contained higher energy as well as protein and fat contents than the other fruit parts. When compared with previous results in the literature, the nutritional contents of *Kadsura* spp. were discussed as per 100 g fresh weight (FW) (Table 5 and Table 6).

Even though the mesocarp contained lower protein, fat, and dietary fiber contents than the seed, it is the only commonly consumed fruit part. This edible portion possessed low energy (33–40 kcal/100 g edible FW) due to a large portion of non-energy components such as moisture content (91–92%). Compared with other fruits, *Kadsura* spp. expressed lower energy than dragon fruit, green grapes, Indian gooseberry, mangosteen and manila tamarind (56–80 kcal/100 g edible FW) (Judprasong et al., 2015). In addition to high moisture content, the low energy observed in *Kadsura* spp. resulted from low protein and fat contents (0.32–0.60 g protein and 0.57–1.20 g fat/100 g edible FW). These protein and fat contents were significantly lower than those reported in Chinese *K. coccinea*, which contained 3.1 g protein and 19 g fat/100 g FW (Sun et al., 2011). These extremely different results from our report were possibly caused by both internal factors (i.e., time of harvesting and stage of maturity) and external factors (i.e., cultivated location, climate and soil type). Consequently, the energy of *Kadsura* spp. was mainly contributed from total carbohydrates (approx. 67–80% of total energy). In the total carbohydrates, 44–78% comprised dietary fibers consisting of soluble and insoluble forms. Soluble dietary fibers form a gel-like substance when dissolved in water and can be fermented by the gut bacteria, while insoluble dietary fibers can increase food substance movement along the digestive tract (Trompette et al., 2014). Dietary fibers are complex carbohydrates that play important roles in promoting gastrointestinal health benefits as prebiotics (Slavin, 2013; Holscher, 2017). Dietary fibers were previously reported to reduce the risk of colon cancer and coronary heart disease (CHD), including hypercholesterolemia, hypertension, obesity and diabetes (type 2) (Sánchez-Muniz, 2012; Trompette et al., 2014). When comparing the recommended amount of dietary fiber intake per day of 25 g (Wong and Jenkins, 2007), *Kadsura* spp. contained 2.90–5.22 g per 100 g edible FW, equating to 11.6–20.9% recommended dietary fiber. Comparably, *Kadsura* spp. contained higher dietary fiber than toddy palm, passion fruit, guava, mango, green and red apples, orange, papaya and pomelo (1.51–5.03 g per 100 g edible FW) (Judprasong et al., 2015) that are considered as fiber-rich fruits. Among total dietary fibers, the insoluble form was significantly higher than the soluble form. This result corresponded to previous reports stating that most fiber resided in food as one-third soluble and two-thirds insoluble forms (Wong and Jenkins, 2007). In addition, total sugar contents of *Kadsura* spp. were extremely low (1.49–2.72 g per 100 g edible FW). Sugar contents were even lower than well-known low sugar fruits including jujube apple, red dragon fruit, red-flesh watermelon, Chinese pear, green apple, star fruit and wild cherry (8–11 g per 100 g edible FW) (Judprasong et al., 2015).

Another factor supporting *Kadsura* spp. as a healthy fruit was the vitamin C content. Compared to 60 mg as the recommended amount of vitamin C per day by the Thai Dietary Reference Intakes (DRIs), *K. coccinea* expressed 73% vitamin C (43.60 mg per 100 g edible FW), a similar amount to star gooseberry, jujube apple, manila tamarind and raspberry with 5–40 mg vitamin C per 100 g FW (Judprasong et al., 2015; Skrovankova et al., 2015). The amount of vitamin C detected in *K. heteroclita* (17.49 mg per 100 g edible FW) was similar to that detected in Malay apple, tangerine orange and wild cherry (15–20 mg per 100 g edible FW) (Judprasong et al., 2015). Furthermore, *Kadsura* spp. collected in Thailand contained significantly higher vitamin C content than *K. coccinea* from China (3.3 mg ascorbic acid per 100 g FW) (Sun et al., 2011). Other than internal and external factors as indicated above, these extremely different results from our report were possibly caused by different methods used for measurement. Ascorbic acid content detected in Chinese *K. coccinea* was evaluated using a reagent kit from Jiancheng Bioengineering Institute in China, while the ones detected in our *Kadsura* spp. used a more sensitive HPLC analysis.

Apart from low protein, trace electrolytes were detected in *Kadsura* spp. including Na (11.84–16.51 mg per 100 g edible FW), P (29.27–36.94 mg per 100 g edible FW) and K (132.54–187.67 mg per 100 g edible FW). Therefore, *Kadsura* spp. was a suitable fruit for electrolyte-limited consumers under chronic kidney disease (CKD). Compared with Chinese *K. coccinea* at 3.80 mg of Ca and 0.57 mg of P per g FW (Sun et al., 2011), lower amounts of Ca (6.48–20.47 mg per 100 g edible FW) and P (29.27–36.94 mg per 100 g edible FW) were found in Thai *Kadsura* spp. On the other hand, *Kadsura* spp. exhibited similar Na content as green grapes, guava and fruit stars and similar K content as green apple, strawberry and pear with similar P content as jambolan plum, sugar apple and cherry (Judprasong et al., 2015).

When considering nutritional contents in the mesocarp, *K. coccinea* provided higher sugar and vitamin C contents than *K. heteroclita*, while the latter contained higher contents of other nutritional contents than the former. *K. coccinea* showed remarkably high vitamin C (up to 73% recommended per day), while sugar content was considered low (5.4% recommended per day). High vitamin C in fruit juice with low calorie and sugar content can be advantageous for future product development from the mesocarp of *K. coccinea*. Additionally, the mesocarp of *K. heteroclita* contained highly beneficial nutritional contents, especially dietary fibers (20.9% recommended dietary fiber). Fiber bars may be a food application of interest, since these are suitable for individuals on a dietary regimen to consume as a snack.

The exocarp of *Kadsura* spp. provided lower sugar but higher vitamin C and dietary fiber contents than the mesocarp. For sugar content, our results corresponded to previous studies, suggesting that fruit peel contained lower sugar content than its flesh (Pereira et al., 2017; Saidani et al., 2017; Khajehei et al., 2018). For example, banana pulp presented 3.4 times higher sugar content than banana peel (Pereira et al., 2017), while the pulp of yellow-flesh peach fruit contained 1.7 times higher sugar content than its peel (Saidani et al., 2017). Greater sugar content in the pulp might be a result of starch accumulation becoming sugars such as glucose, fructose and sucrose through enzymatic hydrolysis when ripening (Emaga et al., 2007; Der Agopian et al., 2011). On the other hand, the exocarp of *Kadsura* spp. provided higher vitamin C than its mesocarp. Our results concurred with previous reports suggesting that peach peel exhibited 1.8 times higher vitamin C than its pulp (Liu et al., 2015). Similar results were also observed in *Annona cherimola* Mill. fruit, orange, lemon and grapefruit (Albuquerque et al., 2016; Sir Elkhatim et al., 2018). Moreover, many researchers stated that dietary fiber was contained in the peel at a greater amount than in the pulp for various fruits such as avocado, pineapple, banana, papaya, passion fruit, watermelon, melon, cactus pear, and buriti fruit (Morais et al., 2017; Jime'nez-Aguilar et al., 2015; Resendea et al., 2019). With low sugar but high dietary fiber, the exocarp of *Kadsura* spp. can be developed as a functional ingredient in many high fiber food products such as bakeries, noodles and healthy snacks, suitable for weight-conscious consumers. However, the high vitamin C content will provide benefits when the exocarp is consumed in the fresh form and not processed. Thus, juice made from the exocarp of *Kadsura* spp. with high vitamin C can be produced as a healthy drink.

Furthermore, the seed of *Kadsura* spp. contained higher energy as well as protein and fat contents than other fruit parts. Similar results were observed in the seeds of sweet orange (*Citrus sinensis*) that demonstrated higher protein and fat contents than its peel (Egbuonul and Osuji, 2016). Protein and fat contents in seeds of papaya, passion fruit, watermelon and melon were also higher than in pulp and peel (Morais et al., 2017). Since seed contains high protein and fat contents (the major components of energy), it also provides high energy. These properties are commonly found in seed because part of its biological function is to provide the essential nutrients for seedling growth from embryo to bud (Bradford and Nonogaki, 2007). This high protein and fat content of seed of *Kadsura* spp. can be developed as a functional ingredient in energy-providing food products for athletes or those who need energy for daily workouts.

5. Conclusion

K. coccinea and *K. heteroclita* as two species of the genus *Kadsura* found in Northern Thailand have high dietary fiber and vitamin C contents with low energy, protein, sugar and electrolytes. This information supports the potential consumption of *Kadsura* spp. as a suitable optional fruit for health-conscious individuals. Knowledge gained from this research will be useful for the industrial sector for future development of nutritive species and new products from many parts of *Kadsura* spp. Furthermore, our results can be used to generate future innovative products and potentially lead to the sustainable conservation of the almost extinct *Kadsura* spp. and, thereby, accomplish the ultimate goal of the RSPG. Nutrient components, bioactive compounds and varieties of biological properties such as phytochemical contents, antioxidant activity and medicinal capability against non-communicable diseases should also be studied with regard to *Kadsura* species in the future.

Declarations

Author contribution statement

Varittha Sritalahareuthai: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Amornrat Aursalung: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Nattira On-nom, Piya Temviriyanukul: Conceived and designed the experiments; Analyzed and interpreted the data.

Somsri Charoenkiatkul: Conceived and designed the experiments; Wrote the paper.

Uthaiwan Suttisansanee: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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