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Research

Compositional Characteristics and Nutritional Quality of Indigenous Fruit of *Artocarpus odoratissimus* Blanco

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ABSTRACT

Artocarpus odoratissimus, locally known as terap, is native to Borneo and holds great potential for providing nutrition and income to rural communities. The fruit's flesh is consumed raw, while the seeds are typically steamed and used in local dishes. The by-products, such as the pedicel and peel, often go to waste. This indigenous species has yet to be fully explored for its nutritional and phytochemical properties. Hence, the present study aims to evaluate the nutritional compositions and phytochemical properties of *A. odoratissimus* fruit. The nutritional and phytochemical properties of *A. odoratissimus* vary across its parts. The edible flesh and seeds exhibited higher carbohydrate content at 12.16±1.01% and 9.96±0.76%, respectively. Seeds possessed significantly higher crude protein (21.89±0.54%) and fat (18.23±0.20%). In contrast, the non-edible parts of the peel (5.57±0.11%) and pedicel (5.79±0.41%) exhibit considerably greater ash content than their edible counterparts in the flesh (3.87±0.42%) and seeds (0.62±0.29%). Potassium (905.61±18.89 to 2001.51±13.00 mg 100 g^{-1}) was the most abundant in *A. odoratissimus* fruits, followed by calcium (578.30±7.00 to 1300.97±23.51 mg 100 g^{-1}). The flesh is primarily composed of non-reducing sugars, including fructose (26.70±0.70 g 100 g^{-1}) and glucose (25.38±0.45 g 100 g^{-1}), with a notable amount of vitamin B1 (11.07±0.31 mg 100 g^{-1}). The seed oil contains essential fatty acids, with a significant proportion of unsaturated fatty acids (57.10%), mainly nervonic acid (45.32%). The pedicel, often considered a by-product, exhibits relatively high levels of phytochemical properties in comparison to the edible portions. The current findings support the ethnobotanical uses of *A. odoratissimus* by local communities, underscoring its growing importance in the nutraceutical and pharmaceutical industries.

Key words: *Artocarpus*, indigenous fruit, product development, phytochemical, utilization

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INTRODUCTION

Borneo is recognized as the land of diversity and a rich heritage of flora, as it is the widest island in the world. Sarawak, one of the parts of Borneo Island, is enriched with bountiful biodiversity consisting of approximately 3000 plant species (Soepadmo & Chung, 1997; FPP, 2020). This tropical rainforest is abundant in the diversity of beneficial indigenous plants, with some species being uniquely endemic to Sarawak, numbering around 200 as per available records. In the broader context, fruits and vegetables native to an area and/or utilized in connection with tradition and culture are considered indigenous and traditional food crops (Cloete & Idsardi, 2013). Various ethnicities and indigenous people have previously exploited the naturally available indigenous plants for various purposes (Ismail *et al*., 2023). Elders passed down their knowledge of native or wild plants since they were more knowledgeable than younger people, giving people in rural areas access to a variety of fruits and vegetables for their meals (Matenge *et al*., 2011; Shahrir *et al*., 2013). Through exchanges of ethnobotanical knowledge and information among the communities in Sarawak, locals and tourists alike can now enjoy the goodness of these remarkable plants.

About 152 indigenous species comprised of mushrooms, vegetables, fruits, nuts, herbs, and medicinal plants were recorded in Sarawak. This has been compiled in a book entitled 'Edible wild plants in Sarawak' published in 2013 (Det *et al*., 2013). Remarkably, the Department of Agriculture (DOA) Sarawak, with the capable stewardship of the Agriculture Research Centre Semongok, has taken up the mantle of conserving approximately 80 indigenous fruit species. The arboretum in Layar Integrated Agriculture Station at Betong has been harnessed to protect and preserve these invaluable indigenous fruit species indigenous to Sarawak. Notably, *Canarium odontophyllum* (dabai), S*olanum lasiocarpum* (terung Asam), *Mangifera pajang* (embang), *Artocarpus odoratisimmus* (terap), *Durio kutejensis* (nyekak), and *Durio graveolens* (isu) were the most promising indigenous fruits that were actively researched. These indigenous fruits have not only been found to be economically viable but also possess the potential for large-scale cultivation.

Artocarpus odoratissimus Blanco, also known as terap, is an indigenous fruit species predominantly found on Borneo Island, which encompasses Sarawak, Sabah, Brunei, Kalimantan, and even extends to the Philippines (Tang *et al*., 2013; Ragasa *et al*., 2014; Gardner *et al*., 2022). Terap fruits have a strong aroma where their scent comes mainly through their peel which could remind people of durian (Bakar & Bakar, 2018). In particular, the fruit availability season lies between August to October and December and January, gaining visibility in the local fruit industry (Goh *et al*., 2023). This indigenous fruit is an important source of food and nutrition and secures the livelihoods of rural farming communities. The ripened fruit is popular for its sweet and juicy flesh and is suitable for raw consumption or making flitters (Tang *et al*., 2013). Furthermore, the seeds of *A. odoratissimus* offer a nutty flavor and can be consumed after roasting and boiling to attain a delightful texture (Lim, 2012). This fruit is enriched with secondary metabolites such as phenolic compounds, and phytochemicals, with the peel particularly displaying remarkable antioxidant activity (Bakar *et al*., 2015). The non-edible parts of *A. odoratissimus*, including its roots, which are employed by Iban communities to combat diarrhea, and its leaves, utilized to treat ailments like gout, fever (Naspiah & Pratama, 2021) and venomous stings of centipede and scorpion (Lim, 2012), hold potential for medicinal use.

Researchers have delved into the nutritional and phytochemical properties of the more common and commercial *Artocarpus* fruits, i.e., *A. heterophyllus* (Thapa *et al*., 2016; Amadi *et al*., 2018; Sulaiman, 2019), *A. altilis* (Turi *et al*., 2015; Soifoini *et al*., 2021) and *A. integer* (Pui *et al*., 2018; Gopinathan *et al*., 2020). However, more attention has recently been drawn to other lesser-known *Artocarpus* species, particularly *A. odoratissimus*. There is little research briefly studied on the properties of *A. odoratissimus* edible parts (Bakar *et al*., 2009; Tang *et al*., 2013; Noorfarahzilah *et al*., 2017). While traditional uses of *A. odoratissimus* have been linked to numerous health benefits, these assertions necessitate validation through scientific investigation. Hence, the present study aims to evaluate the nutritional and phytochemical properties of *A. odoratissimus* fruit parts. A comprehensive understanding of the composition of A. odoratissimus fruit will pave the way for its full-scale cultivation and the development of an array of commercial products.

MATERIALS AND METHODS

Survey and sampling location

The fully ripened fruits were collected during the fruiting season from June 2019 to January 2020 in Pasar Tamu Bintulu (3.1705˚N, 113.0405˚E), Sarawak. The fruits were then brought to the laboratory, inspected, and cleaned. The flesh, seeds, peel, and central core were separated and divided into three divisions. Fresh samples were used for the determination of moisture content in the fruit. Oven-dried samples were used to determine the proximate, mineral, and fatty acid contents. Freeze-dried samples were used to evaluate the vitamins and phytochemical compositions of the fruits. All the processed samples were kept in an airtight container before analyses.

Morphological description of *Artocarpus odoratissimus*

The quantitative characteristics of the fruits of *A. odoratissimus* were measured and recorded. The parameters of the fruits include the fruit weight (g) measured with a weighing scale, the fruit length (cm), the fruit diameter (cm) measured with a measuring tape and a ruler, and the seed length and width (mm) measured with a Vernier caliper. The morphology features of *A. odoratissimus* plant are shown in Figure 1.

Determination of proximate composition in *Artocarpus odoratissimus*

The proximate content of *A. odoratissimus* fruit parts was determined using standard protocols of the Association of Official Analytical Chemists (AOAC, 2000). The oven-drying method determined moisture content until the sample reached a constant weight. The ash content was determined by incinerating air-dried samples in a muffle furnace for 5-6 h at 550 °C (method 930.05). The crude protein was calculated using Kjeldhal's method by multiplying the nitrogen value by 6.25 (method 955.04). The crude lipid of the fruit parts was determined using the Soxtec Avanti Manual System (method 920.39). The crude fiber was distinguished using acid-base digestion following method 993.19. The amount of available carbohydrates was estimated by subtracting the total sum of crude protein, crude lipid, ash, and moisture from a 100% dry weight (DW) basis.

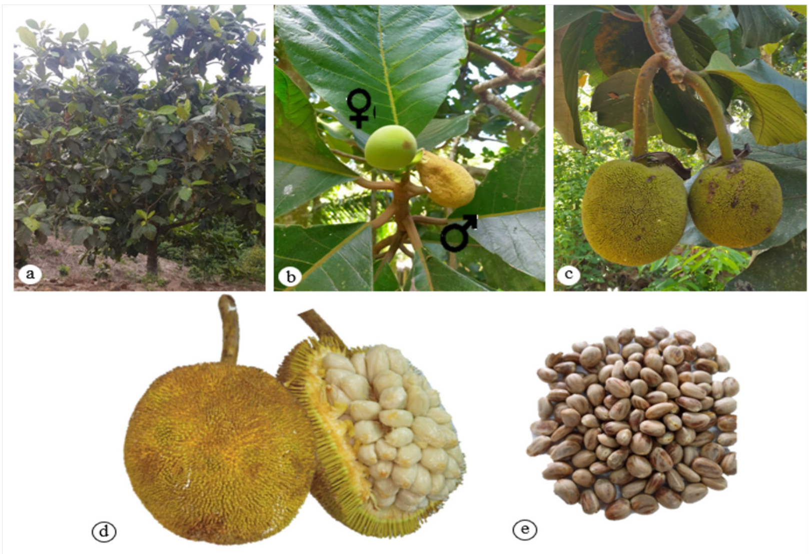

Fig. 1. The morphology of *Artocarpus odoratissimus* plants. (a) The tree, (b) male and female flowers, (c) young fruits, (d) ripe fruit with cross-sectional view, and (e) the seeds

Determination of mineral content in *Artocarpus odoratissimus*

The ash obtained was used to extract the minerals using the dry ashing method following the AOAC (2000). The macromineral elements, potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg), concentration were determined by atomic absorbance spectrophotometer (AA800 PerkinElmer, Germany based on method 975.03) with each determination performed in triplicate. Phosphorus (P) was determined by colorimetric method using a UV-VIS spectrophotometer.

Determination of vitamin content in *Artocarpus odoratissimus*

The flesh samples were freeze-dried and grounded before analysis. Water-soluble vitamins (B-complex) and fat-soluble vitamins (A, D, E, & K) were extracted according to a modified method by Sami *et al*. (2014) and were determined using high-performance liquid chromatography (method 974.29, AOAC, 2000). Chromatographic separation was performed using a reversed-phase (RP) C18 column (Sami *et al*., 2014). Vitamin compounds in the flesh were identified by comparing their retention times with standard sugars and quantified by peak area measurement using Waters Empower Pro software. Ascorbic acid content was determined by Indophenol titration method 967.21 (AOAC, 2000).

Sugar analyses of *Artocarpus odoratissimus* flesh

The sugar content in the flesh of *A. odoratissimus* was determined following the protocol by Ramaiya *et al*. (2013). Five (5 mL) of the flesh was centrifuged at 2500 × *g* for 5 min and at 20 000 × *g* for another 10 min. It was then diluted at a ratio of 1 to 50 with filtered ultrapure water with 0.0001 mol L^{-1} calcium ethylenediaminetetraacetic acid as a mobile phase and was kept refrigerated at 4 °C before analysis. All juices were filtered through a 0.45 µm pore size membrane filter, and 10 µL were used per injection. The soluble sugars were separated by using the complete HPLC system (Waters Corp., Milford, MA, USA) equipped with ion exclusion chromatography Sugar-Pak I column. The 6.5 × 300 mm Sugar-Pak I column was packed with a micro-particulate cation-exchange gel in calcium form. By comparing the retention period of sugar compounds in the flesh to standard sugars, the sugar compounds in the flesh were identified, and their peak area was measured using Waters Empower Pro software.

Fatty acid profiling of *Artocarpus odoratissimus* seed oil

The seed oil was extracted using the Soxtec solvent extraction technique with petroleum ether as the solvent. The extracted oil was kept in a sealed dark bottle glass and stored at 4 °C before analysis. The composition of fatty acids in the seeds of *A. odoratissimus* was determined following method 989.05 (AOAC, 2000). A gas chromatography (GC) capillary column was used to determine the fatty acid composition of the seeds by their fatty acid methyl esters (FAME). The setup and condition for the determination of FAME content with GC were performed according to the protocol by Nzikou *et al*. (2009). The peaks of FAME were identified by comparing their retention time with standards.

Determination of phytochemical properties of *Artocarpus odoratissimus* fruit parts

The fruits were freeze-dried at -74 °C at a vacuum of 150-200 mbar to a constant mass for 48 h. The extraction method follows Ramaiya *et al*. (2021) with slight modification. One (1 g) of samples was extracted with 100 mL of 80% methanol for two days at room temperature on an orbital shaker set at 200 rpm and filtered. The filtered solution was then used to determine total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activities.

Total phenolic content (TPC) was quantified spectrophotometrically using Folin-Ciocalteu's reagent following the protocol by Ramaiya *et al*. (2021). The absorbance was measured at 765 nm, and the results were calculated using the gallic acid calibration curve. The total phenolic content was expressed as mg GAE g^{-1} dried extract. The total flavonoid content (TFC) was determined spectrophotometrically at 510 nm following Ramaiya *et al*. (2021) protocol with slight modifications, and a calibration curve was constructed using standard quercetin and the total flavonoid content was expressed as mg QE g^{-1} dried extract. The Ferric Reducing Antioxidant Power (FRAP) Assay was assessed following Benzie and Strain (1999) protocol with slight modifications where the calibration standard curve was determined by using Trolox with standards ranging from 1 to 4 µg. The scavenging activity of the *A. odoratissimus* extracts was determined by using 2, 2-diphenyl-1-picrylhydrazyl (DPPH) as a free radical assay. Scavenging activity on DPPH was assessed according to the method by Ramaiya *et al*. (2021), and the absorbance was read at 517 nm using a UV-VIS spectrophotometer. The EC_{50} values of the extracts and standard Trolox were calculated by plotting the percentage inhibition versus concentration graph.

Statistical analysis

Mean, standard error, and range were determined in triplicates. SAS 9.4 Windows software was used to statistically analyze the fruit proximate content, minerals, vitamins, sugars, fatty acids, and phytochemicals data (SAS, Buckinghamshire, UK). Means were compared using single-factor ANOVA. Post-hoc Tukey's test (p<0.05) was performed if the ANOVA result was significant. The EC_{50} values for TAA were calculated by linear regression analysis.

RESULTS AND DISCUSSION

Morphological properties of *Artocarpus odoratissimus*

The morphological features of *A. odoratissimus* fruits are presented in Table 1. The weight of *A. odoratissimus* ranged from 1.00 to 1.56 kg, which is similar to the findings of Tang *et al*. (2013) in Brunei, where the reported weight spanned from 0.5-1.0 kg depending on the size. The diameter of *A. odoratissimus* fruits ranged from 40.0 to 48.5 cm, with a length ranging between 12.0 to 17.8 cm. Categorization based on fruit size, as documented by the Philippine National Standard (2013), reveals that fruits weighing between 1.00 to 1.50 kg are considered small, those between 1.50 to 2.00 kg fall into the medium-sized category, and larger fruits weighing in the range of 2.001 to 3.0 kg. The number of seeds per fruit ranged from 90-172 seeds which is in line with a prior study that reported an average of 100 seeds per edible fruit (Tang *et al*., 2013). The length and width of seeds and flesh were 12.18-17.20 × 8.32-13.50 mm and 20.60-32.54 × 11.30- 20.42 mm, respectively. The peel (47%) made up the majority of the fruit, followed by the flesh (30%), pedicel (13%), and seed (10%). A total of 40% of the mass is considered edible, with the remaining 60% being a by-product of this fruit. The fruit of *A. odoratissimus* has bristles on its peel, as well as small, greenish-yellow spines and soft yellowish-white flesh linked to the central core. This is comparable with *A. integer,* which had smooth or spiky peel divided into small hexagons and a green, yellow, or brown color with golden yellow to orange flesh (Lim *et al*., 2011).

Proximate compositions of *Artocarpus odoratissimus* fruit

Fruits play a pivotal role in ensuring food and nutrition security as well as promoting a healthy lifestyle for both current and future generations (Rejman *et al*., 2021). Consuming fruits and vegetables has been shown to improve life expectancy, mental and cardiovascular health, cancer risk, and body weight management. Fruits and vegetables contain phytochemicals, dietary fiber, minerals, and vitamins, among other vital components (Kaparapu *et al*., 2020). Beyond commercially cultivated fruits, indigenous fruit varieties hold the potential to provide a reliable and nutritious food source, particularly for rural communities. *Artocarpus odoratissimus* is highly valued for its aromatic and sweet juicy flesh. According to Tang *et al*. (2013), unripe fruits are commonly cooked with spices and coconut milk, while ripe fruits are consumed raw, and the seeds can be roasted. The proximate composition of *A. odoratissimus* fruit parts is presented in Table 2. The proximate composition of *A. odoratissimus* fruit parts was comparable with other *Artocarpus* species such as *A. heterophyllus* (jackfruit), *A. integer* (cempedak), *A. altilis* (breadfruit) and *A. camansi* (breadnut). In general, all parts of the A. odoratissimus fruit exhibited higher moisture content and lower fiber content, with the central core displaying a moderate fiber content. The proximate composition, presented as percentages, for A. odoratissimus flesh followed the order of moisture > protein > carbohydrate > ash > fat > fiber, while the seed composition followed the order of moisture > protein > fat > carbohydrate > ash > fiber.

Table 1. Measurements and mass composition of *Artocarpus odoratissimus* fruit

Parameters		Measurements	Mass composition (%)
Peel	Weight (g)	585.49±99.57 (460.58-700.11)	47
Pedicel	Weight (g)	160.48±35.46 (100.85-207.10)	13
Flesh	Weight (g)	370.91±77.23 (240.11-440.87)	30
	Length (mm)	26.29±2.12 (20.60-32.54)	
	Width (mm)	26.29±2.12 (11.30-20.42)	
Seed	Weight (g)	111.86±10.35 (100.44-120.15)	10
	Length (mm)	15.64±0.71 (12.18-17.20)	
	Width (mm)	10.77±1.16 (8.32-13.50)	

Values are expressed as mean±standard deviation and values in brackets are the range

Findings showed that higher moisture content was recorded in the central core of *A. odoratissimus* at 84.12±0.62%, and the flesh followed this at 75.90±0.75%. The moisture content of *A. odoratissimus* flesh was comparable with other *Artocarpus* species, such as *A. heterophyllus* at 86.93% (Amadi *et al*., 2018), *A. integer* with 62.30-73.4% (Lim *et al*., 2011) and *A. camansi* at 86.2% (Rabeta & Syafiqah, 2016). Moisture is a critical component in fruits, playing a role as a solvent and facilitating various metabolic processes, ultimately contributing to the overall quality and stability of fruits. The energy value for fruits was inversely proportional to the moisture content available (Zaragoza, 2015). The by-products of the fruit (peel and central core) exhibited significantly higher ash content, with 5.57±0.11% and 5.79±0.41%, respectively. This amount was followed by the flesh (3.87±0.42%) and seeds (0.62±0.29%). The ash content of the central core of *A. odoratissimus* was five times higher than the central core of *A. camansi* (1.12%), as reported by Rabeta and Syafiqah (2016). This higher ash content in the peel and central core suggests their richness in various minerals, making them potentially valuable for the production of diverse products, including food and feed applications.

Artocarpus species are renowned for being rich in protein content. In a study conducted by Liu *et al*. (2015), *A. altilis* was found to have a significantly greater concentration of essential amino acids than other staple crops, positioning it as a promising source of high-quality protein. Similarly, *A. odoratissimus* fruit could also be an alternative source of protein for rural people. The seeds of *A. odoratissimus* possessed significantly ($p<0.05$) higher amounts of crude protein valued at 21.89±0.54% compared to other fruit parts. The flesh contained 14.59±0.19% of crude protein, which was approximately two times higher than the protein content in the peel (5.59±0.37%). According to Bakar & Bakar (2018), the level of maturity and the growing environment impact the crude protein content of the *A. odoratissimus* fruit and seeds. Comparable findings of higher crude protein content in seeds have been reported for several *Artocarpus* species, including *A. heterophylus* (10.09%; Amadi *et al*., 2018); *A. integer* (9.9-11.2%; Lim *et al*., 2011); and *A. altilis* (8.12%); (Tukura & Obliva, 2015). In contrast, the central core of *A. odoratissimus* exhibited the lowest protein content at 0.18±0.10%, and *A. camansi* at 0.17% (Rabeta & Syafiqah, 2016). Protein plays a fundamental role in the diet, supplying the essential amino acids necessary for the synthesis of new proteins (Baum *et al*., 2020).

Lipids and fats in foods serve roles in providing carotenoids, and energy, and aiding in the absorption and transport of fat-soluble vitamins in the intestines (Calder, 2015). The seeds of *A. odoratissimus* possessed a higher crude fat content at 18.23±0.20%, significantly exceeding the fat content in the peel (2.30±0.39%), central core (0.25±0.16%), and flesh (0.26±0.09%). This aligns with the findings of Noorfarahzilah *et al*. (2017), who reported a fat composition of 15.60%, albeit slightly lower than the value observed in this study. The lowest fat content was detected in the flesh of *A.*

odoratissimus, which was approximately nine times lower than the fat composition in the flesh of *A. integer* (2.40-3.50%; Lim *et al*., 2011) and *A. altilis* (2.36%; Appiah *et al*., 2011). The crude fat content of *A. odoratissimus* flesh (0.26±0.09%) was four to five times less than that of *A. camansi*-1.06% (Rabeta & Syafiqah, 2016) and *A. heterophyllus*-1.49% (Amadi *et al*., 2018). Fruit with lower fat content could be included in diets that help to lose weight (Zaragoza, 2015). Dietary fiber, which is a component of plant material that resists enzymatic digestion, is vital in the diet (Dhingra, 2012). The amount of crude fiber in the central core of *A. odoratissimus* was higher (1.24±0.22%) than the peel (0.65±0.04%), seeds (0.05±0.003%), and flesh (0.03±0.01%). The amount of crude fiber in the flesh and seeds was relatively lower than the reported values of 0.90-1.13% (Tang *et al*., 2013) and 12.30% (Noorfarahzilah *et al*., 2017), respectively. The amount of crude fiber in the flesh of *A. odoratissimus* was the lowest as compared to the flesh of *A. heterophyllus* (3.01%) (Amadi *et al*., 2018), *A. integer* (4.6-7.6%) (Lim *et al*., 2011), *A. camansi* (2.13%) (Rabeta & Syafiqah, 2016) and *A. altilis* (3.12%) (Appiah *et al*., 2011).

Artocarpus fruits are valued for their carbohydrate richness and are often referred to as "poor man's food" in certain regions (Prakash *et al*., 2009). *Artocarpus altilis* is regarded as a superfood (Kassia *et al*., 2022) due to its exceptionally high carbohydrate content in both the flesh, with values reaching 79.24% (Appiah *et al*., 2011) and 72.66% (Tukura & Obliva, 2015), respectively. The carbohydrate content in the flesh and seeds of *A. odoratissimus* were 5.35±0.13% and 9.96±0.45%, respectively.

The value obtained experimentally was lower than that reported in a previous study where flesh was 12.0-25.2% (Tang *et al*., 2013), while the seed may exhibit a carbohydrate content as high as 49.65% (Noorfarahzilah *et al*., 2017). The by-products of *A. odoratissimus*, hold substantial value not only for human consumption but also for their potential utilization in animal feed formulation. Among the vital nutrients essential for poultry diets, are protein and carbohydrates. The peel boasts a carbohydrate content of 12.16±1.01%, while the central core contains 8.08±0.98% carbohydrates. A comprehensive analysis could further delve into the presence of non-starch polysaccharides (NSP) and free sugars within the peel and central core of this fruit. The substantial content of carbohydrates and protein in these by-products positions them as highly suitable ingredients for feed formulation, particularly for poultry diets.

Mineral contents of *Artocarpus odoratissimus* fruit

According to Cena *et al*. (2020), dietary minerals raise concern for health specialists and consumers due to the number of processes they engage in the ongoing research that highlights the benefits of their adequate and balanced intake. These minerals are commonly classified into macro- and micronutrients based on their relative concentration of each nutrient necessary for proper tissue operation (Hanif *et al*., 2006). The macronutrient composition of *A. odoratissimus* and other *Artocarpus* species is presented in Table 3. The peel (5.57±0.11%) and central core (5.79±0.41%) of the terap fruit were significantly higher than the edible parts. This correlation underscores the strong relationship between ash content and mineral concentration, as the peel and central core of *A. odoratissimus* house substantial macronutrient concentrations. The macronutrient composition of the flesh and core follows the sequence: K > Ca > Na > Mg > P, while that of the peels and seeds is represented as K > Ca > Mg > Na > P. However, it's important to note that the arrangement of these elements may vary among different *Artocarpus* species, influenced by factors such as species composition and geographical location (Bourn & Prescott, 2002). Among the minerals, potassium (K) plays a significant role in the human body, regulating electrolyte balance, supporting nerve and muscle function, and contributing to blood pressure reduction (Bellows *et al*., 2013). Similar to many other fruits, *A. odoratissimus* has a higher mineral concentration in the flesh, seeds, peel, and inner core. The concentration of K was significantly higher in the central core with 2001.51±13.00 mg 100 g^{-1}, followed by the peel with 1838.52±37.81 mg 100 g^{-1}. This shows that the fruit's by-products can be utilized for various purposes (Kapasidou *et al*., 2015). Potassium concentration in the flesh was 1210±28.00 mg 100 g^{-1} followed by seeds at 905.61±18.89 mg 100 g^{-1}. The concentration of K obtained experimentally was six times higher in the flesh and three times higher in a seed with 176-298 mg 100 g^{-1} and 352-443 mg 100 g^{-1}, respectively as reported by Tang *et al*. (2013). Higher K concentration in the fruit of *A. odoratissimus* indicates that the fruit can be used as a major source of K, which can contribute to improved blood pressure regulation through its influence on endothelial and vascular smooth muscle activities (Ekmekcioglu *et al*., 2016).

Calcium (Ca), the second most abundant mineral in *A. odoratissimus* fruit, is vital for bone and tooth formation, with increased requirements during adolescence (Pravina *et al*., 2013). Higher Ca was recorded in the non-edible part, the central core with 1300.97±23.51 mg 100 g^{-1} followed by the flesh with 916.81±23.70 mg 100 g^{-1}. The Ca content in the flesh of *A. odoratissimus* was six times higher than in A. *camansi* (151 mg 100 g^{-1}) (Rabeta & Syafiqah, 2016) and fifteen times higher than in *A. altilis* (60.83 mg 100 g^{-1}) (Appiah *et al*., 2011). The concentration of Ca in the central core of *A. odoratissimus* was eight times higher than the central core of *A. camansi* (159 mg 100 g^{-1}) (Rabeta & Syafiqah, 2016). This implies that *A. odoratissimus* fruits can provide a substantial amount of calcium, crucial for bone and teeth health, muscle function, and blood clotting (Strohle *et al*., 2015).

Additionally, the peel exhibited a higher concentration of Mg at 263.52±7.02 mg 100 g^{-1} while

Table 2. Proximate composition (%) of the different parts of *Artocarpus odoratissimus* and compared to other *Artocarpus* species

Species	Moisture	Ash	Crude Protein	Crude Fiber	Crude Fat	Carbohydrate	Trend	Reference (s)
Artocarpus odoratissimus								
Flesh (%)	75.90±0.75[b] (74.65-77.23)	3.87±0.42[b] (3.03-4.30)	14.59±1.49[b] (13.13-17.51)	0.03±0.01[c] (0.02-0.04)	0.26±0.09[c] (0.10-0.40)	5.35±0.13[c] (5.24-5.47)	M>P>C>A>F>Fi	Present study
Seeds (%)	49.25±0.31[c] (48.76-49.82)	0.62±0.29[c] (0.05-0.92)	21.89±0.54[a] (20.11-23.12)	0.05±0.003[c] (0.05-0.06)	18.23±0.20[a] (17.90-18.60)	9.96±0.76[a] (9.58-11.31)	M>P>F>C>A>Fi	
Peel (%)	73.73±2.12[b] (71.61-75.75)	5.57±0.11[a] (5.35-5.69)	5.59±0.37[c] (5.39-5.79)	0.65±0.04[b] (0.60-0.69)	2.30±0.39[b] (1.99-2.70)	12.16±1.01[a] (11.10-13.20)	M>C>P>A>F>Fi	
Central core (%)	84.12±0.62[a] (83.49-84.69)	5.79±0.41[a] (5.01-5.94)	0.18±0.10[d] (0.17-0.18)	1.24±0.22[a] (1.46-1.50)	0.25±0.16[c] (0.43-0.78)	7.08±0.98[b] (6.99-8.95)	M>C>A>Fi>F>P	
Artocarpus odoratissimus								
Flesh (%)	67.90-73.40	0.60-0.80	1.31-1.51	0.90-1.13	na	12.00-25.20		Tang *et al.* (2013)
Seeds (%)	12.50	1.17	8.78	12.30	15.60	49.65	C>F>M>Fi>P>A	Noorfarahzilah *et al.* (2017)
Artocarpus heterophyllus								
Flesh (%)	86.93	1.02	10.06	3.01	1.49	7.74	M>P>C>Fi>F>A	Amadi *et al.* (2018)
Seeds (%)	71.92	0.89	10.09	3.92	4.29	7.89	M>P>C>F>Fi>A	
Artocarpus integer								
Flesh (%)	62.30-73.40	2.50-3.90	4.90-5.80	4.6-7.60	2.40-3.90	16.20-28.30	M>C>P>Fi>A>F	Lim *et al.* (2011)
Seeds (%)	52.90-72.80	3.20-5.10	9.90-11.20	3.9-7.10	0.80-2.40	2.80-3.50	M>P>Fi>A>C>F	
Artocarpus camansi								
Flesh (%)	86.20	1.47	1.29	2.13	1.06	7.81	M>C>Fi>A>P>F	Rabeta & Syafiqah (2016)
Seeds (%)	66.30	1.24	1.12	2.72	1.85	26.8	M>C>Fi>F>A>P	
Central core (%)	88.40	1.12	0.17	1.60	0.62	8.14	M>C>Fi>A>F>P	
Artocarpus altilis								
Flesh (%)	9.11	2.37	3.80	3.12	2.36	79.24	C>M>P>Fi>A>F	Appiah (2011)
Seeds (%)	8.05	2.49	8.12	2.2	na	72.66		Tukura & Obliva (2015)

Means with different letters (a>b>c) within a column were significantly different at the level $p<0.05$ (ANOVA, Tukey's test). Values are expressed as mean±standard error ($n=4$) and values in brackets are the range. M-moisture, A-ash, P-crude protein, F-crude fat, Fi-crude fiber, C-carbohydrate, and na- not available the flesh contained the least, with 50.93±2.78 mg 100 g^{-1}. These values were comparatively higher than those reported by Tang *et al*. (2013), which indicated values of 14.8-31.3 mg 100 g^{-1}, and 103-132 mg 100 g^{-1}, respectively. The Mg content of *A. altilis* (0.96 mg 100 g^{-1}) (Tukura & Obliva, 2015) seeds was the lowest, and the Mg content of *A. heterophyllus* (338.0 mg 100 g^{-1}) (Ocloo *et al*., 2010) seeds were the highest among other *Artocarpus* species. Mg is an essential element that regulates various biochemical activities in the human body and serves as a co-factor in enzymatic reactions.

Meanwhile, the phosphorus (P) concentration significantly varied with flesh, seeds, peel, and central core of *A. odoratissimus*. Phosphorus is crucial for metabolic processes and healthy bone development (Penido & Ulon, 2012). Among the fruit parts, seeds possessed significantly higher P concentration at 167.40±1.68 mg 100 g^{-1}. Sodium (Na), important in electrolyte balance, co-regulates ATP and blood pressure (Cena *et al*., 2020). A higher concentration of Na was found in the non-edible parts of the fruit which was the central core with 304.89±6.10 mg 100 g^{-1} and peel with 240.51±5.36 mg 100 g^{-1}. The concentration of Na in the flesh was 182.33±15.53 mg 100 $g^{-1,}$ which was thirteen times higher than in the flesh of *A. camansi* (13.60 mg 100 g^{-1}) (Rabeta & Syafiqah, 2016) and two times higher than in the flesh of *A. altilis* (69.0 mg 100 g^{-1}) (Tukura & Obliva, 2015). Adequate sodium levels are vital for cellular homeostasis and maintaining fluid balance within the body (Farquhar *et al*., 2015).

Vitamin analyses of the flesh of *Artocarpus odoratissimus*

Phytochemicals, vitamins, minerals, and fibers are a few of the bioactive elements found in a wide variety of fruits and other plant-based meals (Abobatta, 2021). The majority of fruits constitute an excellent dietary source of the B-complex vitamins, as well as vitamins A, C, E, and K (Kandasamy & Shanmugapriya, 2015). Notably, *Artocarpus odoratissimus* flesh is an excellent source of vitamins for the human diet, especially in supplying the human body with B vitamins (Figure 2).

Among the various vitamin groups, the vitamin B-complexes stand out as exceptionally important for maintaining the health of multiple bodily systems, including the nervous system, skin, eyes, hair, liver, brain function, muscular tone, and gastrointestinal tract (Kaur, 2015). The findings of this study highlight the abundance of vitamin B1 (Thiamine) in the flesh of *A. odoratissimus*, with a remarkable content (11.07±0.31 mg 100 g^{-1}), which was thirty-nine times higher than in *A. altilis* (0.28 mg 100 g^{-1}), followed by vitamin B3 (Niacin) (0.93±0.06 mg 100 g^{-1}) which was 1.8 times lower than in *A. altilis* (1.70 mg 100 g^{-1}), vitamin B9 (Folic acid) (0.50±0.00 mg 100 g^{-1}) higher than in *A. altilis* (0.0013 mg 100 g^{-1}) (Turi *et al*., 2015). A lower amount of vitamin B2 (Riboflavin) was found in *A. odoratissimus* with 0.27±0.06 mg 100 g^{-1}. It's noteworthy that the vitamin B content in the flesh of *A. odoratissimus* meets the Recommended Dietary Allowance (RDA) for both adult males and females. This composition demonstrates a unique profile compared to other *Artocarpus* species, where vitamin C content is higher in *A. altilis*, while vitamin A content is more prominent in *A. heterophyllus*. Vitamin C, or ascorbic acid, plays a pivotal role in the human body by enhancing immunity, aiding in wound healing, acting as an antioxidant, and contributing to collagen production, which is essential for cell cohesion. Higher vitamin C has been recorded in *A. altilis* (21 mg 100 g^{-1}, Turi *et al*., 2015), *A. heterophyllus* (7.0-10.0 mg 100 g^{-1}, Ranasinghe *et al*., 2019), and *A. integer* (6.20 mg 100 g^{-1}) as compared to *A. odoratissimus* with 0.33±0.06 mg 100 g^{-1}. Additionally, vitamin A is recognized as an anti-inflammation vitamin due to its crucial function in cellular immune responses and humoral immunological processes (Huang *et al*., 2018). Vitamins A, D, E, and K, the values were not detected in the flesh of *A. odoratissimus*. However, *A. heterophyllus* is rich in vitamin A with 175-540 mg 100 g^{-1} (Ranasighe *et al*., 2019). This is the first documentation of the vitamin composition of *A. odoratissimus* flesh. The variation in vitamin content may be due to the flesh pigmentation and composition of the *Artocarpus* species fruit. The flesh of A. integer and *A. heterophyllus* are yellow, while *A. camansi* and *A. odoratissimus* are in white.

The sugar content of the flesh of *Artocarpus odoratissimus*

The sweetness of the fruit is fundamentally determined by the types and composition of sugars it contains, making it a pivotal factor in assessing the fruit's quality and market appeal (Nookaraju *et al*., 2010). *Artocarpus odoratissimus*, at its essence, stands out as the sweetest fruit within the *Artocarpus* genus, cherished by many for its irresistibly sweet and juicy flesh. According to Kasron *et al*. (2020), *A. odoratissimus* is one of the most popular indigenous fruits consumed by locals in Sabah and Sarawak, accounting for 27% of total consumption, compared to dabai (18%), bambangan (14%), engkalak (10%), belimbing hutan (6%), and gelugur (4%). The three main sugars, *i.e*., sucrose, glucose, and fructose, were found to be the prime constituents in the flesh parts of *A. odoratissimus*. The sugar content of *A. odoratissimus* is presented in Table 4. From the analysis, fructose was found to be the most abundant sugar composition in the flesh part, with a range of 26.07±0.70%. The fructose composition in this study was comparatively higher than the reported values (6.90-13.70%) by Tang *et al*. (2013). *Artocarpus odoratissimus* flesh had five times higher fructose than the *A. heterophyllus* flesh, which was 4.53% (Chowdhury *et al*., 1997). Fructose comprised the larger portion of total sugars, ranging from 26.0-27.4 g 100 g^{-1} followed by glucose, ranging from 25.4-26.3 g 100 g^{-1}. Higher fructose values are accompanied by higher glucose content. The fructose and glucose composition in *A. odoratissimus*

Table 3. Mineral composition (mg 100 g^{-1}) of different parts of *Artocarpus odoratissimus* and compared to other *Artocarpus* species

Species	K	P	Na	Ca	Mg	Trend	Reference (s)
Artocarpus odoratissimus							
Flesh (%)	1210.40±28.00[c] (1237.16-1654.17)	98.12±2.51[c] (93.15-101.15)	182.33±15.53[bc] (68.46-184.91)	916.81±23.70[b] (586.80-1156.66)	150.93±2.78[b] (107.58-184.91)	K>Ca>Na>Mg>P	Present study
Seeds (%)	905.61±18.89[d] (878.15-1220.73)	167.40±1.68[a] (164.16-169.77)	131.86±18.22[c] (88.80-388.64)	666.48±54.30[c] (488.41-912.23)	165.01±7.73[b] (162.80-279.02)	K>Ca>Mg>Na>P	
Peel (%)	1838.52±37.81[b] (1790.97-2899.41)	109.02±4.82[bc] (102.32-118.38)	240.51±5.36[ab] (239.52-527.61)	578.30±7.00[d] (583.83-1449.70)	263.52±7.02[a] (154.69-266.27)	K>Ca>Mg>Na>P	
Central core (%)	2001.51±13.00[a] (1975.67-2146.78)	126.38±4.48[b] (117.49-131.73)	304.89±6.10[a] (248.39-299.55)	1300.97±23.51[a] (948.83-1819.95)	177.85±6.96[b] (149.03-184.91)	K>Ca>Na>Mg>P	
Artocarpus odoratissimus							
Flesh	176.00-298.00	na	1.15-1.70	0.48-1.35	14.8-31.30		Tang *et al.* (2013)
Seeds	352.00-443.00	na	0.90-3.80	1.50-3.00	103.00-132.00		
Artocarpus heterophyllus							
Flesh	448.00	21.00	2.00	24.00	29.00	K>Mg>Ca>P>Na	Waghmare *et al.* (2019)
Seeds	1478.10	na	6.06	308.7	338.00		Ocloo *et al.* (2010)
Artocarpus integer							
Flesh	434.00	na	1.10	3.40	46.00		Lim *et al.* (2011)
Seeds	609.00	na	1.20	2.90	65.00		
Artocarpus altilis							
Flesh	673.50	140.00	69.00	60.83	90.63	K>P>Mg>Na>ca	Appiah *et al.* (2011)
Seeds	9.40	na	0.81	2.90	0.96		Tukura and Obliva (2015)

Means with different letters (a>b>c>d) within a column were significantly different at the level $p<0.05$ (ANOVA, Tukey's test). Values are expressed as mean±standard error ($n=4$) and values in bracket are the range.
K-potassium, P-phosphorus, Na-sodium, Ca-calcium, Mg-magnesium, and na-not available

flesh ranged from ~47% and ~45%, respectively, while sucrose comprised 8% of total sugars. Sugar compositions in other *Artocarpus* species varied from *A. odoratissimus.* Similar composition of sugar content was recorded in *A. heterophyllus*. Contradict to this, the trend of sugar compositions in *A. integer* showed it possessed higher sucrose than the fructose and glucose content. As for non-reducing sugar composition (sucrose), the level of sucrose in *A. odoratissimus* (4.38±0.21 g 100 g^{-1}) was lower than the level of sucrose in *A. integer* (20.02±1.88 g 100 g^{-1}). The prevalent sugar content trend in *A. odoratissimus* in this study was fructose > glucose > sucrose, a trend in line with the findings of Shahrir *et al*. (2013) in Sarawak. The glucose/fructose ratio is a crucial indicator for assessing the palatability of fruit flesh, and in the *A. odoratissimus* fruits examined, the measured glucose/fructose ratio stood at approximately 0.95, consistent with the ratio reported by Tang *et al*. (2013) in Brunei. These values play a vital role in understanding the body's sugar intake, particularly about the potential impact of excessive fructose on fructose malabsorption (Levy *et al*., 2015).

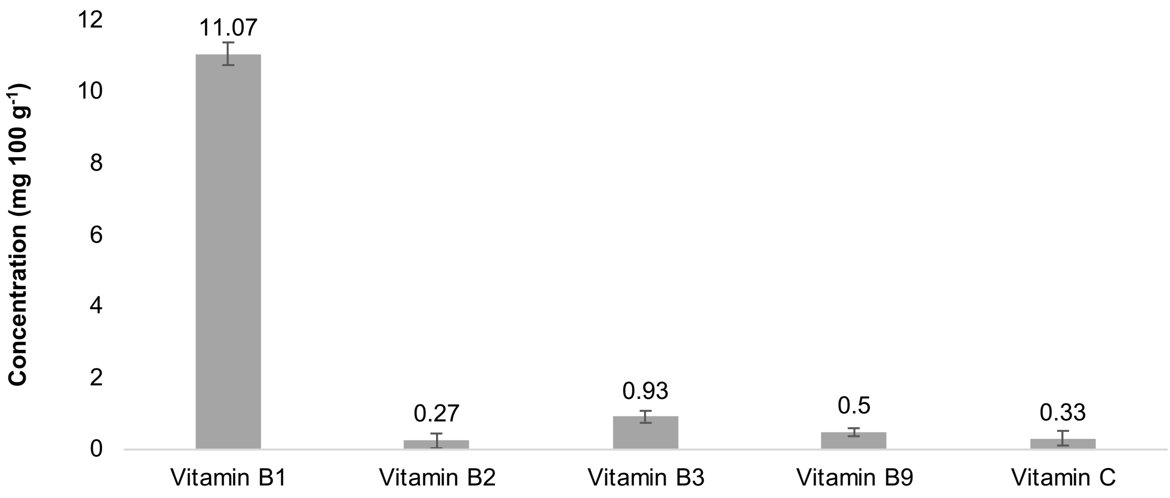

Fig. 2. Vitamin content (mg 100 g^{-1}) in flesh of *Artocarpus odoratissimus*

Table 4. Sugar content (g 100 g^{-1}) in *Artocarpus odoratissimus* flesh compared to other *Artocarpus* species

Species	Non-reducing sugar (g 100 g^{-1})	Reducing sugar (g 100 g^{-1})		G/F ratio	Total sugar (g 100 g^{-1})	Reference
	Sucrose	Glucose	Fructose			
Artocarpus odoratissimus	4.38±0.21 (4.60-5.00)	25.38±0.45 (25.40-26.30)	26.7±0.70 (26.00-27.40)	0.95	57.35±1.91 (56.00-58.70)	Present study
Artocarpus odoratissimus	0.3-11.2	5.8-13.7	6.9-13.7	0.95	13.00-38.6	Tang *et al*. (2013)
Artocarpus integer	20.02	5.52	6.12	0.90	31.66	Pui *et al*. (2018)
Artocarpus heterophyllus	1.49	2.06	4.53	0.45	8.08	Chowdhury *et al*. (1997)

Values are expressed as mean±standard deviation and values in bracket are the range

Fatty acid profiling of *Artocarpus odoratissimus* seed oil

Fatty acids are important biochemical components for all of the body’s organs and are categorized into two types of fatty acids; essential fatty acids that are not generated by the body and non-essential fatty acids that are generated by the body (Elbossaty, 2018). The fatty acid compositions of *Artocarpus* species are presented in Table 5. The seeds of *A. odoratissimus* possessed a higher content of unsaturated fatty acid (57.10%) followed by saturated fatty acids (42.90%). The methyl esters composition obtained in *A. odoratissimus* seeds oil were caprylic acid (C8:0), myriystic acid (C14:0), pentadecanoic acid (C15:0), palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), oleic acid

(C18:2), linoleic acid (C20:0), arachidic acid (C20:1), Eicosenoic acid (C20:5), behenic acid (C22:0), and nervonic acid (C24:1).

Unsaturated fatty acid (UFA) was found as the predominant fatty acid content in the seeds of *A. odoratissimus* (57.10%) and *A. altilis* (82.91%). In *A. odoratissimus* seeds, 52.40% consisted of mono-unsaturated fatty acid (MUFA), which predominantly consisted of nervonic acid (45.32%), oleic acid (5.99%), and eicosenoic acid (1.11%) whereas, in seeds of *A. altilis*, 57.071% of MUFA were mainly consisted of oleic acid (56.775%), palmitoleic acid (0.29%) and erucic acid (0.006%). Nervonic acid was found exclusively in the seeds of *A. odoratisssimus* and not in the seeds of *A. altilis* or *A. heterophyllus*, as reported by Ojwang *et al*. (2015) and Aremu *et al*. (2017). Nervonic acid is an omega-9 fatty acid with a highly extended carbon chain and plays a crucial role in maintaining human health, especially in brain function (Li *et al*., 2019). Amminger *et al*. (2012), suggest that dietary supplementation with nervonic acid is beneficial for infants during early brain development and may help reduce symptoms related to Parkinson's disease, multiple sclerosis, schizophrenia, and early-stage Alzheimer's disease. Furthermore, seeds of *A. odoratissimus* have a lower value of other essential UFA, including oleic acid (5.99%) and eicosenoic acid (1.11%). The value of oleic acid in *A. odoratissimus* seed was nine times lower than *A. altilis* (56.775%), and eicosenoic acid was slightly lower than the values in *A. heterophyllus* (2.24%). *Artocarpus altilis* and *A. heterophyllus* contain other essential fatty acids such as linolenic acid, arachidonic acid, docosatetranoic acid, and erucic acid. Linolenic acids were absent in the seeds of *A. odoratissimus*, making it an ineffective source of essential fatty acids compared to *A. altilis* and *A. heterophyllus*.

Table 5. Fatty acid composition (%) in *Artocarpus odoratissimus* seed compared with other *Artocarpus* species

Methyl esters	Fatty acid	Percentage of fatty acid (%)		
		Artocarpus odoratissimus	*Artocarpus altilis*	*Artocarpus heterophyllus*
Butyric acid	C4:0	-	<0.001	-
Caproic acid	C6:0	-	0.009	-
Caprylic acid	C8:0	0.84	0.007	-
Capric acid	C10:0	-	0.050	-
Lauric acid	C12:0	-	0.031	-
Myristic acid	C14:0	0.95	0.123	2.66
Pentadecanoic acid	C15:0	1.21	-	1.83
Palmitic acid	C16:0	26.22	11.412	39.85
Palmitoleic acid	C16:1	-	0.290	-
Margaric acid	C17:0	-	0.015	-
Stearic acid	C18:0	3.05	4.723	1.30
Oleic acid	C18:1	5.99	56.775	3.30
Linoleic acid	C18:2	3.39	25.710	30.19
Linolenic acid	C18:3	-	0.125	3.73
Octadecatetranoic acid	C18:4	-	-	4.38
Arachidic acid	C20:0	1.36	0.185	-
Eicosenoic acid	C20:1	1.11	-	2.24
Arachidonic acid	C20:4	-	0.004	1.07
Eicosapentaenoic acid	C20:5	1.30	-	3.66
Behenic acid	C22:0	9.26	0.140	-
Erucic acid	C22:1	-	0.006	0.79
Docosatetranoic acid	C22:4	-	-	0.47
Docosapentaenoic acid	C22:5	-	-	2.08
Lignoceric acid	C24:0	-	0.393	-
Nervonic acid	C24:1	45.32	-	-
UFA		57.10	82.910	-
MUFA		52.4	57.071	6.55
PUFA		4.7	0.125	46.37
SFA		42.9	17.089	45.64
Reference		Present study	Aremu *et al*. (2017)	Ojwang *et al*. (2015)

UFA- Unsaturated fatty acids, MUFA- Monounsaturated fatty acids, PUFA- Polyunsaturated fatty acids, SFA- Saturated fatty acids

Polyunsaturated fatty acids (PUFAs) are characterized by having two or more double bonds in their molecular structure (Gazem & Chandrashekariah, 2014). In the seeds of *A. odoratissimus*, 4.70% of the fatty acid consisted of linoleic acid (3.39%) and eicosapentaenoic acid (1.30%). Linoleic acids in *A. odoratissimus* seed were seven times lower than in seeds of *A. altilis* and nine times lower than in seeds of *A. heterophyllus*. Eicosapentaenoic acid in seeds of *A. heterophyllus* (2.24%) was slightly higher than in seeds of *A. odoratissimus*. This study shows that *A. odoratissimus* seeds have a higher content of MUFA (52.4%) as compared to PUFA (4.7%), which was a similar trend to *A. altilis* with 57.071% MUFA and 0.125% PUFA. The Straight chain of organic acids with an even number of carbon atoms is known as saturated fatty acids (SFA), and it can be synthesized by the body (Grundy, 2012). Low-density lipoproteins (LDL) cholesterol, generally known as bad cholesterol, is more likely to increase with the consumption of fatty acids with 8–16 carbon atoms. The value of SFA in *A. odoratissimus* seed oil was 42.9%, slightly lower than the value in *A. heterophyllus* (45.64%) but two times higher than the value in *A. altilis* (17.089%). SFA content recorded in this study was caprylic acid (0.84%), myristic acid (0.95%), pentadecanoic acid (1.21%), arachidic acid (1.36%), stearic acid (3.05%), behenic acid (9.26%) and palmitic acid (26.22%). Palmitic acid was the major constituents of SFA in *A. odoratissimus*, *A. heterophyllus* (39.85%) and *A. altilis* (11.412%). Tang *et al*. (2013) reported the qualitative content of *A. odoratissimus* seeds, and the identified fatty acids were hexanoic acid, octanoic acid, palmitic acid, stearic acid, and tetracosanoic acid. The authors reported that the major component of fatty acids in terap seeds is palmitic acids, and the second most abundant is stearic acid. This contradicts the present results where the seed consisted of higher UFA compared to the SFA.

Phytochemical properties of *Artocarpus* fruit parts

Plants serve as a substantial reservoir of natural medicinal remedies owing to their high polyphenol content and their remarkable capacity for acting as potent antioxidants and scavenging free radicals (Firdose *et al*., 2011). There's a growing interest among people in incorporating bioactive plant products into their diets (Hari *et al*., 2014). Polyphenols, which are secondary metabolites produced by plants to protect themselves and interact with other plants, are primarily abundant in fruits, vegetables, whole grains, and various beverages. Within the realm of polyphenols, phenolics and flavonoids represent the two principal categories (Abbas *et al*., 2017).

The phytochemical content of *A. odoratissimus* fruits and other *Artocarpus* species are presented in Table 6. The TPC of *A. odoratissmus* was higher in the central core (61.49±2.65 mg GAE g^{-1}) followed by peel (23.62±0.88 mg GAE g^{-1}), seed (18.67±0.89 mg GAE g^{-1}) and least at flesh (2.35±0.18 mg GAE g^{-1}). The inedible parts of the fruits contain more phenolic properties than the edible parts. According to a prior study by Bakar *et al*. (2015), TPC was detected in greater concentrations in the peel of *A. odoratissimus* (42.3 mg GAE g^{-1}) and *A. integer* (21.29 mg GAE g^{-1}) and lower concentrations in the flesh of both species (3.53 mg GAE g^{-1} and 4.40 mg GAE g^{-1}, respectively). The TPC content in the flesh of *A. heterophyllus* was relatively higher with 52.04 mg GAE g^{-1} (Peramunugama *et al*., 2018) when compared to *A. odoratissimus* and *A. integer* (Bakar *et al*., 2015). Additionally, both *A. odoratissimus* and *A. integer* seeds (13.72 mg GAE g^{-1}) possessed higher TPC contents than the fruit's flesh. The phenolics in the seed function as antioxidants to prevent internal damage brought on by the oxidation process that occurs during seed germination (Tarzi *et al*., 2012).

As for TFC, all fruit parts of *A. odoratissimus* show significantly different TFC content. The trend of TFC in the study was peel > pedicel > seed > flesh. The relatively higher TFC was observed in the peel, which was 22.27±0.71 mg QE $g^{-1,}$ whereas the lower TFC content was observed in the flesh with 1.14±0.20 mg QE g^{-1}. A similar trend of TFC content was reported by Bakar *et al*. (2015), as higher TFC content was found in the peel of *A. odoratissimus* (36.78 mg QE g^{-1}) and *A. integer* (17.45 mg QE g^{-1}) and the lower content was found in the flesh part (1.23±0.09 mg GAE g^{-1}). This is in agreement with the findings by Bakar *et al*. (2009), who found that the peel and seed of bambangan and terap fruit contained more phytochemicals than the flesh. The central core of *A. odoratissimus* had a TFC concentration that was two times lower than *A. heterophyllus* (24.15 mg QE g^{-1}) (Adan *et al*., 2020). Flavonoids presented have been reported on their effectiveness against cancerous diseases cardioprotective agents, and act as antioxidants, anti-bacteria, skin protection from UV radiation, and capability application in the pharmaceutical and medical industry (Ahmed *et al*., 2016; Meng *et al*., 2018).

Regarding FRAP activity, the *A. odoratissimus* fruit's peel (766.29±7.94 μM TE g^{-1}) and central core (765.54±3.78 μM TE g^{-1}) had significantly greater properties than the fruit's seed (68.26±0.22 M TE g^{-1}) and flesh (40.84±0.12 M TE g^{-1}). The study by Bakar *et al*. (2015), reported that the non-edible parts of *A. odoratissimus* (378.93 μM g^{-1}) and *A. integer* (218.91 μM g^{-1}) have higher FRAP properties than the edible parts. Similarly, the central core and peel of *A. heterophyllus* also have the highest amount of FRAP properties as compared to the other *Artocarpus* species at 5200 μM g^{-1} and 6690 μM g^{-1}, respectively (Adan *et al*., 2020). Like FRAP, the central core displayed higher scavenging activity in the free radical activity, which ranged from 6.16-7.19 mg mL^{-1}, followed by the seeds at 9.15-10.80 mg mL^{-1}. A significantly lower TAA was recorded in the flesh of *A. odoratissimus* at 188.48±0.65 mg mL^{-1}. Bakar *et al*. (2009) reported that the seed of *A. odoratissimus* demonstrated higher antioxidant

Table 6. Phytochemical properties of different parts of *Artocarpus odoratissimus* fruit compared with other *Artocarpus* species

Species	TPC (mg GAE g^{-1})	TFC (mg QE g^{-1})	FRAP (µm TE g^{-1})	DPPH (mg mL^{-1})	Reference
Artocarpus odoratissimus					
Flesh	2.35±0.18^{c}	1.14±0.20^{d}	40.84±0.12^{c}	188.48±0.65^{a}	Present study
	(2.11-2.70)	(0.75-1.44)	(40.66-40.79)	(187.25-189.48)	
Seed	18.67±0.89^{b}	12.64±0.17^{c}	68.26±0.22^{b}	10.25±0.55^{c}	
	(16.9-19.74)	(12.32-12.88)	(68.00-68.69)	(9.15-10.80)	
Central core	61.49±2.65^{a}	15.20±0.67^{b}	765±3.78^{a}	13.45±0.007^{b}	
	(56.19-64.26)	(13.79-16.09)	(758.71-771.77)	(13.42-13.44)	
Peel	23.62±0.88^{b}	22.27±0.71^{a}	766.29±7.94^{a}	6.85±0.34^{d}	
	(22.60-25.36)	(20.85-23.12)	(756.94-782.10)	(6.16-7.19)	
Artocarpus odoratissimus					
Flesh	3.53	1.23	17.92	na	Bakar *et al*. (2015)
Seed	13.72	10.18	68.06	na	
Peel	42.38	36.78	378.93	na	
Artocarpus integer					
Flesh	4.40	0.82	13.59	na	Gopinathan *et al*. (2020)
Seed	11.87	3.58	76.58	na	
Peel	21.29	17.45	218.91	na	
Artocarpus heterophyllus					
Flesh	52.04	27.56	na	0.68	Peramunugama *et al*. (2018)
Seed	0.40	10.10	na	0.39	Bhat *et al*. (2017)
Central core	15.68	24.15	5200.00	na	Adan *et al*. (2020)
Peel	17.07	28.55	6690.00	na	Adan *et al*. (2020)

Means with different letters (a>b>c>d) within a column were significantly different at the level p<0.05 (ANOVA, Tukey's test). Values are expressed as mean±standard error and values in bracket are the range. TPC-total phenolic content, TFC-total flavonoid content, FRAP- Ferric Reducing Antioxidant Power, DPPH-2, 2-diphenyl-1-picrylhydrazyl and na-not available activity and had higher phytochemical contents than the flesh part of the fruit. The antioxidant activity in *A. odoratissimus* is notable since the fruit is rich in compounds that function in free radical scavenging activity that benefits human health.

CONCLUSION

The results of this study demonstrate that both the edible and non-edible components of the *A. odoratissimus* fruit exhibit favorable proximate compositions and mineral content. In comparison to other *Artocarpus* species, the flesh of *A. odoratissimus* stands out with its exceptional sweetness and rich B-complex vitamin content. Furthermore, the edible by-product, the seed, is notably rich in both unsaturated and saturated fatty acids. As for the non-edible portions, the central core and peel are particularly abundant in antioxidants, presenting valuable potential for applications in the pharmaceutical and nutraceutical industries. This approach not only maximizes the utilization of fruit by-products but also contributes to reducing waste.

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ETHICAL STATEMENT

Not applicable.

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