Review Article

Primary, Secondary Metabolites and Antioxidant Activity of *Castanopsis Argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* Fruit as Food for the Tapanuli Orangutan (*Pongo tapanuliensis*) in the Batang Toru Forest, North Sumatra

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Abstract | Food plays a crucial role in providing optimal nutrition to maintain the health of the Tapanuli orangutan (*Pongo tapanuliensis*). The diet of the Tapanuli orangutan consists of *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* which contain important components such as phytochemicals and proximates with antioxidant effects. The composition of these metabolites correlates with the health of the Tapanuli orangutan. This research aims to identify primary and secondary metabolites, such as proximates and amino acids, as well as bioactive compounds with antioxidant activity. *Castanopsis argantea, Artocarpus heterophyllus*, and *Aglaia tomentosa* fruits were tested for proximate, amino acid, phytochemical, and total flavonoid content. Liquid Chromatography-Mass Spectrometry/Mass Spectrometry (LC-MS/MS) and the Ferric Reducing Antioxidant Potential (FRAP) method were employed to determine antioxidant activity. Proximate content and amino acid content tests showed that *Castanopsis argantea* had significantly higher levels ($P<0.05$) of carbohydrates (84.09%), fat (3.07%), energy from fat (27.69 Kcal/100 g), total energy (386.34 Kcal/100g), and amino acids such as L-Histidine (1721.09ppm), L-Isoleucine (1329.17ppm), and L-Lysine (1484.99ppm). Phytochemical screening is most notable in *Aglaia tomentosa,* showing positive results for alkaloids, flavonoids, saponins, tannins, phenolics, and quinolines. *Aglaia tomentosa* contains the highest total flavonoid content (23.27 ± 3.46 mg QE/g). The bioactive compounds found in *Castanopsis argantea* consist of caffeine and flazin. *Artocarpus heterophyllus* comprises Synephrine and Schinifoline while *Aglaia tomentosa* consists of Artoindonesianin B and 2,5-Di-tert-butylhydroquinone. The highest antioxidant was found in *Artocarpus heterophyllus* (4.85 ± 1.13μg/mL). The results of the research show that the three foods of the Tapanuli orangutan have excellent potential as sources of nutrition and natural antioxidants. Understanding the relationship between diet and health, including stress from habitat changes, immune system suppression, and environmental factors affecting the Tapanuli orangutan, can lead to more effective and sustainable conservation strategies through the cultivation of these plants.

Keywords | Primary and secondary metabolites, Antioxidant, Food, Fruit, Orangutans

Received | September 05, 2024; **Accepted** | October 27, 2024; **Published** | December 03, 2024
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Citation | Sianipar HF, Widoretno W, Hakim L, Amolia RR, Fatchiyah F (2025). Primary, secondary metabolites and antioxidant activity of *Castanopsis argantea*, *Artocarpus heterophyllus,* and *Aglaia tomentosa* fruit as food for the Tapanuli orangutan (*Pongo tapanuliensis*) in the batang toru forest, North Sumatra. Adv. Anim. Vet. Sci. 13(1): 64-72.
DOI | https://dx.doi.org/10.17582/journal.aavs/2024/13.1.64.72
ISSN (Online) | 2307-8316; **ISSN (Print)** | 2309-3331

INTRODUCTION

The Tapanuli orangutan (*Pongo tapanuliensis*), the newest species of great ape, is endemic to North Sumatra. These orangutans play a crucial role in forest ecosystems, acting as pollinators and seed dispersers, and are considered a keystone species. According to the IUCN (International Union for Conservation of Nature), they are classified as Critically Endangered due to drastic population declines caused by habitat loss, hunting, slow reproduction, and disease (Arief and Mijiarto, 2024).

The Tapanuli orangutan is found in the Batang Toru Forest, south of Lake Toba . The population has continued to decrease, with around 800 individuals recorded in 2017, and currently estimated between 577 and 760. Conservation efforts focus on maintaining their population through improved dietary resources (Rahman *et al*., 2019; Purwoko *et al*., 2022).

Food is fundamental for the growth, development, and behavior of primates (Wilson *et al*., 2014). Orangutans are selective feeders due to their large body size, primarily consuming fruit when available, and preferring soft pulp. They distinguish between preferred and fallback foods, with preference foods chosen when abundant (Arief *et al*., 2024; Lambert and Rothman, 2024). According to Arief and Mijiarto (2024), the fruits of *Castanopsis argantea, Artocarpus heterophyllus,* and *Aglaia tomentosa* are preferred in the Batang Toru Forest.

Castanopsis argentea, locally known as chestnut or sanint-en, serves ecologically as a source of food, rest, and nesting for forest animals. Its fruit is consumed by wild boars and primates (Putri *et al*., 2022). Plant parts of *Artocarpus heterophyllus* such as stems, roots, leaves, and fruit have medicinal properties. Jackfruit leaves contain sapogenins, cycloartenone, cycloartenol, β-sitosterol, and tannins. It is a potential cytotoxic agent with high phenolic and flavonoid content (Utari and Warly, 2021), providing essential vitamins, minerals, and calories (Ranasinghe *et al*., 2019).

According to Widayati *et al*. (2023), fruit is rich in water, carbohydrates, and energy but low in protein, making it the primary food choice for orangutans. In contrast, seeds, flowers, young leaves, cambium, and young stems are selected as less preferred alternatives. The nutrient content is usually analyzed using the Proximate analysis method (Ganogpichayagrai and Suksaard, 2020). Onrizal and Auliah, (2019) examined the nutrient content of orangutan food in Tanjung Puting. They found two types of flowers eaten by orangutans (*Dillenia sp* and *Xanthophyllum sp*) which have higher protein levels than other food categories (18.1% and 16.6%).

The high nutritional value of *Pongo tapanuliensis* food is important for growth in tropical forests, as are the important chemical compounds found in fruit. The initial assessment of secondary metabolites in plants involves testing for color changes indicating alkaloids, flavonoids, tannins, saponins, and steroids. These secondary metabolites possess antibacterial and antioxidant properties (Contreras *et al*., 2022).

Differences in habitat conditions negatively impact animal life. The lack or poor quality of food sources and inadequate facilities and space in zoos lead to concerning conditions for many animals, including orangutans. Such conditions cause stress and even death (Sjahfirdi *et al*., 2023; Wolfensohn *et al*., 2018).

Stress contributes to the generation of free radicals. Evidence has long shown the involvement of free radicals and oxidative damage in metabolic disorders, incompatibility, and various diseases. Many chronic diseases are believed to originate from stress-induced free radicals and oxidative damage. Free radicals can be reduced by consuming fruits with natural antioxidants (Srivastava and Kumar, 2015). The type of fruit, along with its nutritional content, phytochemicals, and antioxidant activity, significantly influences the daily activities and health of the Tapanuli orangutan.

This research aimed to identify the primary and secondary metabolite, and antioxidant activity of *Pongo tapanuliensis* food. This study shows that the food of Tapanuli orangutans can be a potential source of phytochemicals, offering good medicinal and nutrition with strong antioxidant activity, which is important to consider in Tapanuli orangutan conservation efforts.

MATERIALS AND METHODS

Plant Material

This research was conducted from October 2023 to May 2024 at the Sustainable Ecosystem Foundation Orangutan Conservation Program Research Station in the Batang Toru Forest Area (Camp Mayang), North Sumatra Province, in collaboration with PT. Saraswanti Indo Genetech, the Bioscience Laboratory Center, and Brawijaya University. Plant samples were identified at the UPT Herbal Materia Medica Batu Laboratory in East Java Province.

Preparation and Extraction of Sample

Two hundred grams of ripe fruits from *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* were washed with clean water and dried in an oven at 60°C for 36 hours. They were then crushed with a blender to produce Simplicia powder. Ten grams of this powder was weighed, and 100 ml of 96% ethanol was added. The extraction was filtered, and the ethanol, capable of dissolving both polar and non-polar compounds , was concentrated using a rotary evaporator at 40°C and 90 rpm.

Proximate Analysis

The analysis was performed in triplicate using the crushed fruit powder, measuring carbohydrates, protein, lipids, energy from fat, total energy, ash, and water content according to the Indonesian National Standard method SNI 01-2891-1992 (Wijayanti *et al*., 2023).

Determination of Amino Acids

Amino acid levels were determined using fruit powder. Ultra Performance Liquid Chromatography (UPLC) was chosen for its ability to accurately separate components with similar chemical structures, allowing precise identification and quantification. Analyses were conducted in triplicate. UPLC was used to analyze L-histidine, L-isoleucine, L-leucine, and L-lysine according to Protocol 18-5- 17/MU/SMM-SIG. UPLC was performed using an AccQ, tag ultra C18 1.7µm Column (2.1 × 100mm). The mobile phase consisted of A: Eluent A concentrate Amino Acid Analysis AccQ.Tag Ultra; B: Amino Acid Analysis of Eluent B AccQ.Tag Ultra 10% in water; C: Aquabides; D: Amino Acid Analysis of Eluent B AccQ. Ultra Tags. The flow rate was set at 0.5mL/min. A photometric diode array (PDA) at a wavelength of 260nm was used as a detector (Fatchiyah *et al*., 2020).

Phytochemicals Test

Analyses were performed in triplicate. *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* extracts were filtered using Whatman No. 1 paper to assess phytochemical content. A positive result was indicated by a color change: alkaloids (brown precipitate), flavonoids (yellow), saponins (foam), steroids (green), tannins (blue-black), phenolics (blue-black), and quinoline (green) (Gonfa *et al*., 2023).

Determination of Total Flavonoid Content

Analyses were performed in triplicate. The total flavonoid content was determined by the colorimetric method. Extract (0.5 mL) was mixed with methanol (1.5 mL) and 5% NaNO2 solution (0.1 mL). After 5 minutes, 10% AlCl3 H2O solution (0.1 mL) was added, followed by 1M NaOH (0.1 mL) and distilled water (2.8 mL). Absorbance was measured at 700 nm (Phuyal *et al*., 2020).

LC-MS/MS

LC-MS/MS was used to determine phytochemical components. This technique allows accurate identification of structurally similar compounds. The concentrated extract was dissolved in methanol and filtered through a 0.2 µm nylon filter. Using a GIST C18 shim-pack column, 5 µL of filtrate was injected. The mobile phase, methanol, and water (1% HAc) (65:35, v/v), had a flow rate of 0.2 mL/min at 35 °C, with a detector set at 320 nm. Results were compared with compound composition percentages (Abu Bakar *et al*., 2020).

Antioxidant Activity with FRAP Method

Samples and positive controls (0, 2, 4, 6, 8, 10 µg/mL) were added to 2.5 mL of pH 6.6 phosphate buffer and 2.5 mL of 1% potassium ferricyanide, then incubated at 50 °C for 20 minutes in the dark. Following the addition of 2.5 mL of 10% TCA, 5 mL of distilled water, and 1 mL of 0.1% FeCl3 were derived from each solution. Absorbance was measured at 700 nm using a UV-Vis spectrophotometer. Ascorbic acid and quercetin, with the highest antioxidant capacity, were used as positive controls (Agustin *et al*., 2021).

$$\%\ Antioxidant = \frac{Control\ absorbance - Sample\ absorbance}{Control\ absorbance} \times 100$$

Data Analysis

A statistical analysis of Tapanuli orangutan food content, including proximate and amino acids among *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa*, was conducted using a t-test at a 95% confidence level. The Shapiro-Wilk test for normality showed p-values > 0.05, indicating normal distribution. Levene's test for homogeneity of variance resulted in p-values > 0.05, suggesting homogenous variances. To analyze variations in food content among the three species, a one-way ANOVA and subsequent Tukey's Post Hoc Test were performed at a 95% confidence level using SPSS version 16.0 and GraphPad Prism 8 (Dwiwibangga *et al*., 2022).

RESULTS AND DISCUSSION

Proximate Content

The highest proximate content was found in *Castanopsis argantea,* containing carbohydrates (84.09%), fat (3.07%), energy from fat (27.69 Kcal/100 g), and total energy (386.34 Kcal/100 g). The lowest was in *Artocarpus heterophyllus* with protein (5.56%), fat (0.46%), energy from fat (4.21 Kcal/100 g), and total energy (344.83 Kcal/100 g). Significant differences ($p < 0.05$) were observed among *Castanopsis argantea*, *Artocarpus heterophyllus,* and *Aglaia tomentosa* in terms of carbohydrates, protein, fat, energy, total energy, ash, and water, except for protein and ash. This highlights the distinct nutritional profiles, as shown in Table 1.

Amino Acid Content

The highest amino acid content was found in *Castanopsis argantea* with L-Histidine (1721.09 ppm), L-Isoleucine (1329.17 ppm), and L-Lysine (1484.99 ppm). The lowest was in *Artocarpus heterophyllus,* with L-Histidine (754.95 ppm), L-Isoleucine (1065.25 ppm), and L-Leucine (2124.16 ppm). Significant differences ($p < 0.05$) were found among the species regarding L-Histidine, L-Isoleucine, L-Leucine, and L-Lysine, as in Table 2.

Table 1: Proximate content of *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* fruit.

Sample	Component proximate						
	Carbohydrate (%)	Protein %	Lipid (%)	Energy from fat (Kcal/ 100 g)	Energy total Kcal/ 100 g	Ash (%)	Water (%)
Castanopsis argantea	84.09^{a}	5.57^{b}	3.07^{a}	27.69^{a}	386.34^{a}	2.61^{c}	4.64^{b}
Artocarpus heterophyllus	79.59^{b}	5.56^{c}	0.46^{c}	4.21^{c}	344.83^{c}	4.41^{b}	9.96^{a}
Aglaia tomentosa	77.7^{c}	8.52^{a}	1.94^{b}	17.51^{b}	362.39^{b}	4.65^{a}	1.94^{c}

Note: Significant changes were noted by the different letters (Tukey's HSD; $P < 0.05$).

Table 2: Amino acid content of *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* fruit.

Sample	Concentration (ppm)			
	L-Histidine	L-Isoleucine	L-Leucine	L-Lysine
Castanopsis argantea	1721.09^{a}	1329.17^{a}	2736.28^{b}	1484.99^{a}
Artocarpus heterophyllus	754.95^{c}	1065.25^{c}	2124.16^{c}	990.5^{b}
Aglaia tomentosa	1398.75^{b}	1314.17^{b}	2880.18^{a}	523.66^{c}

Note: Significant changes were noted by the different letters (Tukey's HSD; $P < 0.05$).

Table 3: Phytochemical test by color reactions.

Sample	Alkaloids	Flavonoids	Saponin	Steroids	Tannin	Phenolics	Quinolines
Castanopsis argantea	++	+	-	-	+	+	-
Artocarpus heterophyllus	++	+	-	-	+	+	+
Aglaia tomentosa	++	++	+	-	++	++	++

Note: Targeted compound absence (-); low target compound intensity (+); moderate target compound intensity (++);high target compound intensity (+++).

According to Herring *et al.* (2021), recommended dietary amino acid levels for omnivorous mammals in zoos are L-Histidine (38.6-48.8 ppm), L-Isoleucine (65.4-82.5 ppm), L-Leucine (132-176 ppm), and L-Lysine (100 ppm). All three orangutan food samples meet these requirements.

Phytochemicals Screening

Based on positive color change tests, the highest phytochemical components were found in *Aglaia tomentosa* containing alkaloids, flavonoids, saponins, tannins, phenolics, and quinolines. The lowest was in *Castanopsis argantea*, which showed only alkaloids, flavonoids, tannins, and phenolics, as detailed in Table 3.

Total Flavonoid Content

The total flavonoid content refers to the amount of secondary metabolite compounds derived from plants, quantified using a UV-Vis spectrophotometer. *Aglaia tomentosa* contained the highest flavonoid content (23.27 ± 3.46 mg QE/g), while *Artocarpus heterophyllus* had the lowest (3.44 ± 1.37 mg QE/g). Significant differences ($p < 0.05$) were observed among *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa*, as shown in Table 4 and Figure 1. Higher flavonoid content in food is linked to greater potential health benefits for Tapanuli orangutans.

Table 4: Total flavonoids content.

Sample	Concentration (mgQE/g)
Castanopsis argantea	4.38± 3.25^{b}
Artocarpus heterophyllus	3.44± 1.37^{c}
Aglaia tomentosa	23.27±3.46^{a}

Note: Significant changes were noted by the different letters (Tukey's HSD; $P < 0.05$).

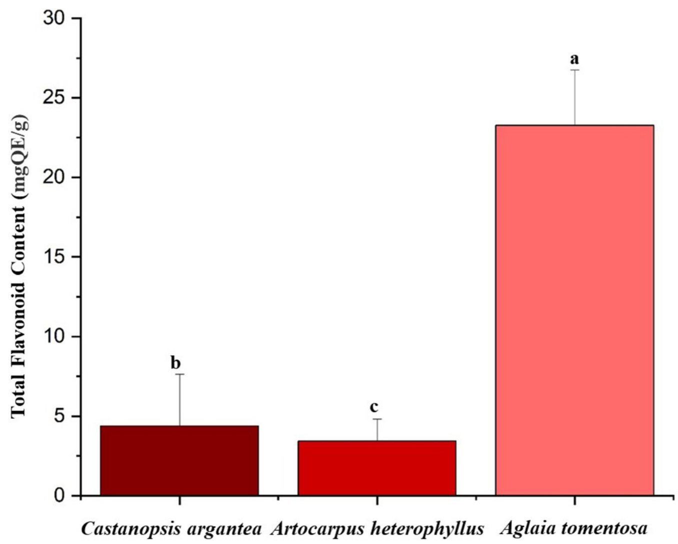


Figure 1: Total flavonoid content of *Castanopsis argantea*, *Artocarpus heterophyllus*, dan *Aglaia tomentosa*.

LC-MS/MS Analysis

LC-MS/MS analysis was carried out by providing a visual chromatogram as in Figure 2 to identify five bioactive compounds in *Castanopsis argantea*, including alkaloids (Caffeine), diterpenoids (D-Pinitol), flavonoids (Flazin), phenols (Dihydrocapsaicin), and terpenoids (Semiplenamide A).

Artocarpus heterophyllus contained two bioactive compounds: alkaloid (Synephrine) and quinoline (Schinifoline). In *Aglaia tomentosa*, nine bioactive components were identified, including coumarins (Scopoletin and Fraxidin), alkaloids (Methysergide and Tryprostatin A), terpenoids (Santonin and 4alpha-(hydroxymethyl)-4alpha-demethylterritrem B), flavonoid (Artoindonesianin B), phenolic (2,5-Di-tert-butylhydroquinone), and a glycoside (5,7-Dihydroxy-2-(4-methoxyphenyl)-8-(3-methylbutyl)-4-oxo-4H-chromen-3-YL 6-deoxy-alpha-L-mannopyranoside), as presented in Table 5.

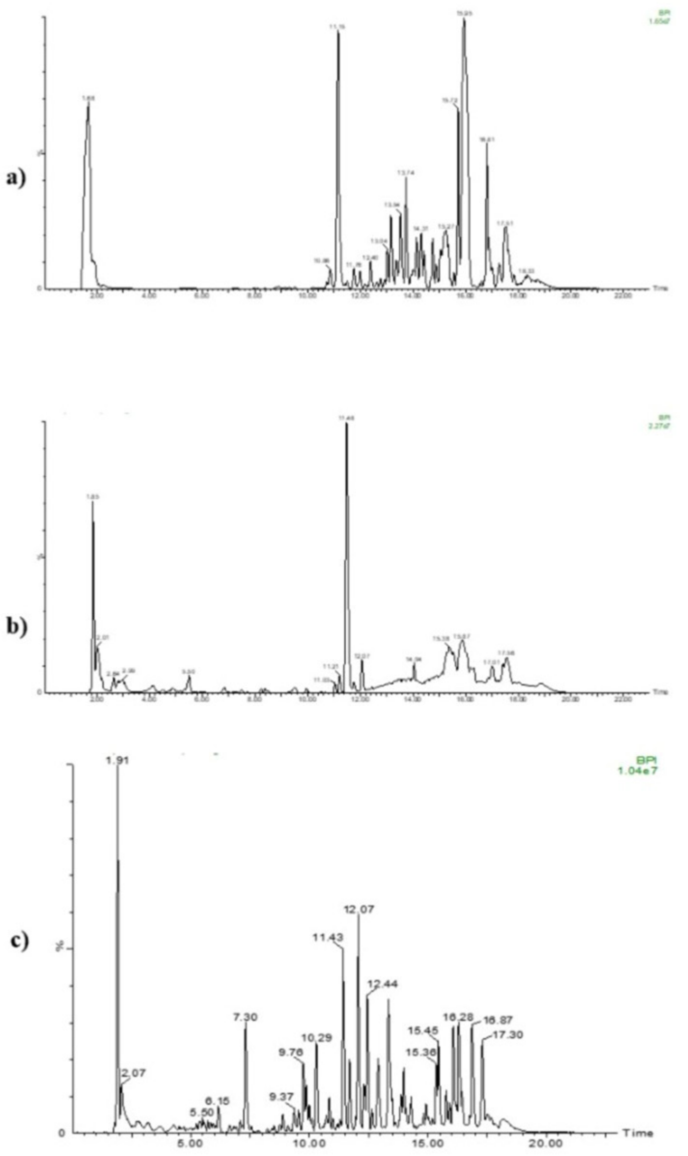


Figure 2: LC-MSMS chromatogram profile of a) *Castanopsis argantea* fruit extract, b) *Artocarpus heterophyllus* fruit extract, c) *Aglaia tomentosa* fruit extract.

Antioxidant Activity

IC_{50} calculationshowed that *Artocarpus heterophyllus* (4.85 ± 1.13µg/mL) had the highest antioxidant content (4.85 ± 1.13 µg/mL), while *Castanopsis argantea* had the lowest (6.98 ± 1.46 µg/mL). *Aglaia tomentosa* (5.15 ± 0.16 µg/mL) was classified as having very strong antioxidant activity, as IC_{50} values < 50 µg/mL indicate very strong antioxidants. Significant differences ($p < 0.05$) were noted among the three foods, as illustrated in Figure 3. The lower the IC_{50} value, the higher the antioxidant activity, increasing the potential of the immune system in the Tapanuli orangutan (Aziz *et al*., 2023).

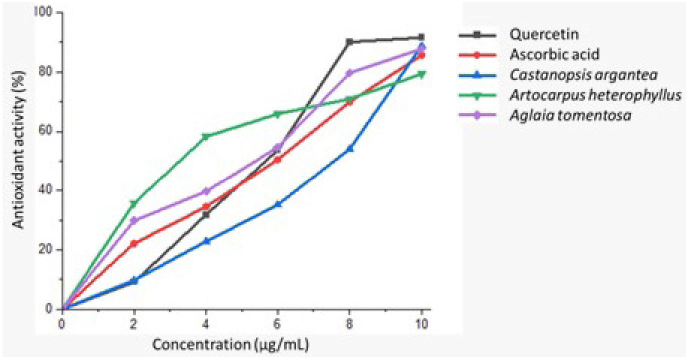


Figure 3: Antioxidant activity of *Castanopsis argantea*, *Artocarpus heterophyllus*, dan *Aglaia tomentosa*.

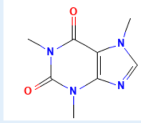
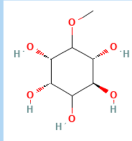
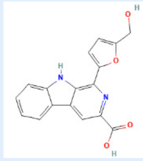
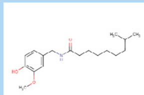
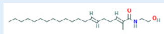
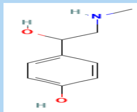
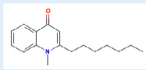
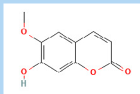
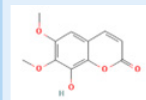
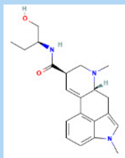
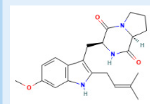
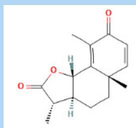
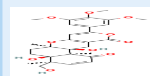
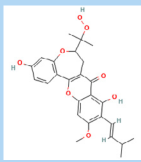
The relationship between orangutans and food plants is mutually beneficial, as orangutans aid in seed dispersion. *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* also serve as shelter and nesting sites for orangutans, help prevent landslides, and maintain soil fertility, crucial for orangutan habitats (Atmoko and Ma'ruf, 2009).

The Batang Toru forest, a dense tropical rainforest, features high humidity and consistent rainfall throughout the year. Soil temperatures of 24.9-25.8°C accelerate fruit ripening but may reduce acid and vitamin C levels, with soil pH ranging from 6.6 to 6.8. This optimal pH allows nutrients to dissolve easily and be absorbed by plants. Fruit sizes range from 3-5 cm for *Castanopsis argantea*, 4-8 cm for Artocarpus heterophyllus, and 1-3 cm for *Aglaia tomentosa* (Rahman *et al*., 2019).

Orangutans require proteins (6.1-26.0%), fats (2.9-9.8%), and energy (3.2-4.3 Kcal/100 g) (Dierenfeld, 1997). *Castanopsis argantea* can meet the fat and energy needs, *Artocarpus heterophyllus* meet the fat requirement, and *Aglaia tomentosa* provides protein and energy. For optimal nutrition, Sumatran orangutans prefer Polyalthia lateriflora for its water (62.13%), fat (0.10%), ash (0.21%), protein (13.72%), and carbohydrate (23.81%) content (Onrizal and Auliah, 2019). Jackfruit contains 7.3g carbohydrates, 1.6g protein, 0.2g fat, and 2.2g ash per 100g (Ranasinghe *et al*., 2019). Orangutans consume large fruit quantities during seasons of abundance and store nutrients as fat during shortages for energy (O'Connell *et al*., 2021). When fruit is in short supply, the nutrients are stored as fat, which can be used as a source of energy (O'Connell *et al*., 2021).

Muscle catabolism can result from calorie deficits. Amino acids like histidine, isoleucine, leucine, and lysine are crucial for various metabolic functions, including immune response (Herring *et al*., 2021; Lee *et al*., 2023). According to Herring *et al*. (2021), the dietary amino acid requirements

Table 5: Data from LCMS/MS chromatogram interpretation results of *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa* fruit extract.

Sample	Measured mass(m/z)	Formula	% Fit Conf	Bioactive Compound	Group	Structure
Castanopsis argantea	195.08	$C_8H_{11}N_4O_2$	89.88	Caffeine	Alkaloids	
	195.08	$C_7H_{15}O_6$	96.83	D-Pinitol	Diterpenoids	
	309.08	$C_{17}H_{13}N_2O_4$	98.87	Flazin	Flavonoids	
	308.22	$C_{18}H_{30}NO_3$	91.48	Dihydrocapsaicin	Phenol	
	366.33	$C_{23}H_{44}NO_2$	99.98	Semiplenamide A	Terpenoids	
Artocarpus heterophyllus	168.1025	$C_9H_{14}NO_2$	97.99	Synephrine	Alkaloids	
	242.1181	$C_{15}H_{16}NO_2$	100	Schinifoline	Quinoline	
Aglaia tomentosa	193.0511	$C_{10}H_9O_4$	100	Scopoletin	Coumarin	
	223.0607	$C_{11}H_{11}O_5$	87.11	Fraxidin		
	354.2187	$C_{21}H_{28}N_3O_2$	99.68	Methysergide	Alkaloids	
	282.2136	$C_{22}H_{28}N_3O_3$	97.18	Tryprostatin A		
	247.1346	$C_{15}H_{19}O_3$	96.09	Santonin	Terpenoids	
	543.2231	$C_{29}H_{35}O_{10}$	94.27	4alpha-(hydroxymethyl)-4alpha-demethylterritrem B		
	469.1864	$C_{26}H_{29}O_8$	94.87	Artoindonesianin B	Flavonoids	

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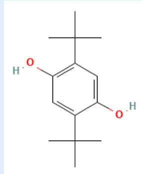
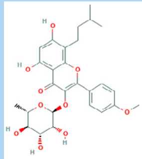
	223.1707	$C_{14}H_{23}O_2$	100	2,5-Di-tert-butylhydroquinone	Phenolic	
	517.2072	$C_{27}H_{33}O_{10}$	99.82	5,7-Dihydroxy-2-(4-methoxyphenyl)-8-(3-methylbutyl)-4-oxo-4H-chromen-3-YL 6-deoxy-alpha-L-mannopyranoside	Glycoside	

for omnivorous mammals in zoos are as follows: histidine (38.6-48.8 ppm), isoleucine (65.4-82.5 ppm), leucine (132-176 ppm), and lysine (100 ppm). The foods consumed by Tapanuli orangutans, specifically *Castanopsis argantea*, *Artocarpus heterophyllus*, and *Aglaia tomentosa*, meet these amino acid needs. Amino acids are crucial for animal health, supporting various metabolic functions, including immune maintenance and response (Lee *et al*., 2023).

Based on phytochemical tests, several foods of Kalimantan orangutan contain phytochemical compounds such as alkaloids, flavonoids, and tannins, namely *Hoya sp, Myristica lowiana, Diospyros siamang, Etlingera triorgyalis, Alseodaphne elmeri, Archidendron clypearia, and Campnospema coriacum* (Atmoko and Ma'ruf, 2009). Based on the third table, samples of Castanopsis argantea, Artocarpus heterophyllus, and Aglaia tomentosa contain moderate levels of alkaloids, which can stimulate the nervous system, regulate blood pressure, and combat microbial infections (Dey *et al*., 2020). Additionally, flavonoids, tannins, and phenols offer significant benefits. Flavonoids support liver function and have anti-microbial and anti-viral properties (Ullah *et al*., 2020), as well as antioxidant effects that may reduce cardiovascular disease risk (Khan *et al*., 2021). Tannins possess antibacterial, antioxidant, and anti-diarrheal properties (Tong *et al*., 2022). Phenolic compounds protect against oxidative stress and inflammation and exhibit anti-inflammatory, anti-cancer, anti-aging, antibacterial, and antiviral activities (Zhang *et al*., 2022).

Kuswanda *et al*. (2021) conducted research in the Batang Toru Forest in North Sumatra, identifying food plants consumed by orangutans among the durian trees (*Durio zibethinus*). The total flavanol content of these plants ranges from 0.13 mg to 5.18 mg CE per 100 g FW (Aziz and Mhd, 2019). Flavonoids, metabolites produced and absorbed during photosynthesis, are bioactive polyphenols with antioxidant potential. The antioxidant capacity of *Durio zibethinus*, measured using the ferric reducing antioxidant power (FRAP) method, is between 71.84 and 749.08 µM TE per 100 g FW (Roy *et al*., 2022).

The FRAP testing method measures the antioxidant ability to reduce the ferric complex ($Fe3+$) to the ferrous complex ($Fe2+$) indicated by a color change to blue (Hsieh and Rajashekaraiah, 2021). Based on Table 6, *Artocarpus heterophyllus* (4.85 ± 1.13µg/mL) exhibits the highest antioxidant content due to its secondary metabolites such as phenols, flavonoids, and vitamin C (Konsue *et al*., 2023). Flavonoids demonstrate antioxidant activity by capturing free radicals and reducing the formation of singlet oxygen (O–). Based on their structure, flavonoids have more than one phenol group (-OH and aromatic groups) and have conjugated double bonds, enabling them to neutralize free radicals (Hassanpour and Doroudi, 2023).

Table 6: Antioxidant activity.

Sample	IC_{50} (µg/mL)	Level
Quercetin	5.16 ± 0.40[c]	Very strong
Ascorbic acid	5.17 ± 0.11[b]	Very strong
Castanopsis argantea	6.98± 1.46[a]	Very strong
Artocarpus heterophyllus	4.85± 1.13[e]	Very strong
Aglaia tomentosa	5.15 ± 0.16[d]	Very strong

Note: Significant changes were noted by the different letters (Tukey's HSD; $P < 0.05$).

Future research should explore this fruit for bioactivity tests, including anti-inflammatory, antiparasitic, and antibacterial effects. Cultivation of this plant is crucial to support the survival of the Tapanuli orangutan.

CONCLUSIONS AND RECOMMENDATIONS

Based on primary metabolite tests, such as proximate analysis and amino acid profiling, *Castanopsis argantea* is identified as the optimal food for the Tapanuli orangutan, meeting its nutritional requirements. For secondary metabolites, *Aglaia tomentosa* excels in phytochemical screening and total flavonoid content. The bioactive compounds in *Castanopsis argantea* include caffeine and flazin; in *Artocarpus heterophyllus*, synephrine and schinifoline; and in *Aglaia tomentosa*, artoindonesianin B and 2,5-di-tert-butylhydroquinone. The highest antioxidant activity is observed in *Artocarpus heterophyllus*. A conservation strategy involving the cultivation of these three plants is recommended. This research also informs habitat restoration efforts, emphasizing plant species that are primary food sources for orangutans. Additionally, data on food content can be utilized to monitor orangutan population health.

ACKNOWLEDGMENTS

We would like to express our gratitude to the Higher Education Funding Agency (BPPT) of the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, through the Education Fund Management Agency (LPDP), for funding this research (00723/J5.2.3./BPI.06/9/2022). We also thank Universitas HKBP Nommensen Pematangsiantar for supporting the provision of field laboratory equipment. Additionally, this research is partially supported by the Brawijaya University Professorship Research Grant 2024.

NOVELTY STATEMENT

There has been no research regarding the content of Tapanuli orangutan food such as amino acids, bioactive compounds, and antioxidant activity. Previous research was limited to the qualitative content of phytochemicals and their proximates. Data and information regarding phytochemical content, nutrition, and antioxidant activity will be useful for the health of Tapanuli orangutans.

AUTHORS' CONTRIBUTIONS

Herna Febrianty Sianipar and Rezi Rahmi Amolia contributed to the data collection and manuscript drafting. The manuscript was corrected by Wahyu Widoretno, Luchman Hakim, and Fatchiyah Fatchiyah.

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this article.

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