



## PHYTOCHEMICAL SCREENING, NUTRITIONAL PROFILING AND ENZYMATIC ACTIVITY OF THE LIPOSU (*Baccaurea lanceolata*) PULPAS POTENTIAL ANTI-OBESITY AGENT

MOHD NAZRI ABDUL RAHMAN<sup>1,2\*</sup>, TAN YEW MING<sup>1</sup>, NOR HAYATI MUHAMMAD<sup>3</sup>, NURUL HUDA<sup>4</sup>, MOHD KHALIZAN SABULLAH<sup>5</sup> AND HALID SHERIFF ADEGBUSI<sup>6</sup>

<sup>1</sup>Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu Sabah, Malaysia.

<sup>2</sup>Nutritional Biochemistry Research Group, Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia. <sup>3</sup>Centre of Foundation Studies, Universiti Teknologi MARA, Selangor Branch, Dengkil Campus, 43800 Dengkil, Selangor, Malaysia. <sup>4</sup>Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Locked Bag No. 3, 90509 Sandakan, Sabah, Malaysia. <sup>5</sup>Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu Sabah, Malaysia. <sup>6</sup>Department of Biological Sciences, Nigeria Police Academy, Wudil, Kano. PMB 3474, Maiduguri Road, Kano State, Nigeria.

\*Corresponding author: [mdnazri@ums.edu.my](mailto:mdnazri@ums.edu.my)

### ARTICLE INFO

#### Article History:

Received: 12 September 2024

Revised: 6 April 2025

Accepted: 22 September 2025

Published: 15 February 2026

#### Keywords:

Liposu, *Baccaurea lanceolata*, phytochemicals, nutritional profiling, enzymatic activity, anti-obesity.

### ABSTRACT

Liposu (*Baccaurea lanceolata*) is an underutilised tropical fruit with potential health benefits that have not been extensively studied. Despite its promise, the nutritional composition and functional properties of liposu remain poorly understood. With rising obesity rates and the increasing need for natural alternatives, this study aimed to characterise the nutritional composition, phytochemical content, and enzymatic activities of liposu pulp to evaluate its potential anti-obesity effects. Proximate analysis revealed a high moisture content ( $93.67 \pm 0.20\%$ ) and dietary fibre ( $61.69\%$ ), but minimal fat ( $0.00\%$ ) and carbohydrates ( $0.82 \pm 0.18\%$ ), indicating low caloric density. Its high acidity (pH 2.51) contributes to its sour taste. Liposu exhibited strong antioxidant activity ( $90.71 \pm 0.25\%$  DPPH inhibition) and high phenolic and flavonoid contents but showed moderate pancreatic lipase inhibition ( $22.20 \pm 0.42\%$ ). The unique nutritional and phytochemical composition of liposu suggests its potential use in low-calorie functional foods. Combined with other food sources, liposu could serve as a functional, fibre-rich ingredient for promoting health and supporting anti-obesity interventions.

© UMT Press

## Introduction

Malaysia, renowned for its rich and diverse tropical landscape has fostered the development of a wide variety of tropical fruits, plants, and wildlife. However, numerous indigenous fruits remain either undiscovered or underutilised by consumers. Liposu (*Baccaurea lanceolata*) is a fruit native to Southeast Asia, including Malaysia, Thailand, Indonesia, and the Philippines (Mojulat & Surugau, 2021a; John *et al.*, 2025). It is known by various names such as limpasu, kalampesu, and lampaong in different regions (Lim, 2012; Mojulat & Surugau, 2021a). The fruit grows in clusters on tree branches,

starting off green or purple and maturing to light brown or whitish yellow. Its flesh is translucent, white, and notably sour (John *et al.*, 2025). Despite extensive research on commonly eaten fruits, there is limited information available about liposu. Notably, a study by Abu Bakar *et al.* (2014b) revealed that liposu possesses antioxidant properties, with its flesh exhibiting the highest free radical scavenging activity, highlighting its potential health benefits.

The consumption of fruits rich in antioxidants and phytochemicals is widely acknowledged to have protective effects

against chronic diseases such as cardiovascular diseases, hypertension, and type 2 diabetes (Ofori, 2024). Generally, fruits are composed of carbohydrates, contributing to their sweetness, and contain minimal lipids and proteins. They are rich in dietary fibre, as well as vitamins C, E, and B, all of which possess essential antioxidant properties. Although fruits typically have low mineral content, they are crucial sources of various nutrients. According to Hoe and Siong (1999), the nutrient composition of liposu fruit per 100 g of edible portion includes significant amounts of water, carbohydrates, and dietary fibre, along with essential minerals and vitamins, indicating its potential as a nutritious food source.

Phytochemicals or secondary metabolites found in plants are natural bioactive compounds that promote health and prevent diseases (Kaushik *et al.*, 2021). These compounds possess pharmacological activities that can produce fewer side effects compared to modern medicine (Blahova *et al.*, 2021). Phytochemicals in fruits and vegetables have been shown to stimulate the immune system, slow cancer cell growth, and prevent DNA damage, among other health benefits (Alzate-Yepes *et al.*, 2023). Given its potential richness in phytochemicals, further research into liposu could unveil significant health benefits, making it a promising candidate for commercialisation and inclusion in diets.

The underutilisation of indigenous fruits like liposu leads to a lack of dietary diversity and missed opportunities for improving food and nutrition security. The sour taste of liposu has limited its consumption and commercial value. Moreover, there is scant information on its nutritional and phytochemical properties, making it difficult to evaluate its potential contributions to diet and health. This underutilisation represents a missed opportunity for enhancing food and nutrition security. Limited information on liposu's phytochemical, nutritional, and enzymatic characteristics further hampers its utilisation. Thus, exploring these aspects could significantly contribute to dietary adequacy and offer new nutritional and medicinal benefits.

Liposu is a readily available indigenous fruit in East Malaysia with potential nutritional and medicinal benefits. Indigenous fruits play a crucial role in enhancing food security, nutrition, health, and income in rural communities (Suwardi *et al.*, 2020). However, detailed knowledge about liposu's composition and health benefits remains fragmented. Understanding its nutritional profile, phytochemical contents, and enzymatic activities is essential for promoting its utilisation and commercialisation, ultimately contributing to food security and income generation.

Obesity has become a global health crisis, with its prevalence increasing at an alarming rate. The World Health Organisation (WHO) classifies obesity as a chronic disease associated with severe metabolic disorders such as type 2 diabetes, cardiovascular diseases, and hypertension. In Malaysia, obesity rates have reached concerning levels, with the National Health and Morbidity Survey (NHMS) reporting a significant rise in overweight and obese individuals in recent years. Lifestyle changes, poor dietary habits, and excessive consumption of high-calorie, processed foods have exacerbated this issue. Current pharmacological treatments for obesity often come with side effects, including gastrointestinal discomfort, liver toxicity, and dependency risks, limiting their long-term use.

Given these challenges, there is an urgent need for alternative, natural interventions to manage obesity safely and effectively. Functional foods and bioactive compounds derived from natural sources have gained attention for their potential role in weight management. Liposu fruit, being rich in bioactive compounds may offer therapeutic benefits by modulating metabolic pathways involved in fat accumulation and energy balance. Investigating its anti-obesity potential, alongside its overall nutritional and phytochemical properties could provide valuable insights into developing functional foods or nutraceuticals that support weight management while promoting overall health.

The objective of this study is to explore the potential health benefits and nutritional value of liposu fruit (*Baccaurea lanceolata*) as an underutilised fruit by determining its phenolic and flavonoid content, analysing its nutritional composition, and investigating its enzymatic activity with potential anti-obesity effects.

## Materials and Methods

### Raw Material

Mature liposu fruits (*Baccaurea lanceolata*) (3 kg), characterised by their creamy white skin and uniform size and shape were sourced from Kampung Lasau Tintapon in Kota Belud, Sabah, Malaysia. According to Mojulat and Surugau (2021a), the maturity classification of liposu fruit is categorised into three stages: Young, maturing, and mature. These stages are distinguished by variations in fruit skin coloration. Young fruits exhibit a purple skin while maturing or mid-developing fruits display a green skin. Fruits with a creamy white or yellowish-white skin are classified as mature, whereas those with a light brown or brown skin are considered fully matured. The fruits were refrigerated at  $-18^{\circ}\text{C}$  and used within one month.

### Chemicals and Reagents

Various chemicals and reagents were used for phytochemical screening, nutritional profiling, and enzymatic activity assays. These included glacial acetic acid (Merck, Germany), Folin-Ciocalteu's reagent (Sigma-Aldrich, USA), sodium hydroxide (Fisher Chemical, UK), sodium carbonate (R&M Chemicals, Malaysia), gallic acid (Sigma-Aldrich, USA), aluminium chloride (R&M Chemicals, Malaysia), potassium acetate (Sigma-Aldrich, USA), rutin (MedChemExpress, USA), 2,2-diphenyl-1-picrylhydrazyl (DPPH) (Sigma-Aldrich, USA), Trolox (Sigma-Aldrich, USA), and other analytical-grade chemicals sourced from reputable suppliers, including Merck, Sigma-Aldrich, R&M Chemicals, MedChemExpress, Lab Scan, Fisher Chemical, and Megazyme.

### Sample Preparation

Selected liposu fruits were rinsed, peeled, and deseeded. The flesh was used for nutritional profiling, a portion was lyophilised, ground into a fine powder, and stored at  $-20^{\circ}\text{C}$  for extraction and analysis.

### Sample Extraction

Adapted from Abu Bakar *et al.* (2014b), 80% methanol was used to extract the liposu fruit powder at a ratio of 1:20. The mixture was shaken for 12 hours at 200 rpm at room temperature, then, filtered using Whatman No. 1 filter paper. The extract was used for phenolic, flavonoid, DPPH, and Porcine Pancreatic Lipase (PPL) assays.

### Experimental Design

The study conducted at the Faculty of Food Science and Nutrition, Universiti Malaysia Sabah (UMS), from March 2023 to February 2024, involved laboratory-based phytochemical screening, nutritional profiling, and enzymatic activity assays of liposu pulp. The pulp was chosen due to its high phytochemical content and antioxidant activity, as reported by Abu Bakar *et al.* (2014b).

### Phytochemical Screening

#### Phenolic Content

The phenolic content of liposu pulp extracts was determined using the Folin-Ciocalteu reagent, following the method described by Abu Bakar *et al.* (2014a), Mojulat and Surugau (2021b), and Jaradat *et al.* (2021a). The samples were mixed with 10% Folin-Ciocalteu reagent and 7.5% sodium carbonate, incubated, and the absorbance was measured at 765 nm using a spectrophotometer. The determination of phenolic content involved constructing a calibration curve for gallic acid through serial dilutions. The results were expressed as milligrams of Gallic Acid Equivalent (GAE) per gram of sample.

### Flavonoid Content

The phenolic compounds were quantified using the Folin-Ciocalteu reagent, following the method described by Abu Bakar *et al.* (2014a), Mojulat and Surugau (2021b), and Jaradat *et al.* (2021a). The samples were mixed with 10% Folin-Ciocalteu reagent and 7.5% sodium carbonate, followed by incubation, and the absorbance was measured at 765 nm using a spectrophotometer. The results were expressed as milligrams of Gallic Acid Equivalent (GAE) per gram of sample.

The determination of flavonoid content involved the construction of a calibration curve for quercetin through serial dilutions. Working solutions were prepared by mixing each sample with methanol, 10% aluminium chloride ( $\text{AlCl}_3$ ), 1 M potassium acetate, and distilled water, followed by incubation at room temperature for 30 minutes. The absorbance was recorded at 415 nm using a blank solution as a reference. The flavonoid content was calculated using the calibration curve of rutin and expressed as milligrams of rutin equivalent per gram of sample (mg RUE/g).

### DPPH Scavenging Activity Assay

Adapted from Jaradat *et al.* (2021b), the DPPH radical scavenging assay involved diluting liposu pulp extract and mixing it with a DPPH solution. The mixture was incubated in the dark and absorbance was measured at 517 nm. The percentage of inhibition was calculated using Equation (1).

$$\% \text{ DPPH inhibition} = (A_B - A_E) / A_B \times 100\% \quad (1)$$

where  $A_B$  represents the recorded absorbance of the control solution and  $A_E$  represents the recorded absorbance of the liposu sample solution. This equation was used in the analytical study to determine the percentage of DPPH inhibition.

### Nutritional Profiling

#### Total Soluble Solids, pH, and Titratable Acidity

The physicochemical properties of liposu fruit (*Baccaurea lanceolata*) were evaluated by

measuring Total Soluble Solids (TSS), pH, and Titratable Acidity (TA). TSS was determined using a digital refractometer (e.g., Atago PAL-1, Japan) and expressed in degrees Brix ( $^{\circ}\text{Brix}$ ), indicating the concentration of dissolved sugars and other soluble solids in the fruit pulp (Abu Bakar *et al.*, 2014b; Mojulat & Surugau, 2021b).

The pH of the liposu pulp was measured using a digital pH meter (e.g., Mettler Toledo FiveEasy Plus), which was calibrated with standard buffer solutions (pH 4.0 and 7.0) before analysis to ensure accuracy (Jaradat *et al.*, 2021a). pH is an important parameter influencing fruit quality, acidity perception, and microbial stability.

TA was assessed through titration with 0.1 M sodium hydroxide (NaOH) using phenolphthalein as an indicator. The endpoint was determined by a persistent light pink colour, indicating the neutralisation of organic acids present in the fruit. TA was expressed as a percentage of citric acid equivalent per 100 g of sample (AOAC, 2023). This measurement provides insight into the acidity level of liposu fruit, which affects flavour, stability, and potential applications in food products.

### Ash Content

Ash content was determined using the AOAC (2023) method 923.03, which employs the dry ashing method. In brief, a crucible was preheated to  $105^{\circ}\text{C}$  for 3 hours, then, cooled in a desiccator, weighed, and marked as (a). A sample of 2 g was placed into the crucible and weighed (b). The sample was incinerated in a cold muffle furnace set at  $550^{\circ}\text{C}$  for at least 3 hours, until a whitish/greyish ash was obtained. The weight of the crucible containing the ash was recorded as (c). The ash content (%) was calculated using Equation (2).

$$\text{Ash content (\%)} = \frac{c - b}{b - a} \times 100 \quad (2)$$

a = weight of empty preheated crucible (g)

b = weight of crucible with sample before heating (g)

c = weight of crucible with sample after heating (g)

*Carbohydrate Content*

The carbohydrate content was determined following the AOAC (2023) by difference method, using Equation (3).

$$\text{Carbohydrate content (\%)} = 100\% - (a + b + c + d) \quad (3)$$

- a = moisture content
- b = ash content
- c = protein content
- d = fat content

*Fat Content*

Fat content was determined according to the AOAC (2023) method using the Soxhlet extraction method with the Soxtec™ 2050 Automatic System (FOSS). Briefly, a 2 g sample was placed into a cellulose thimble, covered with wool, and weighed (a). The extraction was performed in the Soxtec™ 2050 Automatic System (FOSS) using petroleum ether for 10 hours. After extraction, the flask was removed from the Soxtec machine and placed in a hot air oven at 105°C for 30 minutes, then, cooled in a desiccator, and the weight was recorded (b). The fat content (%) was calculated using Equation (4).

$$\text{Fat content, \%} = \frac{b - a}{c} \times 100\% \quad (4)$$

- a = weight of flask with sample before extraction
- b = weight of flask with sample after extraction (g)
- c = weight of sample (g)

*Moisture Content*

The determination of moisture content was conducted according to the AOAC (2023) hot air oven method. An empty crucible was placed in a hot air oven at 105°C overnight. The crucible was then transferred to a desiccator to cool. Once cooled, the crucible was weighed and recorded as (a). A 2 g sample was placed into the crucible, weighed, and recorded as (b). The crucible containing the sample was then placed back in the oven at 105°C overnight. After this, the crucible was weighed again and recorded as

(c). The moisture content was calculated using Equation (5).

$$\text{Moisture content, \%} = \frac{b - c}{b - a} \times 100\% \quad (5)$$

- a = weight of empty preheated crucible (g)
- b = weight of crucible with sample before heating (g)
- c = weight of crucible with sample after heating (g)

*Protein Content*

The protein content of the sample was determined based on the principle of the Kjeldahl method (AOAC, 2023). Liposu samples were weighed accordingly and placed into a digestion tube. Concentrated sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) was then added to the digestion tube, which was heated at the highest temperature for 1 hour and 30 minutes or until the solution became clear.

Afterwards, the distillation and titration processes were carried out using the Kjeltec™ 2300 Analyser Unit (FOSS). NaOH solution was used in the distillation process with boric acid (H<sub>3</sub>BO<sub>3</sub>), followed by titration with hydrochloric acid. All chemical reagents were prepared and kept in the solution tank together with the KJELTEC instrument. To convert the measured nitrogen content to protein content, a conversion factor of 6.25 was used. The protein content (%) was calculated using Equation (6).

$$\text{Protein content (\%)} = \frac{(a - b) \text{ml} \times N \times 1.40 \times 6.25 \times 100}{w(\text{g}) \times 1000} \quad (6)$$

- a = volume of HCl in sample titration (mL)
- b = volume of HCl in titration without sample (mL)
- N = HCl normality
- w = weight of the sample
- 14.0 = nitrogen atomic mass
- 6.25 = nitrogen conversion factor

*Total Dietary Fibre*

The determination of dietary fibre content was carried out using the Enzymatic – Gravimetric method, adapted from Baenas *et al.* (2020). A duplicate set of 1 g liposu pulp samples was weighed in a 50 mL phosphate buffer solution,

ensuring a pH of  $6.0 \pm 0.1$ . Sequential enzymatic digestion was performed on the samples, beginning with the addition of 50  $\mu\text{L}$  of heat-stable  $\alpha$ -amylase, followed by incubation at  $95^\circ\text{C}$  for 30 minutes.

Once the solution cooled to room temperature, the pH was adjusted to  $7.5 \pm 0.1$  by adding 10 mL of 0.275N NaOH solution, and the pH was verified. Subsequently, 100  $\mu\text{L}$  of protease was introduced and the mixture was incubated at  $60^\circ\text{C}$  with continuous agitation for 30 minutes. The solution was then allowed to cool and 10 mL of 0.325N HCl solution was added to adjust the pH to  $4.5 \pm 0.2$ , followed by a final pH verification.

Next, 200  $\mu\text{L}$  of amyloglucosidase was added to the mixture and incubated at  $60^\circ\text{C}$  for 30 minutes to complete the enzymatic digestion. Following digestion, 280 mL of 95% ethanol, preheated to  $60^\circ\text{C}$  was added to facilitate precipitation, which occurred at room temperature. A blank crucible was weighed and 1 g of Celite 545 was added as a filtration aid.

The Celite was then wetted with 78% ethanol using the Fibertec filtering aid system. Suction was applied to ensure the formation of a uniform Celite mat. The precipitated fibre was filtered using the Fibertec system and the residue was sequentially washed with three 20 mL portions of 78% ethanol, followed by two 10 mL portions of 95% ethanol, and finally two 10 mL portions of acetone. The crucible containing the residue was then dried overnight in a  $105^\circ\text{C}$  air oven. After drying, the residue was cooled in a desiccator and subsequently weighed to determine the final mass.

The weight of the residue was calculated by subtracting the weights of the crucible and Celite. One portion of the sample was analysed for protein and the other was incinerated at  $525^\circ\text{C}$  for ash content determination.

Determination of the blank:

$$\text{Blank (B) (mg)} = \text{weight residue} - P_B - A_B \quad (7)$$

weight residue = average of residue weights (mg) for duplicate blank determinations

$P_B$  = weight of protein

$A_B$  = weight of ash

Total Dietary Fibre (%)

$$= \frac{(\text{weight residue} - P - A - B)}{\text{weight sample}} \times 100 \quad (8)$$

weight residue = average of weight (mg) for duplicate blank determination

$P$  = weight of Protein (in first and second sample residues)

$A$  = weight of Ash (in first and second sample residues)

weight sample = average of 2 sample weights (mg)

### Porcine Pancreatic Lipase Inhibitory Assay

The porcine pancreatic lipase inhibitory assay was adapted from Jaradat *et al.* (2021b). To prepare the plant extract fractions, a stock solution of 500  $\mu\text{g/mL}$  was made in 10% dimethylsulfoxide (DMSO) and then five different solutions were prepared with concentrations of 50  $\mu\text{g/mL}$ , 100  $\mu\text{g/mL}$ , 200  $\mu\text{g/mL}$ , 300  $\mu\text{g/mL}$ , and 400  $\mu\text{g/mL}$ . A stock solution of porcine pancreatic lipase enzyme was prepared at a concentration of 1 mg/mL in Tris-HCl buffer. The substrate used in the study was p-nitrophenyl butyrate (PNPB), which was prepared by dissolving 20.9 mg in 2 mL of acetonitrile.

For each working test tube, 0.1 mL of the enzyme solution was mixed with 0.2 mL of each diluted plant extract fraction. The mixture was brought to a total volume of 1 mL with Tris-HCl solution and incubated at  $37^\circ\text{C}$  for 15 minutes. After the incubation period, 0.1 mL of PNPB solution was added to each test tube, which was then incubated for another 30 minutes at  $37^\circ\text{C}$ . The activity of the pancreatic lipase was determined by measuring the hydrolysis of PNPB into p-nitrophenolate ions at 410 nm using a UV spectrophotometer. Orlistat was used as a standard reference compound and the same procedure was repeated with it. The equation used in this analytical study is shown below:

$$\% \text{ Lipase inhibition} = (A_B - A_E)/A_B \times 100\% \quad (9)$$

$A_B$  is the recorded absorbance of the blank solution;  $A_E$  is the recorded absorbance of the liposu sample solution.

### Statistical Analysis

Experiments were conducted in triplicate and the results were expressed as mean values  $\pm$  standard deviation (mean  $\pm$  SD). Statistical analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) version 26, where the mean and standard deviation were calculated to assess data variability. Descriptive statistics were applied to summarise the data, ensuring the accuracy and reproducibility of the findings.

## Results and Discussion

### Phytochemical Screening

#### Phenolic and Flavonoid Content

Phytochemical analysis revealed that the phenolic content was  $6.34 \pm 0.05$  mg GAE/g while the flavonoid content was  $5.47 \pm 0.15$  mg RUE/g in liposu pulp (Table 1). These values were higher than those reported in previous findings by Abu Bakar *et al.* (2014b). The differences in phenolic and flavonoid content may be attributed to variations in fruit ripeness, as the maturity stage significantly influences the accumulation of bioactive compounds. In this study, mature liposu fruits, characterised by creamy white skin were used for analysis. However, Abu Bakar *et al.* (2014b) did not specify the ripeness stage of the fruit used in their study, which may contribute to discrepancies in the reported phytochemical content. Future studies should standardise the ripeness condition to allow for more accurate comparisons.

The calculations were based on the gallic acid and quercetin standard curves. Although the concentrations are relatively moderate,

they possess health-promoting effects such as lowering the risk of cancer, cardiovascular diseases, and diabetes (Hadidi *et al.*, 2024).

These compounds are known for their antioxidant, anti-inflammatory, and antimicrobial properties. The differences in phytochemical content could be due to environmental factors such as soil quality, water availability, and sunlight exposure (Cruz-Carrión *et al.*, 2023).

In the current research, liposu fruit was sourced from Kota Belud, whereas the liposu fruits studied by Abu Bakar *et al.* (2014b) were obtained from Beaufort. Although both belong to the same species, differences in growing regions may influence the synthesis of phenolic compounds in the fruit. Various environmental factors, including sunlight exposure, temperature, and soil nutrition can significantly impact the production of secondary metabolites, leading to variations in nutritional and phenolic composition (Pant *et al.*, 2021; Qaderi *et al.*, 2023). Liposu is a fruit that thrives in diverse habitats, including rainforests, slopes, and riverine forests, these varying ecological conditions may contribute to differences in its phytochemical profile.

Additionally, the ripeness of the fruit plays a crucial role in determining its phenolic content. As the fruit matures, phenolic compounds typically accumulate, reaching peak levels before gradually declining as over-ripening progresses and chlorophyll degradation occurs. This trend has been observed in several fruits, where phenolic content decreases with advanced maturity, as reported in date palm (*Phoenix dactylifera*), strawberry (*Fragaria*  $\times$

Table 1: Phenolic and flavonoid content of liposu pulp

Analysis	$y=mx+c$ (Standard Curve)	<i>Baccaurea lanceolata</i> (80% Methanol)
Phenolic content	$y= 6.3466x + 0.0103$	$6.34 \pm 0.05$
Flavonoid content	$y= 1.0449x + 0.0182$	$5.47 \pm 0.15$

Result of phenolic content is expressed as (mg GAE/g sample).

Result of flavonoid content is expressed as (mg RUE/g sample).

*ananassa*), and mulberry (*Morus* spp.) (O'Brien et al., 2021; Abdalla et al., 2022).

The changes in phenolic content in fruits during maturation are related to the synthesis of polyphenols, which occurs in the phenylpropanoid metabolic pathway under enzymatic control (Khedr & Khedr, 2024). This is because the synthesis of these compounds changes according to the maturation stage of the fruits, as enzyme activity also changes during the different phases of growth and development of the fruits (Topcu et al., 2022).

#### *DPPH Scavenging Activity*

Liposu pulp exhibited high DPPH scavenging activity at  $90.71 \pm 0.25\%$  (Table 2), indicating strong antioxidant capacity similar to previous reports by Abu Bakar et al. (2014b), which recorded  $94.36 \pm 0.02\%$ .

This suggests that liposu is rich in bioactive compounds highly capable of neutralising free radicals and protecting against oxidative stress. It possesses characteristics that enable it to exert synergistic effects in reducing the risk of chronic diseases, particularly diabetes mellitus and obesity (Chaudhary et al., 2023). This high DPPH activity also indicates that liposu is rich in bioactive compounds, including phenolic acids, flavonoids, and vitamins.

Thus, consuming liposu fruit would also bring benefits such as countering lipid peroxidation, DNA damage, inflammation, and other oxidative stressors associated with chronic disease (Chaudhary et al., 2023). According to Shen et al. (2022) and Lupu et al. (2024), fruits with high antioxidant properties not only increase the antioxidant capacity of human blood

but also can counterbalance the negative effects of high-fat and carbohydrate meals, decreasing the risk of developing diseases, which results in a significant advantage for patients with diabetes and obesity. Fruits with high antioxidant properties are also shown to significantly reduce cancer, Alzheimer's disease, diabetes, and heart diseases (Rahaman et al., 2023). Thus, liposu might be able to contribute as a potential anti-obesity agent.

However, fruits and vegetables primarily serve as a source of phytochemicals only when they are in their raw and unprocessed state. If they undergo processing, their phytochemical bioavailability might decrease (Jideani et al., 2021). Liposu (*Baccaurea lanceolata*) is traditionally utilised in the preparation of local chili paste, known as sambal (John et al., 2025). However, the process of blending liposu into sambal may lead to a reduction in its antioxidant capacity.

This decline is likely due to the degradation of heat-sensitive antioxidants during the cooking process, as well as potential interactions with other ingredients that can affect the stability of these compounds (Mojulat & Surugau, 2021b). While specific studies on liposu's antioxidant retention in sambal are limited, similar trends have been observed in other fruits where processing methods impact their phytochemical content. Therefore, further research is warranted to quantify the extent of antioxidant loss in liposu when incorporated into sambal and to explore strategies for preserving its beneficial properties during food processing and culinary applications such as in yogurt production (Ismanto et al., 2022).

Table 2: Calculation of antioxidant activity of liposu pulp

Sample	Antioxidant Activity (%)	Mean	SD
I	90.47	90.71	0.25
II	90.96		
III	90.70		

### Nutritional Profiling of Liposu

#### Total Soluble Solids, pH, and Total Titratable Acidity

TSS measure the combined content of all soluble components in the liquid portion of the fruit. It indicates the concentration of sugars, acids, vitamins, amino acids, and other water-soluble compounds present. The TSS of liposu pulps is 2.7 °Brix, suggesting that the fruit contains very low levels of sugars and sugar alcohols, as fruits with a high Brix value typically consist of approximately 85% sugars (sucrose, glucose, and fructose) and sugar alcohols such as sorbitol and mannitol. Nearly 75% to 85% of the TSS of juice is made up of sugars and higher TSS values correspond with increased sweetness (El-Hadary *et al.*, 2023). Therefore, the sour taste of liposu may be attributed to its lack of sugars, which results in it being underutilised as a native fruit due to its unpleasant taste (bland and sour). However, TSS may not always align with the sensory sweetness of certain fruits, as some studies have reported a low association between soluble solids and sweetness in fruits.

The titratable acidity of liposu is 28.2 ± 0.85, indicating a high concentration of acidic protons that can be neutralised by titration with sodium hydroxide. The low pH value of 2.54 confirms that liposu is a highly acidic fruit. This acidic nature is likely due to the presence of organic acids within the fruit (Table 3). The high acidity of liposu pulp may explain why this fruit has a very sour taste, as sourness is triggered by low pH. The high acidity suggests that liposu could be applicable as a food acidulant or acidity regulator, similar to indigenous fruits such as *Garcinia indica*, *Embllica officinalis*, and *Tamarindus indica*, which also have low pH

and high antioxidant capacity (Tripathi, 2021; Chattopadhyay *et al.*, 2023).

#### Ash Content

The ash content of liposu pulp was determined to be 0.50 ± 0.03%, which is comparable to the findings reported by Mojulat and Surugau (2021b). A low ash content indicates a minimal presence of minerals and metal residues remaining after combustion. Although liposu pulp has a low ash content, this may suggest that it possesses a relatively mild flavour profile aside from its inherent sourness. Minerals present in ash can contribute to the overall taste of fruits, influencing their flavour complexity (Vicente *et al.*, 2022).

Therefore, low mineral levels in fruits can lead to diminished flavour profiles and less vibrant coloration. Minerals play a crucial role in the synthesis and stability of flavour compounds and pigments. For instance, a study on guava cultivars demonstrated that variations in mineral content significantly influenced postharvest quality attributes, including flavour and colour intensity (Kumari *et al.*, 2020). Additionally, research indicates that the biosynthesis of pigments such as carotenoids and anthocyanins responsible for fruit colouration is affected by mineral nutrition, with deficiencies leading to paler hues (Swami *et al.*, 2020; Kapoor *et al.*, 2022). Therefore, insufficient mineral levels can result in fruits with less appealing flavours and subdued coloration, potentially reducing consumer acceptance.

Table 3: Physicochemical properties of liposu pulp

Nutritional Parameters	Mean ± SD
pH	2.51 ± 0.00
Total soluble solid (°Brix)	2.7 ± 0.46
Titratable acidity	28.2 ± 0.85

The value is expressed in the mean ± the standard deviation (n=3).

\*n: triplicate on three reading.

The ash content of liposu, measured at 0.50% is comparable to other high-moisture fruits such as watermelon (0.36%) and pomegranate (0.60%). This suggests that liposu pulp likely shares similar mineral composition characteristics, with relatively low levels of essential minerals such as iron, calcium, magnesium, and chloride (Subedi, 2023). The combination of high moisture content and low ash percentage indicates that liposu is predominantly composed of water, with minimal dissolved solids or salts contributing to its overall ash content.

#### *Carbohydrate Content*

The carbohydrate content of liposu is also shown to be very low, at a value of  $0.82 \pm 0.18\%$ . According to the review by Hoe and Siong (1999), liposu contains 3.7% carbohydrate, which is not in agreement with the current findings. Nonetheless, the value of  $0.82 \pm 0.18\%$  indicates that liposu contains very few components that supply energy, including sugars and other starches. This is also reflected in the low Total Soluble Solids (TSS) value in liposu. While it has an extremely low carbohydrate content, it means that liposu would have very low caloric density and glycaemic impact.

Therefore, it would not produce significant spikes in blood glucose after consumption. This is particularly important for liposu as a potential fruit for the treatment of obese patients, as it has the potential to be applied in specialty diets and low-calorie formulations. The low carbohydrate value also highlights the opportunities for liposu to aid in diabetes management and obesity. According to the study by Alalwan *et al.* (2020), consuming low glycaemic index fruits can help control lipid profiles and fasting blood glucose levels in overweight adults. Another study by Chiavaroli *et al.* (2021) also demonstrated that increasing the intake of low glycaemic index fruit can lead to reductions in haemoglobin A1c, blood pressure, and coronary heart disease risk in type 2 diabetes patients.

#### *Fat Content*

The fat content of liposu pulps is  $0.01 \pm 0.00\%$ . This indicates that the fruit has very little fat, which is negligible. In the review by Mojulat and Surugau (2021b), a similar value was reported, with liposu containing only 0.2% fat. Therefore, based on this value, liposu is very low in calories, making it a potentially healthier choice for diabetic or obese patients, as it is unlikely to contribute significant calories.

The lowfat content also suggests that the fruit lacks a smooth or creamy texture. Instead, the texture of liposu is waterier and crunchier, rather than rich and indulgent, which can be attributed to its high moisture and low-fat content. This aligns with the high moisture content of liposu, which is watery in nature and lacks the creamy texture found in fruits like durian. Additionally, the pulps of liposu taste bland and sour, likely due to their low fat content, as fat contributes to flavour, texture, and aroma compounds such as esters. Consequently, low-fat fruits tend to possess a relatively simple flavour profile.

#### *Moisture Content*

Table 4 shows the nutritional profiling of liposu (*Baccaurea lanceolata*). When compared to the ash, carbohydrate, and fat content, which all have values below 1%, the moisture content accounts for nearly the entirety of the fruit. The moisture content of liposu is similar to the finding by Mojulat and Surugau (2021b), which reported a value of 92.4%.

The current study focuses on the mature form of the liposu fruit. A mature liposu contains a higher moisture content, as it accumulates more water during the ripening process. This high moisture content refers to the amount of water present in the fruit relative to its total weight, meaning that a significant portion of the fruit's weight is due to moisture.

While this high moisture content affects the texture, juiciness, and overall sensory experience of the fruit, it also results in a sourer taste as the fruit reaches maturity. This sourness can be attributed to the moisture levels in the

Table 4: Nutritional composition of liposu pulp

Nutritional Parameters (%)	Mean $\pm$ SD
Ash content	0.50 $\pm$ 0.03
Moisture content	93.67 $\pm$ 0.20
Available carbohydrate	0.82 $\pm$ 0.18
Fat content	0.00 $\pm$ 0.00
Protein content	5.01 $\pm$ 0.03
Total dietary fibre	61.69

The value is expressed in the mean  $\pm$  the standard deviation (n=3).

\*n: triplicate on three reading.

fruit. Furthermore, research on other fruits such as oranges has shown that maturation is associated with changes in physicochemical and sensory characteristics, including an increase in juice content and the TSS/acid ratio (Habibi *et al.*, 2021).

Studies have also indicated that the moisture content of fruits increases as they approach maturity (Ameen *et al.*, 2023). This suggests that the more mature the fruit, the wetter it becomes. When storing liposu, it is important to avoid high-humidity conditions, as high-moisture fruits, including mangoes are prone to spoilage under such conditions (Hussen, 2021). Although high humidity can delay weight loss and prevent shrivelling, it can also lead to quicker cracking and browning of the fruit.

### **Protein Content**

Liposu pulp has a protein content of 5.01  $\pm$  0.03%. The protein constitutes a relatively small portion of the fruit's overall value. However, the findings by Hoe and Siong (1999) indicated that the protein content of *Baccaurea lanceolata* is 0.2%, which does not correspond with the results obtained in this study. This discrepancy may be attributed to factors such as the ripeness of the fruit and the conditions under which the fruit is grown. For example, since the fruit in the current research is mature, it may have a higher protein content due to its advanced ripeness level.

Studies have also shown that various fruits, including Asian pears, pineapples, tomatoes,

and elderberries consistently exhibit an increase in protein content as they mature (Huang *et al.*, 2024). Thus, the phenomenon of increasing protein content with maturity is observed in many fruits.

Additionally, the liposu pulp reported by Hoe and Siong (1999) was sourced from Sarawak while the liposu in this study is grown in Sabah. Therefore, the nutritional content of liposu may be influenced by the soil characteristics of different geographical regions, including variations in soil environment and cultivar differences within the same fruit species.

### **Total Dietary Fibre**

The total dietary fibre content of liposu pulp is 61.69%, suggesting that it can be an excellent source of dietary fibre. This has important nutritional implications, as it provides both insoluble and soluble fibre in the diet, requiring only small servings to meet fibre needs. With its high dietary fibre value, liposu has the potential to mitigate issues for patients with obesity. According to Snauwaert (2023), dietary fibre can assist with obesity by protecting the body against various conditions that may correlate with it such as cardiovascular disease, diverticulosis, constipation, irritable bowel syndrome, colon cancer, and diabetes.

Additionally, fibre that acts as prebiotics can support gut health, promote satiety, and maintain a balanced gut microbiota. Indigestible dietary fibres are fermented in the intestine, resulting in the production of metabolites that

can help support a healthy body weight and prevent dysbiosis associated with obesity. Furthermore, benefits such as improved insulin sensitivity, a lower risk of depression, and a reduced mortality rate have been linked to a high dietary fibre intake (Barber *et al.*, 2020).

Regular consumption of a high-fibre diet has been strongly associated with a reduced risk of inflammatory diseases due to its role in modulating gut microbiota, improving glycaemic control, and reducing systemic inflammation. Given that liposu is a rich source of dietary fibre, it has the potential to contribute to these health benefits. Additionally, the presence of other bioactive compounds such as phenolics and flavonoids may further enhance its anti-inflammatory and antioxidant properties, making it a suitable dietary option for individuals managing diabetes and obesity.

**Anti-obesity Activity**

*Porcine Pancreatic Lipase Inhibitory Assay*

Based on Table 5, pancreatic lipase is a digestive enzyme that breaks down triglycerides into fatty acids and glycerol. When pancreatic lipase is inhibited, fat absorption is reduced. The concentration of the PPL solution in the current experiment is 0.1 mL. Based on the results obtained, liposu pulps exhibit an inhibitory effect of  $22.20 \pm 0.42\%$ . This suggests that liposu has the capability to inhibit pancreatic lipase, although the level of inhibition is not high. This may be attributed to the polyphenol content present in liposu pulp, as the phenolic and flavonoid content is not high.

According to He *et al.* (2023), fruits with high polyphenol content, particularly flavonoids have a strong effect on pancreatic inhibition, which is linked to improved lipid metabolism by

reducing cholesterol and inhibiting pancreatic lipase enzymatic activity. Numerous studies have also found that phenolic acids possess a high ability to inhibit pancreatic lipase activity; for example, ligands such as vanillic acid contain a high number of hydroxyl groups that facilitate interaction with pancreatic lipase (He *et al.*, 2023; Nabil-Adam *et al.*, 2023). Therefore, pancreatic lipase inhibitory activity is highly correlated with the polyphenol content in fruits, resulting in the comparatively low PPL inhibition levels observed in liposu pulps.

Nonetheless, based on the study by Huang *et al.* (2020), the phenolic acids in the citrus fruits studied did not contribute to the lipase inhibitory effects. Hence, flavonoids, including anthocyanins, hesperidin, and caffeic acid glycosides may be more responsible for the PPL inhibitory effects that demonstrate inhibitory activity (He *et al.*, 2023). Further studies are needed to establish a clearer relationship between the polyphenolic compounds present in liposu and their potential to inhibit pancreatic lipase, a key enzyme in dietary fat digestion.

Pancreatic lipase inhibitors have been widely studied as therapeutic agents for obesity management, as they reduce fat absorption and promote lipid excretion, ultimately leading to weight loss and improved metabolic health. The presence of multiple polyphenolic compounds in liposu, including flavonoids and phenolics may act synergistically to enhance lipase inhibition, potentially regulating lipid metabolism and reducing adipogenesis.

Additionally, these bioactive compounds have demonstrated antioxidant and anti-inflammatory properties, which can further mitigate obesity-related complications such as insulin resistance, oxidative stress, and chronic low-grade inflammation. Therefore,

Table 5: Calculation of PPL inhibition of liposu pulp

Sample	PPL Inhibition (%)	Mean	SD
I	22.67	22.2	0.42
II	21.87		
III	22.06		

incorporating liposu into the diet may not only contribute to weight management but also provide protective effects against obesity-associated metabolic disorders, including type 2 diabetes and cardiovascular diseases. However, further in-depth mechanistic and clinical studies are required to validate these potential health benefits and to determine the optimal bioavailability and effective dosage of liposu polyphenols for therapeutic applications.

The inhibitory effects of liposu on pancreatic lipase may be influenced by the levels of phenolic and flavonoid compounds present in the fruit. Typically, phenolic and flavonoid content above 10 mg GAE/g and 8 mg RUE/g, respectively are considered high and have been associated with significant enzyme inhibition (Alkowni *et al.*, 2023). However, the phenolic and flavonoid content in liposu falls below these thresholds, which may explain the lower inhibitory effects observed.

This finding aligns with previous studies indicating that higher concentrations of these bioactive compounds correlate with stronger enzyme inhibition. Therefore, while liposu contains polyphenols, their levels may not be sufficient to exert a pronounced inhibitory effect on pancreatic lipase, necessitating further studies to explore their functional properties in greater detail.

## Conclusions

Liposu fruit (*Baccaurea lanceolata*) is a promising underutilised fruit containing bioactive compounds that may enhance metabolic health. Its high dietary fibre content suggests potential benefits for regulating glycaemic control, reducing fat absorption, and promoting satiety—mechanisms that could support weight management and aid in diabetes prevention. Additionally, the fruit's antioxidant properties may help mitigate oxidative stress, which is associated with obesity-related inflammation and insulin resistance.

Beyond its role in metabolic health, the bioactive compounds in liposu could be explored

for applications in nutraceuticals, functional foods, and pharmaceuticals. Future research should focus on elucidating its anti-obesity and anti-diabetic mechanisms, particularly concerning its effects on lipid metabolism, glucose homeostasis, and gut microbiota modulation. Investigating additional bioactive compounds such as saponins, tannins, and carotenoids could further reveal its therapeutic potential across various health domains. Clinical trials are necessary to validate its efficacy as a supplemental food or natural therapeutic agent for obesity and diabetes.

## Acknowledgements

The authors thank Universiti Malaysia Sabah (UMS) for their support through Geran Penyelidikan Bidang Keutamaan (SPBK) Fasa 1/2021 (grant no. SBK0483-2021) and Skim Geran Inovasi (SGI) UMS (grant code: SGI0168-2022).

## Conflict of Interest Statement

The authors declare that they have no conflict of interest.

## References

- Abdalla, N., El-Ramady, H., Seliem, M. K., El-Mahrouk, M. E., Taha, N., Bayoumi, Y., Shalaby, T. A., & Dobránszki, J. (2022). An academic and technical overview on plant micropropagation challenges. *Horticulturae*, 8(8), 677. <https://doi.org/10.3390/horticulturae8080677>
- Abu Bakar, M. F., Mohamed, M., Rahmat, A., & Fry, J. (2014a). Phytochemical and antioxidant properties of *Baccaurea* species. *Food Chemistry*, 146, 97-103.
- Abu Bakar, M. F., Ahmad, N., Karim, F., & Saib, S. (2014b). Phytochemicals and antioxidative properties of Borneo indigenous Liposu (*Baccaurea lanceolata*) and tampoi (*Baccaurea macrocarpa*) fruits. *Antioxidants*, 3(3), 516-525. <https://doi.org/10.3390/antiox3030516>

- Alalwan, T. A., Perna, S., Mandeel, Q. A., Abdulhadi, A., Alsayyad, A. S., D'Antona, G., Negro, M., Riva, A., Petrangolini, G., Allegrini, P., & Rondanelli, M. (2020). Effects of daily low-dose date consumption on glycemic control, lipid profile, and quality of life in adults with pre-and type 2 diabetes: A randomised controlled trial. *Nutrients*, *12*(1), 217. <https://doi.org/10.3390/nu12010217>
- Alkowni, R., Jaradat, N., & Fares, S. (2023). Total phenol, flavonoids, and tannin contents, antimicrobial, antioxidant, vital digestion enzymes inhibitory and cytotoxic activities of *Verbascum fruticosum*. *European Journal of Integrative Medicine*, *60*, 102256. <https://doi.org/10.1016/j.eujim.2023.102256>
- Alzate-Yepes, T., Pérez-Palacio, L., Martínez, E., & Osorio, M. (2023). Mechanisms of action of fruit and vegetable phytochemicals in colorectal cancer prevention. *Molecules*, *28*(11), 4322. <https://doi.org/10.3390/molecules28114322>
- Ameen, M., Mahmood, A., Ahmad, M., Mansoor Javaid, M., Nadeem, M. A., Asif, M., Balal, R. M., & Khan, B. A. (2023). Impacts of climate change on fruit physiology and quality. In Hasanuzzaman, M. (Ed.), *Climate-resilient agriculture, Vol. 1* (pp. 93-124). Springer International Publishing. [https://doi.org/10.1007/978-3-031-37424-1\\_5](https://doi.org/10.1007/978-3-031-37424-1_5)
- Association of Official Analytical Chemists (AOAC). (2023). *Official Methods of Analysis of AOAC International* (22<sup>nd</sup> ed.). AOAC International.
- Baenas, N., Nuñez-Gómez, V., Navarro-González, I., Sánchez-Martínez, L., García-Alonso, J., Periago, M. J., & González-Barrío, R. (2020). Raspberry dietary fibre: Chemical properties, functional evaluation and prebiotic in vitro effect. *LWT*, *134*, 110140. <https://doi.org/10.1016/j.lwt.2020.110140>
- Barber, T. M., Kabisch, S., Pfeiffer, A. F., & Weickert, M. O. (2020). The health benefits of dietary fibre. *Nutrients*, *12*(10), 3209. <https://doi.org/10.3390/nu12103209>
- Blahova, J., Martiniakova, M., Babikova, M., Kovacova, V., Mondockova, V., & Omelka, R. (2021). Pharmaceutical drugs and natural therapeutic products for the treatment of type 2 diabetes mellitus. *Pharmaceuticals*, *14*(8), 806. <https://doi.org/10.3390/ph14080806>
- Chattopadhyay, K., Xavier, K. M., Ngasotter, S., Karmakar, S., Balange, A., & Nayak, B. B. (2023). Chitosan gel prepared with citric acid as the food acidulant: Effect of the chitosan concentration and gel pH on physicochemical and functional properties of fish protein emulsion sausages. *Acs Omega*, *8*(8), 7829-7837. <https://doi.org/10.1021/acsomega.2c07538>
- Chaudhary, P., Janmeda, P., Docea, A. O., Yeskaliyeva, B., Abdull Razis, A. F., Modu, B., Calina, D., & Sharifi-Rad, J. (2023). Oxidative stress, free radicals and antioxidants: Potential crosstalk in the pathophysiology of human diseases. *Frontiers in Chemistry*, *11*, 1158198. <https://doi.org/10.3389/fchem.2023.1158198>
- Chiavaroli, L., Lee, D., Ahmed, A., Cheung, A., Khan, T. A., Blanco, S., Mirrahimi, A., Jenkins, D. J. A., Livesey, G., Wolever, T. M. S., Rahelić, D., Kahleová, H., Salas-Salvadó, J., Kendall, C. W. C., & Sievenpiper, J. L. (2021). Effect of low glycaemic index or load dietary patterns on glycaemic control and cardiometabolic risk factors in diabetes: Systematic review and meta-analysis of randomised controlled trials. *BMJ*, *374*. <https://doi.org/10.1136/bmj.n1651>
- Cruz-Carrión, Á., Ruiz de Azua, Ma. J., Muguerza, B., Mulero, M., Bravo, F. I., Arola-Arnal, A., & Suarez, M. (2023). Organic vs. non-organic plant-based foods – A comparative study on phenolic content

- and antioxidant capacity. *Plants*, 12(1), 183. <https://doi.org/10.3390/plants12010183>
- El-Hadary, A. R. E., Sulieman, A. M., & El-Shorbagy, G. A. (2023). Comparative effects of hibiscus leaves and potato peel extracts on characteristics of fermented orange juice. *Journal of Food Quality and Hazards Control*, 10(1). <https://doi.org/10.18502/jfqhc.10.1.11988>
- Habibi, F., Guillén, F., Serrano, M., & Valero, D. (2021). Physicochemical changes, peel colour, and juice attributes of blood orange cultivars stored at different temperatures. *Horticulturae*, 7(9), 320. <https://doi.org/10.3390/horticulturae7090320>
- Hadidi, M., Liñán-Atero, R., Tarahi, M., Christodoulou, M. C., & Aghababaei, F. (2024). The potential health benefits of gallic acid: Therapeutic and food applications. *Antioxidants*, 13(8), 1001. <https://doi.org/10.3390/antiox13081001>
- He, X., Chen, L., Pu, Y., Wang, H., Cao, J., & Jiang, W. (2023). Fruit and vegetable polyphenols as natural bioactive inhibitors of pancreatic lipase and cholesterol esterase: Inhibition mechanisms, polyphenol influences, application challenges. *Food Bioscience*, 55, 103054. <https://doi.org/10.1016/j.fbio.2023.103054>
- Hoe, V. B., & Siong, K. H. (1999). The nutritional value of indigenous fruits and vegetables in Sarawak. *Asia Pacific Journal of Clinical Nutrition*, 8(1), 24-31. <https://doi.org/10.1046/j.1440-6047.1999.00046.x>
- Huang, J., Chen, J., Zhu, H., Zheng, Y., Zheng, J., Wen, X., Cai, S., Zhu, Y., Wu, Q., Chen, Z., & Wu, F. (2024). *Metabolomics combined with transcriptomics reveals the accumulation mechanism of the fruit pulp colour of *Baccaurea ramiflora* Lour.* <https://doi.org/10.21203/rs.3.rs-3964227/v1>
- Huang, R., Zhang, Y., Shen, S., Zhi, Z., Cheng, H., Chen, S., & Ye, X. (2020). Antioxidant and pancreatic lipase inhibitory effects of flavonoids from different citrus peel extracts: An in vitro study. *Food Chemistry*, 326, 126785. <https://doi.org/10.1016/j.foodchem.2020.126785>
- Hussen, A. (2021). Impact of temperature and relative humidity in quality and shelf life of mango fruit. *International Journal of Horticulture and Food Science*, 3(1), 46-50.
- Ismanto, A., Khizanatusani, L., Haris, M. I., Indana, K., & Wibowo, A. (2022). The effect of addition Lempahong (*Baccaurea lanceolata*) fruit extract on pH, organoleptic, and antioxidants of the making yoghurt. In *International Conference on Tropical Agrifood, Feed and Fuel (ICTAFF 2021)* (pp. 224-228). Atlantis Press. <https://doi.org/10.2991/absr.k.220102.033>
- Jaradat, N., Al Zabadi, H., Rahhal, B., Hussein, F., Al-Lahham, S., & Assadi, M. (2021a). Variability in phytochemical composition and antioxidant activity of wild *Baccaurea lanceolata* fruits. *Journal of Food Biochemistry*, 45(4), e13620.
- Jaradat, N., Dacca, H., Hawash, M., & Abualhasan, M. N. (2021b). *Ephedra alata* fruit extracts: Phytochemical screening, anti-proliferative activity and inhibition of DPPH,  $\alpha$ -amylase,  $\alpha$ -glucosidase, and lipase enzymes. *BMC Chemistry*, 15(1). <https://doi.org/10.1186/s13065-021-00768-9>
- Jideani, A. I., Silungwe, H., Takalani, T., Omolola, A. O., Udeh, H. O., & Anyasi, T. A. (2021). Antioxidant-rich natural fruit and vegetable products and human health. *International Journal of Food Properties*, 24(1), 41-67. <https://doi.org/10.1080/10942912.2020.1866597>
- John, O. D., Surugau, N., Kansedo, J., Panchal, S. K., & Brown, L. (2025). Plant-based functional foods from Borneo. *Nutrients*, 17(2), 200. <https://doi.org/10.3390/nu17020200>
- Kapoor, L., Simkin, A. J., George Priya Doss, C., & Siva, R. (2022). Fruit ripening: dynamics and integrated analysis of carotenoids and anthocyanins. *BMC Plant Biology*, 22(1),

27. <https://doi.org/10.1186/s12870-021-03411-w>
- Kaushik, B., Sharma, J., Kumar, P., & Shourie, A. (2021). Phytochemical properties and pharmacological role of plants: secondary metabolites. *Biosciences Biotechnology Research Asia*, 18(1), 23. <https://doi.org/10.13005/bbra/2894>
- Khedr, E. H., & Khedr, N. (2024). Enhancing productivity, modifying biochemical parameters, and regulating the phenylpropanoid pathway in 'Le-Conte' pears through optimal protocathechuic acid treatments. *BMC Plant Biology*, 24(1), 50. <https://doi.org/10.1186/s12870-023-04715-9>
- Kumari, P., Mankar, A., Karuna, K., Homa, F., Meiramkulova, K., & Siddiqui, M. W. (2020). Mineral composition, pigments, and postharvest quality of guava cultivars commercially grown in India. *Journal of Agriculture and Food Research*, 2, 100061. <https://doi.org/10.1016/j.jafr.2020.100061>
- Lim, T. K. (2012). *Baccaurea lanceolata*. In Lim, T. K. (Ed.), *Edible medicinal and non-medicinal plants*. Springer. [https://doi.org/10.1007/978-94-007-4053-2\\_31](https://doi.org/10.1007/978-94-007-4053-2_31)
- Lupu, A., Fotea, S., Jechel, E., Starcea, I. M., Ioniuc, I., Knieling, A., Salaru, D. L., Sasaran, M. O., Cirstea, O., Revenco, N., Mihai, C. M., Lupu, V. V., & Nedelcu, A. H. (2024). Is oxidative stress-antioxidants imbalance the physiopathogenic core in pediatric obesity?. *Frontiers in Immunology*, 15, 1394869. <https://doi.org/10.3389/fimmu.2024.1394869>
- Mojulat, M. P., & Surugau, N. (2021b). Characterisation and potential applications of *Baccaurea lanceolata* fruit: A review. *International Journal of Food Science & Technology*, 56(3), 1123-1135.
- Mojulat, M. B. C., & Surugau, N. (2021a). *IOP Conference Series: Earth and Environmental Science*, 736, 012042. <https://doi.org/10.1088/1755-1315/736/1/012042>
- Nabil-Adam, A., Ashour, M. L., Tamer, T. M., Shreadah, M. A., & Hassan, M. A. (2023). Interaction of *Jania rubens* polyphenolic extract as an antidiabetic agent with  $\alpha$ -amylase, lipase, and trypsin: In vitro evaluations and in silico studies. *Catalysts*, 13(2), 443. <https://doi.org/10.3390/catal13020443>
- O'Brien, C., Hiti-Bandaralage, J., Folgado, R., Hayward, A., Lahmeyer, S., Folsom, J., & Mitter, N. (2021). Cryopreservation of woody crops: The avocado case. *Plants*, 10(5), 934. <https://doi.org/10.3390/plants10050934>
- Pant, P., Pandey, S., & Dall'Acqua, S. (2021). The influence of environmental conditions on secondary metabolites in medicinal plants: A literature review. *Chemistry & Biodiversity*, 18(11), e2100345. <https://doi.org/10.1002/cbdv.202100345>
- Qaderi, M. M., Martel, A. B., & Strugnell, C. A. (2023). Environmental factors regulate plant secondary metabolites. *Plants*, 12(3), 447. <https://doi.org/10.3390/plants12030447>
- Rahaman, M. M., Hossain, R., Herrera-Bravo, J., Islam, M. T., Atolani, O., Adeyemi, O. S., Owolodun, O. A., Kambizi, L., Daştan, S. D., Calina, D., & Sharifi-Rad, J. (2023). Natural antioxidants from some fruits, seeds, foods, natural products, and associated health benefits: An update. *Food Science & Nutrition*, 11(4), 1657-1670. <https://doi.org/10.1002/fsn3.3217>
- Shen, N., Wang, T., Gan, Q., Liu, S., Wang, L., & Jin, B. (2022). Plant flavonoids: Classification, distribution, biosynthesis, and antioxidant activity. *Food Chemistry*, 383, 132531. <https://doi.org/10.1016/j.foodchem.2022.132531>
- Snauwaert, E., Paglialonga, F., Vande Walle, J., Wan, M., Desloovere, A., Polderman, N., Renken-Terhaerd, J., Shaw, V., & Shroff, R. (2023). The benefits of dietary fiber: The gastrointestinal tract and beyond. *Pediatric Nephrology*, 38(9), 2929-2938. <https://doi.org/10.1007/s00467-022-05837-2>

- Subedi, T. (2023). An assessment of mineral contents in fruits. *Prithvi Academic Journal*, 21-31. <https://orcid.org/0009-0009-9343-2809>
- Suwardi, A. B., Navia, Z. I., Harmawan, T., & Mukhtar, E. (2020). Ethnobotany and conservation of indigenous edible fruit plants in South Aceh, Indonesia. *Biodiversitas Journal of Biological Diversity*, 21(5). <https://doi.org/10.13057/biodiv/d210511>
- Swami, S. B., Ghgare, S. N., Swami, S. S., Shinde, K. J., Kalse, S. B., & Pardeshi, I. L. (2020). Natural pigments from plant sources: A review. *The Pharma Innovation Journal*, 9(10), 566-574.
- Topcu, H., Degirmenci, I., Sonmez, D. A., Paizila, A., Karci, H., Kafkas, S., Kafkas, E., Ercisli, S., & Alatawi, A. (2022). Sugar, invertase enzyme activities and invertase gene expression in different developmental stages of strawberry fruits. *Plants*, 11(4), 509. <https://doi.org/10.3390/plants11040509>
- Tripathi, P. C. (2021). Medicinal and therapeutic properties of minor fruits-a review. *International Journal of Minor Fruits, Medicinal and Aromatic Plants*, 7(2), 1-28.
- Vicente, A. R., Manganaris, G. A., Darre, M., Ortiz, C. M., Sozzi, G. O., & Crisosto, C. H. (2022). Compositional determinants of fruit and vegetable quality and nutritional value. In Florkowski, W. J., Banks, N. H., Shewfelt, R. L., & Prussia, S. E. (Eds.), *Postharvest handling* (pp. 565-619). Academic Press. <https://doi.org/10.1016/B978-0-12-822845-6.00019-1>