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RESEARCH ARTICLE

Phytochemical profile of native wild plants of Central Kalimantan with potential use for the development of functional foods and sustainable dietary interventions

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Abstract

The study investigates the phytochemical profiles of selected wild local vegetables in Central Kalimantan, Indonesia, assessing their potential health benefits in addressing nutritional deficiencies prevalent in the region. A comprehensive analysis was conducted on key metabolites, including phenols, flavonoids, carotenoids, alkaloids, phytosterol, terpenoid, saponin, and glucosinolates. The vegetables examined in this study included *Solanum torvum*, *Cnesmone javanica*, *Gymnopetalum cochinense*, *Stenochlaena palustris*, *Helminthostachys zeylanica*, *Nauclea orientalis*, *Neptunia oleraceae*, *Crinum* sp., *Etlingera elatior*, *Calamus* sp., *Solanum ferox*, *Colocasia esculenta*, *Diplazium esculentum*, and *Rorippa indica*. Using the Folin-Ciocalteu method, the total phenolic content in the ethanolic extract ranged from 107.20 to 7393.10 mg GAE 100 g^{-1}. Total flavonoids varied from 27.17-1163.82 mg QE 100 g^{-1} fresh weight. Carotenoids, alkaloids, phytosterols, terpenoid, saponin ranging from 1.273-1448.80 mg 100 g^{-1}, 78.94-1061.67 mg 100 g^{-1}, 168.33 - 4926.67 mg 100 g^{-1}, 914.44-15503.33 mg 100 g^{-1}, respectively. Additionally, saponins and glucosinolates were found in concentrations ranging from 1742.22 to 19164.44 mg 100 g^{-1}, and 92.4 to 4726.52 mg 100 g^{-1}, respectively. *N. orientalis*, *N. oleracea*, and *R. indica* showed strong potential as functional foods due to their high levels of antioxidants and anti-inflammatory compounds. *R. indica* and *D. esculentum* stand out for their rich carotenoid. Additionally, the substantial amounts of phytosterols, saponins, glucosinolates, and terpenoids in *N. oleracea*, *H. zeylanica*, *R. indica*, and *D. esculentum*. Linking phytochemicals to health supports targeted diets for vulnerable groups, strengthened through diverse local vegetables and culturally adapted functional food products.

Keywords: Dayak's tribe; food security; health benefit; underutilized vegetable.

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1. Introduction

The increasing prevalence of malnutrition and diet-related chronic diseases, particularly in developing regions, presents a significant public health challenge. Nutritional deficiencies, resulting from inadequate dietary diversity and the over-reliance on staple crops, have led to adverse health outcomes, including stunted growth, weakened immunity, and increased susceptibility to chronic diseases (Bechoff et al., 2023, Muridzo et al., 2024). Indigenous vegetables, often overlooked or underutilized, hold significant potential as a source of essential nutrients and bioactive compounds, potentially mitigating these nutritional deficits (Chaudhari et al., 2023, Durst & Bayasgalanbat, 2014, Talucder et al., 2024).

Central Kalimantan known for its vast tropical rain-forest and unique ecosystems, is home to a wealth of wild local vegetables consumed by indigenous communities for generations. These plants play an important role in local diets, providing essential nutrients and serving as important sources of food security, especially in rural areas (Afentina et al., 2020, Magandhi & Lestari, 2023). Many of these wild vegetables contain bioactive compounds with potential health benefits, making them valuable as functional foods and natural medicines. Despite their cultural and ecological significance, few scientific studies have focused on their phytochemical diversity (Agarwal et al., 2025, More et al., 2024, Patra et al., 2024, Ravetto Enri et al., 2024, Singh et al., 2023).

Local vegetables have been consumed for generations by the Dayak tribe, native to Central Kalimantan (Chotimah et al., 2013). For example, *Stenochlaena palustris* is one of the most popular local vegetables, believed to help treat anemia due to its high iron content (Chotimah et al., 2022). Similarly, the leaves of *Rorippa indica* have been traditionally utilized for their rich vitamins, minerals, and antioxidant content. However, a study conducted in the Heart of Borneo, Central Kalimantan, revealed energy consumption from fruits and vegetables remains below the recommended level (1.75% - 3.65%) compared to the 6% requirement suggested by Widyakarya's Food and Nutrition guidelines (Jagau et al., 2017).

Despite the widespread recognition of fruits and vegetables as essential components of a healthy diet, their consumption remains inadequate. National and international health authorities strongly advocate for their intake, as they are rich in vital nutrients and bioactive compounds, including terpenoids, carotenoids, phenolic acids, phytosterols, and glucosinolates. These compounds exhibit antioxidant, immunomodulatory, anti-osteoporotic, antihypertensive, antimicrobial, antidiabetic, and anticancer properties, contributing to a reduced risk of cardiovascular diseases and other health complications (Guldas et al., 2022, Rashmi & Negi 2020). Furthermore, epidemiological studies have demonstrated that regular fruits and vegetables play a crucial role in preventing chronic diseases (Kongkachuichai et al., 2015).

Recent studies suggest that several local vegetables have the potential to be developed into functional foods due to their significant levels of minerals, amino acids, phytochemicals, and antioxidants (Olugbuyi et al., 2023). Phytochemicals, recognized for their antioxidant and anti-nutritive properties, play a crucial role in human health (Sultanbawa & Sivakumar, 2022) and have gained attention for their protective effects against degenerative diseases (Mukherjee et al., 2022, Sharma et al., 2020). Regular and long-term consumption of these vegetables has been associated with a lower risk of obesity, cancer, atherosclerosis, inflammation, and metabolic syndrome (Shree et al., 2022). In addition, vegetables are rich sources of bioactive compounds such as flavonoids, carotenoids, and phenolic acids, which are essential for functional foods and medicinal applications (Banwo et al., 2021). Flavonoids, naturally present in vegetables, have been linked to reduced incidence of neuro-degenerative diseases (Achika et al., 2023). Specifically, flavonoids from *H. zeylanica* have shown potential as anti-inflammatory, anti-hyperuricemia (Arina et al., 2022), anti-diabetic (Ridhasya et al., 2019), and anti-cancer agents (Tsai et al., 2021). Furthermore, phenolic compounds have demonstrated a strong correlation with human well-being due to their antioxidant activity (Banwo et al., 2021). Carotenoids, known for their antioxidative properties, are associated with a reduced risk of cancer and cardiovascular disease, with higher consumption linked to lower cancer incidence (Kongkachuichai et al., 2015). Lastly, glucosinolates found in indigenous leafy vegetables in Africa exhibit anticarcinogenic, anti-inflammatory, and antidiabetic properties, reinforcing their importance in health-promoting diets (Neugart et al., 2017). Some functional food derived from wild local vegetables in Central Kalimantan include carbonated *S. ferox* drink, *N. orientalis* chips, *S. ferox* and *E. elatior kandas*, *S. ferox* sweets, *N. oleracea* jelly drink, cookies made from the inner shoot of *Calamus* sp. and *S. palustris* leaves, as well as catfish nugget enriched with *D. esculentum*.

Phytochemical profiling of local vegetables is essential for uncovering their nutritional and medicinal potential, despite uncertainties about the specific active components responsible for their health benefits (Patra et al., 2024). This process not only promotes native vegetables as functional foods but also supports the development of herbal medicines and sustainable agricultural practices. Additionally, it fosters interdisciplinary collaboration among nutrition, botany, and agriculture, contributing to food security and biodiversity conservation (More et al., 2024). This study aims to profile the phytochemical composition of wild local vegetables from Central Kalimantan, offering scientific insights to support functional food development, promote sustainable agriculture, and preserve indigenous knowledge.

2. Methodology

Sample collection and name, and place of analysis

Local vegetables for this study were collected from traditional markets, with a focus on the parts commonly consumed in the local community's diet.

A detailed list of the selected vegetables and the specific components analyzed is provided in Table 1. Furthermore, all analyses were carried out in the Plant Physiology Laboratory of the School of Life Sciences and Technology, Institut Teknologi Bandung, ensuring standardized and controlled conditions.

Extraction

First, the samples were thoroughly cleaned, and then they were freeze-dried for 48 h. We weighed, crushed, and mixed 0.1 g of each sample with 7 - 8 mL of ethanol (p.a) after freezing-drying. The mixture was then sonicated (Branson 3510) for 1 h to facilitate the breakdown of cell structures, ensuring optimal extraction of phytochemicals. Following sonication, the samples were centrifuged (Cole Parmer) at 3400 rpm for 15 min, after which the supernatant was collected and supplemented with 10 mL of ethanol to obtain the ethanol extract. This extract was subsequently used for phytochemical analysis to identify the presence of phenols, flavonoids, carotenoids, alkaloids, phytosterols, terpenoids, and saponins (Shotorbani et al., 2013). Additionally, methanol extraction was employed for the specific analysis of anthocyanins and glucosinolates. All analyses were conducted using a UV-vis spectrophotometer (Biorad SmartSpec Plus type) to determine the concentration of these phytochemicals.

Determination of phenols

Total phenolic content was determined using the Folin-Ciocalteu method. Briefly, 75 µL of the prepared extract was mixed with 925 µL of distilled water, followed by the addition of 1 mL of Folin-Ciocalteu reagent (Merck) and one mL of Na_2CO_3 (Merck). The mixture was stirred to ensure homogeneity and left to react for 15 min. Subsequently, the absorbance of the resulting solution was measured at 730 nm using gallic acid (Merck) as a standard. The total phenolic content was expressed as milligrams of gallic acid equivalents (GAE) per 100 g of fresh weight (mg GAE 100 g^{-1}) (Shotorbani et al., 2013).

Determination of flavonoids

The flavonoid content was determined using the method described by (Shotorbani et al., 2013). Initially, 150 µL of the extract was mixed with 850 µL of distilled water, followed by the addition of 1 mL $AlCl_3$ (Merck). The mixture was stirred thoroughly and allowed to react for 10 min. Subsequently, the absorbance of the sample was measured at a wavelength of 430 nm.

Determination of carotenoids

For carotenoids, the ethanol extract of the sample was diluted 10 - 20 times before measurement. The absorbance was then recorded at a wavelength of 452 nm (Nurung, 2016).

Determination of alkaloids

The alkaloid content was determined following the method described by Karim et al., (2022). First, 500 µL of the extract was mixed with 500 µL of a pH 4.7 buffer and 500 µL of bromocresol green (BCG), followed by the addition of 2 mL of chloroform (Merck). The mixture was vortexed for 1 min to ensure thorough mixing. Finally, the absorbance of the chloroform phase was measured at a wavelength of 273 nm (Karim et al., 2022).

Determination of phytosterols

To determine of phytosterols content, 1 mL of extract was dried and then mixed with 0.5 mL chloroform. Subsequently, 1 mL of Liebermann-Burchard (LB) reagent was added, followed by another 1 mL chloroform. The mixture was allowed to stand for 5 min to ensure a complete reaction. Finally, the absorbance was measured at a wavelength of 627 nm (Herawati & Saptarini, 2020).

Determination of terpenoid

To determine terpenoid content, 0.5 mL of the extract was mixed with 0.75 mL of chloroform and left to stand for 3 min. Then, 50 µL of sulfuric acid (Merck 97% - 98%) was added, and the sample was incubated for 1.5 - 2 h. After incubation, 0.75 mL of methanol was added, and the absorbance was measured at a wavelength of 538 nm (Hutasuhut et al., 2022).

Determination of saponins

To determine saponin content, 1 mL of the extract was freeze-dried and then mixed with 1 mL of 25% sulfuric acid (Merck 97% - 98%). After autoclaving for 10 min, 2 mL of ether was added to the mixture. After phase separation, 1 mL of the ether phase was dried and reconstituted with 1 mL of water. The solution was vortexed for 5 min before adding 50 µL of anisaldehyde and shaken for 10 min. It was then heated at 60 °C for 10 min, followed by the addition of 4 mL of water, and left to stand for another 10 min. The absorbance was measured at a wavelength of 435 nm (Dewi, 2020).

Determination of glucosinolate content

To determine glucosinolate content, 0.1 g of the sample was crushed and mixed with 2 mL of 80% methanol, followed by centrifugation at 3000 rpm for 4 min. The supernatant was adjusted to a final volume of 2 mL with 80% methanol (p.a). Then, 50 µL of this solution was mixed with 0.15 mL of water and 1.5 mL of 2 mM Na_2PdCl_4 (Sigma). After incubation for 1 h, the absorbance was measured at a wavelength of 425 nm. The glucosilonate content was calculated using the formula Y = 1.4 + 118.86 (Mawlong et al., 2017).

Statistical analysis

The data was analyzed using SPSS for Windows version 25. Mean differences in phytochemical profiles among local vegetables were determined using ANOVA, followed by the Duncan Multiple Range Test for post hoc analysis. Significant differences were considered at $p < 0.05$ and $p < 0.001$.

3. Results and discussion

Table 2 shows that the phenol content in local vegetables from Central Kalimantan varies from 107.20 mg GAE 100 g^{-1} in *Solanum ferox* to 7,393.10 mg GAE 100 g^{-1} fresh weight in *N. orientalis*. Notably, the three primary sources of phenolic compounds were *N. orientalis*, *N. oleracea* (4,305.39 mg GAE 100 g^{-1}), and *Calamus* sp. (2,199.15 mg GAE 100 g^{-1}), respectively. Furthermore, the total flavonoid content in selected local vegetables varied from 27.17 to 1,163.82 mg 100 g^{-1}, with the highest content found in *R. indica*, commonly known as *segau* or *sawi pahit* (*pahit* meaning bitter), whose young leaves are typically consumed.

Meanwhile, the total carotenoid content in this study ranged from 1 to 1,449 mg 100 g^{-1}. Similarly, alkaloid content varied between 78.94 mg 100 g^{-1} and 1,061.66 mg 100 g^{-1}, wherein the lowest concentration was detected in *Calamus* sp., whereas *R. indica* exhibited the highest content. Moreover, Table 2 indicates that the phytosterol content in the vegetables analyzed ranged from 168.33 mg 100 g^{-1} to 4,926.67 mg 100 g^{-1}. Likewise, the terpenoid content of vegetables grown in Central Kalimantan varied depending on which part of the plant was consumed. Specifically, leafy vegetables contained higher terpenoid levels (6,158.89 – 15,503.33 mg 100 g^{-1}) compared to fruit and shoot vegetables (914.44 – 3,570 mg 100 g^{-1}), except for *S. palustris*. Additionally, the saponin content ranged from 1,742.22 mg 100 g^{-1} in *E. elatior* to 19,164.44 mg 100 g^{-1} in *H. zeylanica*. Notably, *R. indica* L. Hiern (Brassicaceae) and *N. oleracea* (Fabaceae), were detected to contain the two highest glucosinolate content of 1,761.2 mg 100 g^{-1} and 4,726.52 mg 100 g^{-1}.

The phytochemical composition presented in Table 1 is influenced by various factors, including species and genetics (Mohammadi Bazargani et al. 2021), growing environment, the function of secondary metabolites within the plant, interactions with microbes and biotic factors (Salam et al., 2023), as well as the extraction and analysis methods used (Saxena, 2023). Each plant species demonstrates a unique biosynthetic capacity for secondary metabolites, including phenols, flavonoids, alkaloids, carotenoids, and glucosinolates. Notably, *N. oleracea* exhibits the highest glucosinolate content, likely due to its distinct metabolic pathways. The production of secondary metabolites is strongly influenced by the growing environment, including soil type, water availability, light intensity, and stress conditions (Salam et al., 2023). The role of secondary metabolites in plants is influenced by their function, interactions with microbes and biotic factors, as well as the extraction and analysis methods used. Further research is needed to fully understand their diverse functions. For example, phenols and flavonoids contribute to UV protection and defense against herbivores and pathogens (Krebs & Schummer, 2024). Alkaloids are primarily associated with plant defense mechanisms (Srivasatava, 2022), while carotenoids serve as pigments and antioxidants within the photosynthetic system (Hashimoto et al., 2016). Additionally, glucosinolates, which are abundant in Brassicaceae species, play a crucial role in pest protection and offer potential health benefits for humans (Miao et al., 2021). In the domain of functional foods, the phytochemical composition presented in the Table 2 is particularly relevant, as compounds such as phenols, flavonoids, carotenoids, alkaloids, phytosterols, terpenoids, saponins, and glucosinolates have been shown to confer a range of health benefits.

Phenols and flavonoids

Phenols and flavonoids, which function as antioxidants and anti-inflammatory agents respectively, play a critical role in protecting the body against oxidative stress, a contributing factor in the development of degenerative diseases such as cancer, diabetes, and cardiovascular disorders (Ozturk et al., 2022, Wali et al., 2018). Notably, *N. orientalis* exhibits the highest phenol content, highlighting its strong potential as a natural antioxidant source. Moreover, several studies have demonstrated that dietary phenols are associated with a reduced risk of chronic and degenerative diseases, including cancer, neurodegenerative disorders, and cardiovascular diseases. However, despite their recognized health benefits, official guidelines for daily phenol intake remain limited (DelBo et al., 2019).

Table 1
List of vegetables and parts analyzed

Vernacular name	Scientific name	Part being analyzed
Terong pipit/sanggau	*Solanum torvum*	Young fruits
Lampinak	*Cnesmone javanica*	Young leaves and stems
Kanjat	*Gymnopetalum cochinense*	Young fruits
Kelakai	*Stenochlaena palustris*	Young leaves and stems
Teken parei/tunjuk langit	*Helminthostachys zeylanica*	Young leaves
Taya	*Nauclea orientalis*	Young leaves
Supansupan/uru mahamen	*Neptunia oleraceae*	Young leaves and stems
Bakung	*Crinum* sp.	Inner shoot
Potok/kecombrang	*Etlingera elatior*	Inner shoot
Umbut rotan	*Calamus* sp.	Inner shoot
Rimbang/terong asam	*Solanum ferox*	Seedless fruit flesh
Sulur keladi	*Colocasia esculenta*	Inner tendril
Bajei/pakis/paku	*Diplazium esculentum*	Young leaves and stems
Segau/sesawi/sawi pahit	*Rorippa indica*	Young leaves and stems

Table 2
The phytochemical content of local vegetables from Central Kalimantan

Scientific name	Phenol (mg 100 g^{-1})	Flavonoid (mg 100 g^{-1})	Carotenoid (mg 100 g^{-1})	Alkaloid (mg 100 g^{-1})	Phytosterol (mg 100 g^{-1})	Terpenoid (mg 100 g^{-1})	Saponin (mg 100 g^{-1})	Glucosinolate (mg 100 g^{-1})
Solanum torvum	1,214.28^{ab}	102.71^{ab}	39.27^{a}	180.15^{a}	757.92^{ab}	1,147.78^{a}	4,164.44 ^{b}	92.4^{a}
Cnesmone javanica	926.31^{ab}	655.74^{d}	659.40^{c}	576.20^{bc}	2,897.50^{e}	10,681.11^{de}	6,253.33^{de}	824.52^{b}
Gymnopetalum cochinense	386.69^{a}	75.66^{ab}	72.73^{a}	129.78^{a}	1,370.42^{bc}	2,047.78^{a}	8,764.44^{f}	189.08^{a}
Stenochlaena palustris	514.94^{a}	232.71^{b}	162.73^{a}	333.89^{ab}	1,053.75^{ab}	2,836.67^{a}	5,297.78^{cd}	230.38^{a}
Helminthostachys zeylanica	1,210.64^{ab}	1,019.27^{e}	958.53^{d}	977.38^{d}	4,847.50^{f}	12,869.99^{ef}	19,164.44^{h}	1,439.6^{cd}
Nauclea orientalis	7,393.10^{d}	422.44^{c}	437.73^{b}	986.60^{d}	1,960.00^{cd}	8,514.45^{cd}	4,320^{bc}	1,339.6^{c}
Neptunia oleraceae	4,305.39^{c}	778.30^{d}	873.07^{cd}	865.45^{cd}	4,662.08^{f}	14,270^{f}	4,386.67^{bc}	4,726.52^{e}
Crinum sp.	147.13^{a}	35.01^{a}	6.44^{a}	120.18^{a}	168.33^{a}	1,703.33^{a}	7,164.44^{e}	114.52^{a}
Etlingera elatior	251.18^{a}	62.72^{ab}	1.27^{a}	126.44^{a}	370.42^{a}	2,025.56^{a}	1,742.22^{a}	119.32^{a}
Calamus sp.	2,199.15^{b}	27.17^{a}	1.44^{a}	78.94^{a}	297.50^{a}	3,570^{ab}	5,364.44^{cd}	147.88^{a}
Solanum ferox	107.20^{a}	30.82^{a}	28.47^{a}	166.65^{a}	278.75^{a}	913.44^{a}	9,853.33^{g}	181.2^{a}
Colocasia esculenta	160.44^{a}	56.97^{ab}	41.21^{a}	193.85^{a}	566.25^{ab}	970^{a}	3,920^{b}	170^{a}
Diplazium esculentum	132.61^{a}	435.36^{c}	665.07^{c}	568.43^{bc}	2,266.25^{de}	6,158.89^{bc}	3,786.67^{b}	727.88^{b}
Rorippa indica	542.77^{a}	1,163.82^{e}	1,448.80^{e}	1,061.66^{d}	4,926.67^{f}	15,503.33^{f}	2,164.44^{a}	1,761.2^{d}

Values of the mean (n=3) with different superscript letters within the same column of each phytochemical differ significantly at $p < 0.05$.

Variations in plant phenolic content are influenced by species-specific properties and environmental factors (Ozturk et al., 2022). Furthermore, total polyphenol content in vegetables is significantly affected by plant variety, ripening stage, cultivation site, climate conditions, fertilization, sample collection, transportation, preparation, and analytical methods (Rop et al., 2011). The phenol content of local vegetables from Central Kalimantan was lower than that of Southern Thailand, where it ranged from 21.38 to 4,762.76 mg GAE 100 g^{-1} (Kongkachuichai et al., 2015), but higher than that of wild vegetables consumed by Jakun Malaysians, which ranged from 1.708 to 9.387 mg 100 g^{-1} (Mohd et al., 2020). According to Andarwulan et al., (2010), the total phenol content in Indonesian vegetables varies from 0.33 to 1.52 mg GAE g^{-1} fresh weight. *E. elatior* from Central Kalimantan contained lower phenol content (251.18 mg GAE 100 g^{-1}) compared to the West Java variant (80.6 mg GAE g^{-1} fresh weight). This difference may be attributed to the specific plant parts used. The flower is commonly consumed as a vegetable in Central Java, while the inner shoot is preferred in Central Kalimantan. In contrast, *R. indica* contains the highest levels of flavonoids, which may underpin its notable anti-inflammatory properties. Notably, *H. zeylanica* contained significantly higher flavonoid levels, reaching 1,020 mg 100 g^{-1} in its young leaves. Additionally, *D. esculentum* was found to contain 437 mg 100 g^{-1} of flavonoids, while *S. torvum* exhibited lower levels (103 mg 100 g^{-1}) compared to previously reported values in India (773.4 mg 100 g^{-1}) (Meenakshi et al., 2022). Meanwhile, the young fronds of *S. palustris*, a wild vegetable commonly consumed by the Dayak tribe, contained 232.71 mg 100 g^{-1} of flavonoids, which was substantially higher than the 4.66 mg 100 g^{-1} reported by Akter et al., (2014). Flavonoids are widely recognized for their crucial roles in human health, particularly due to their anti-inflammatory and antioxidant activities (Mohd et al., 2020). For instance, *H. zeylanica* roots have been reported to exhibit anti-inflammatory, antihyperuricemic, and anticancer properties (Arina et al., 2022, Tsai et al., 2021). Similarly, *D. esculentum* has been shown to contain seven flavonoid compounds (Zannah et al., 2022). Furthermore, the flavonoids in *S. torvum* have been associated with antidiabetic activity, as they promote the regeneration of damaged pancreatic beta cells and act as insulin secretagogues, largely due to the presence of quercetin in the fruit extract (Satyanarayana et al., 2022).

Carotenoids

Carotenoids play a vital role in human health due to their provitamin A activity and antioxidant properties (Crupi et al., 2023). The observed carotenoid content in local vegetables, ranging from 1 to 1,449 mg 100 g^{-1}, underscores their potential as functional foods that support eye health and enhance immune function. As a natural pigment responsible for the yellow, orange, and red hues of fruits and vegetables (Liu et al., 2022), carotenoids include health-promoting compounds such as lutein, β-carotene (Bélanger et al., 2010), tocopherols, and phylloquinone (Wen Lee et al., 2022). These compounds function as antioxidants, immune enhancers, retinoid precursors, and facilitators of intercellular communication (Castenmiller, 2000). In comparison, the total carotenoid content reported in this study (1 - 1,449 mg 100 g^{-1}) is markedly higher than that found in some local Malaysian vegetables (*ulam*), which ranged from only 0.09809 to 0.3589 mg 100 g^{-1} (Fatimah et al. 2012), but lower than the levels reported by (Bajracharya & Bajracharya, 2022) for *H. zeylanica*, which contained 2.1 mg 100 g^{-1} of carotene. Among the leafy local vegetables analyzed in our study, *N. oleracea* (873.07 mg 100 g^{-1}), *H. zeylanica* (958.53 mg 100 g^{-1}), and *R. indica* (1,448.80 mg 100 g^{-1}) were found to contain the highest levels of carotenoids (Table 2).

Alkaloids

Alkaloids, known for their diverse pharmacological properties, were detected in varying concentrations across the studied vegetables, with *R. indica* exhibiting the highest level. In this study, alkaloid content ranged from 78.94 mg 100 g^{-1} to 1,061.66 mg 100 g^{-1}, with *Calamus* sp. Containing the lowest and *R. indica* the highest. Notably, seven alkaloids, including a novel compound, have been isolated from *C. asiaticum* var *sinicum*, suggesting potential applications in the treatment of Alzheimer's disease (Duc, 2023). However, in our study, *Crinum* sp. ranked as the second lowest in alkaloid content. Similarly, *S. torvum* contained 180.15 mg 100 g^{-1} of alkaloids, which is lower than the values reported by Uddin et al., (2021). The young fronds of *D. esculentum* were found to contain 145.54 mg g^{-1} of alkaloids (Table 2). Among related species, *Solanum nigrum* has been shown to have higher alkaloid levels than both *S. torvum* and *S. ferox* (Essack et al., 2017). Meanwhile, *N. orientalis* exhibited a notably high alkaloid content of 986.60 mg 100 g^{-1} of alkaloids (Table 2). Alkaloids derived from *Nauclea* species have been previously reported to demonstrate antiproliferative, antimalarial (Liu et al., 2022), and cytotoxic activities (Wang et al., 2015), further supporting their potential therapeutic applications.

Phytosterols

Table 2 shows that the phytosterol content of the vegetables analyzed in this study ranged from 168.33 mg 100 g^{-1} to 4,926.67 mg 100 g^{-1}. The three vegetables with the highest phytosterol levels were *R. indica*, *H. zeylanica*, and *N. oleracea*, suggesting their strong potential in managing cholesterol levels and supporting cardiovascular health. Consequently, these vegetables are promising candidates for functional food formulations designed to promote heart health. Although the bioavailability of phytosterols from vegetables is relatively low (0.5 – 2%), they nonetheless play a crucial role in maintaining cholesterol homeostasis and offer various health benefits (Li et al., 2022, Lobo et al., 2018). Phytosterols are also widely present in vegetable-derived foods (Albuquerque et al., 2020), and research by Shin et al. (2016) demonstrated that cooked vegetables contain higher phytosterol levels than their raw counterparts. Furthermore, consuming phytosterols twice daily-amounting to a total intake of approximately 0.8 g – is considered part of an effective cholesterol-lowering diet (Daud et al., 2022). The beneficial effects of increased phytosterol intake in reducing total and LDL cholesterol levels have been well-documented (Li et al., 2022, Munoz & Ramos, 2016). Indeed, a daily intake of two to three g of phytosterols can result in an average 10% reduction in LDL-C levels (Stellaard & Lütjohann, 2025).

Terpenoids

The terpenoid content of local vegetables grown in Central Kalimantan varies depending on the plant part consumed. Leafy vegetables exhibited significantly higher terpenoid levels, ranging from 6,158.89 to 15,503.33 mg 100 g^{-1} compared to fruit and shoot vegetables, which ranged from 914.44 to 3,570 mg 100 g^{-1}, except for *S. palustris*, which showed an atypical pattern (Table 2). These findings suggest that leafy vegetables may be prioritized for their medicinal and antioxidant properties, particularly in the development of functional food formulations. Among the leafy vegetables, *R. indica* had the highest terpenoid content followed by *N. oleracea*, and *H. zeylanica*. In contrast, Howlader et al. (2013) reported that terpenoids are the most abundant bioactive compounds in the Cucurbitaceae family, alongside alkaloids, tannins, saponins, flavonoids, steroids, glycosides, sugar molecules, and amino acids. Notably, members of the Cucurbitaceae family also produce cucurbitacin – a unique group of highly unsaturated terpenoids known for their intense bitterness (Montesano et al., 2018, Murthy & Paek, 2020). These compounds vary in concentration across plant tissues, with the mature fruits containing the highest levels and seeds the lowest. However, in the current study, *G. cochinense*, a bitter fruit vegetable belonging to the Cucurbitaceae family, exhibited relatively low terpenoid content (2,047.78 mg 100 g^{-1}) (Table 2). This discrepancy may be attributed to the fact that *G. cochinense* is typically harvested while the fruit is still young, leading to reduced terpenoid accumulation. Nevertheless, when administered appropriately, cucurbitacins at doses ranging from 2 to 12.5 mg kg^{-1} have demonstrated therapeutic efficacy in treating inflammation and autoimmune diseases (Rolnik & Olas, 2020).

Saponin

The saponins content of local vegetables varied widely, ranging from 1,742.22 mg 100 g^{-1} in *E. elatior* to 19,164.44 mg 100 g^{-1} in *H. zeylanica* (Table 2). *H. zeylanica*, a rare and endangered terrestrial fern native to southern Asia and Australia (Dhawal et al., 2023), exhibited the highest saponin concentration. This finding underscores its promising health potential, as saponin is well known for its anticholesterol (Cao et al., 2024), antidiabetic (El Barky et al., 2017), antioxidant and anti-inflammatory (Chen et al., 2024), antimicrobial (Victoria Obayomi et al., 2024), and anticancer (Khan et al., 2022) properties. In vegetables, saponin contributes to a bitter and acrid taste, which affects their palatability and sensory characteristics. However, it is noteworthy that certain sweet saponins can be up to 100 times sweeter than sucrose (Lobo et al., 2018), indicating a wide variation in saponin types and sensory effects. In our study, among the vegetables analyzed, *N. orientalis* exhibited the most pronounced bitterness, corresponding to a saponin content of 4,320 mg 100 g^{-1}, further supporting the role of saponins in influencing taste profiles alongside their functional health benefits.

Glucosinolates

Table 2 shows that the glucosinolate content in the vegetables studied ranged study ranged from 2.310 to 118.163 μmol g^{-1}, with *N. oleracea* (water mimosa) emerging as the richest source. *N oleracea*, an invasive legume from the Fabaceae family, is a nutrient-dense weed traditionally consumed by the Dayak tribe. It contains high levels of crude protein, up to 32%, and is also rich in essential nutrients such as calcium, phosphorus, beta-carotene, and vitamins A and C. Due to its nutritional profile, it holds potential both as a functional food and as a protein-rich feed source. However, it also poses safety concerns, as it can accumulate heavy metals such as Pb, Cu, and Cd. Additionally, its high alkaloid, saponin, and tannin content may exert toxic effects on microorganisms (Sumantri et al., 2023), which must be considered in its utilization. In contrast, members of the Cruciferae (Brassicaceae) family are well known for their glucosinolate content, which contributes to their rising popularity due to the potential anticancer properties of these secondary metabolites (Drozdowska et al., 2020, Malabed et al., 2022, Melim et al., 2022). Among the local vegetables analyzed, *R. indica*, a bitter-tasting leafy vegetable commonly consumed as *lalap* (fresh salad) in Central Kalimantan, was found to contain 44.03 μmol g^{-1} of glucosinolates (Table 2). Furthermore, Lin et al. (2014) identified 24 glucosinolate compounds in *R. indica*, including 14 novel ones, highlighting its potential health as a rich source of bioactive metabolites.

The presence of glucosinolates in these wild local vegetables is particularly significant, as these compounds are precursors to isothiocyanates, well-recognized for their anticancer, antioxidant, and detoxifying effects (Kamal et al., 2022). Therefore, incorporating glucosinolate-rich vegetables like *N. oleracea* and *R. indica* into traditional diets may enhance their functional value. Moreover, their potential applications in functional food development underscore the importance of preserving and promoting wild local vegetables for health promotion and disease prevention, particularly in the context of cancer prevention and detoxification (Drozdowska et al., 2020, Flore et al., 2023, Kalogerakou & Antoniadou, 2024).

In leafy vegetables, saponins show the most dominan content among all phytochemical observed. *H. zeylanica* has the highest saponin content, indicating that *H. zeylanica* has great potential as a source of bioactive compounds. Saponin are known to have surfactant properties and various biological activities, including anti-inflammatory, anti-cancer, and hypocholesterolemic (Hayunanda et al., 2025; Ahyanti & Yushananta, 2023). Terpenoids and phenols were the second and third highest phytochemical groups after saponins. *R. indica* and *N. oleracea* showed the highest terpenoid concentrations (Figure 1). Terpenoids act as antimicrobial, antioxidant, and anti-inflammatory agents. Their high presence in *R. indica* and *N. oleracea* indicates that both plants have potential in pharmaceutical or nutraceutical applications. The highest phenolic content was found in *N. orientalis*, indicating strong antioxidant capacity. Flavonoids, carotenoids, alkaloids, phytosterols, and glucosinolates were generally found in much lower concentrations than saponins and terpenoids, mostly below 5000 mg 100 g^{-1}.

Figure 2 shows that saponins were the dominant compounds in the phytochemical profile of most of the samples tested, particularly in *S. ferox* and *G. cochinense*, which had the highest levels, followed by *Crinum* sp, suggesting that the these species possess hemolytic, anti-inflammatory, and hypo-cholesterolemic properties. Research of Satyanarayana et al. (2022) on the *S. torvum* fruit extract showed that *S. torvum* can be good candidate for novel phytomedicine that can be used to treat several diseases. Terpenoids and phenols are the second and third highest phytochemical groups after saponins, but with a more specific distribution. The dominance of terpenoids and phenols in *Calamus sp*. Phenolic compounds are the main contributors to the free radical scavenging activity in plants. The combination of high phenol and terpenoid levels in *Calamus* sp. indicates superior antioxidant capacity. Other compounds are minor, such as flavonoids, carotenoids, alkaloids, phytosterols, and glucosinolates, which were found in very low concentrations. The drastic differences in phytochemical composition between species emphasize the need for further research to link specific content with its bioactivity potential.

Table 3 shows that there are strategies for producing sustainable dietary strategies with ecological, nutritional, cultural, and food system approaches, so that dietary interventions are not only healthy but also applicable in the long term. Some strategies that can be implemented include diversifying vegetable consumption, such as *S. palustris*, *S. torvum*, *R. indica*, *N. oleracea*, and *E. elatior*, which contain antioxidants, anti-inflammatory properties, and antidiabetic properties, by including these vegetables in the weekly household menu. Several food forms are also culturally appropriate, such as clear soup, jelly, *S. ferox* jam, *S. ferox* carbonated beverage, *tepe dawen jawau*, *kandas potok*, *D. esculentum* nuggets, *patin potok* floss, and *Calamus* cookies, which have the potential to be developed into functional food products based on local plants. Each species has specific bioactivity, enabling bioactivity-based dietary interventions to be tested by creating dietary intervention packages and linking these diets to community-level disease prevention programs.

Table 3
Comparative profile of phytochemicals and their potential for functional food development and sustainable dietary strategies

Scientific name	Main phytochemicals	Functional benefits	Potential food	Dietary intervention
Solanum torvum	Saponin, phenol, terpenoid	Antidiabetic potential (Satyanarayana et al., 2022)	Beverages (Anggriani et al., 2023), soup, *tepe dawen jawau*.	Low glycemic foods in diet with prediabetes/diabetes, regular consumption as a vegetable side dish to support blood sugar regulation and use standardized extract-based beverages/herbs.
Cnesmone javanica	Terpenoid, saponin, phytosterol	Improving mental health and cognitive function (Obaidullah et al., 2021).	Clear soups, light coconut-milk soups (*juhu*), stir-fries	Support regular consumption for seniors and mental workers, consume *C. javanica* weekly.
Gymnopetalum cochinense	Saponin, terpenoid, phytosterol	Antidiabetic (Syiem & Lyngdoh, 2013).	Curry soup, side dish, *panginan simpan*	Consume regularly in curry soups or side dishes, development of healthy traditional menus is low in coconut milk to maintain metabolic stability.
Stenochlaena palustris	Saponin terpenoid, phytosterol	Anti-anemia, lactation aid, antioxidant, anti-aging, antidiabetic, antimicrobial	Noodle, salad, soup, snacks, ice cream, meatball, gummy candies, beverages (Santoso et al., 2022).	Dietary intervention for nursing mothers and anemia prevention, consume S. palustris-based menu as daily functional food.
Helminthostachys zeylanica	Saponin, terpenoid, phytosterol	Anti-inflammatory anticancer, antihyperuricemic (Arina et al., 2022; Tsai et al., 2021).	Fresh salad, clear soup, light coconut milk soup,	Anti-inflammatory interventions, regular consumption in the form of clear soups or salads to prevent hyperuricemia, diet targeting cancer prevention.
Nauclea orientalis	Terpenoid, phenol, saponin	Antimalaria, antiproliferative (Liu et al., 2022), antidiarrhea, antidysentery, antiinfection, antihypertension, antidiabetes.	Clear soup, juice	Diet in malaria-endemic areas, diet to boost immunity and improve gastrointestinal health, and use juices or soups to strengthen the health of rural communities.
Neptunia oleraceae	Terpenoid, glucosinolate, phytosterol	Anticancer (Bhumireddy et al., 2022).	Clear soup, salad	Anti-cancer dietary intervention based on consumption of glucosinolates-containing vegetables, consume fresh as a salad or clear soup to maintain metabolic stability, and preventive diet for colon/digestive cancer.
Crinum sp.	Saponin, terpenoid, phytosterol	Alzheimer's disease treatment (Duc, 2023).	Light coconut milk soup	Diet that supports nerve health and prevents cognitive decline, proper education on processing, as some Crinum species are mildly toxic.
Etlingera elatior	Terpenoid, saponin, phytosterol	Antioxidant, anti-inflammatory (Mutmainah et al., 2024), antidiabetic, antibacterial, anticancer (Ainur et al., 2025).	*Asam laksa*, *kandas potok*, salad, curries, jelly candies, noodles, meat floss, juice (Devi et al., 2023).	Daily antioxidant intervention for people at high risk of oxidative stress, anti-inflammatory and anti-diabetic dietary components, and integration into a healthy, phenolic-rich diet.
Calamus sp.	Saponin, terpenoid, phenol	Anti-inflammatory, antitumor (Yu et al., 2008).	Sour soup, *juhu humbut uwe* (Fambayun & Kalima, 2022), cookies	Anti-inflammatory diet and tumor prevention program, sustainable swamp food intervention.
Solanum ferox	Saponin, terpenoid, phytosterol	Antioxidant, antibacterial, anticariogenic (Ibrahim et al., 2022).	Syrup, ice cream, jam, soft candy, jelly	Dietary interventions for oral health and immunity, consumption in the form of syrup, jam, or soft candy for children as a dietary strategy to increase phytochemical intake, and substitution of imported fruits in the local diet.
Colocasia esculenta	Saponin, terpenoid, phytosterol	prebiotic effects, antioxidant, anti-inflammatory, hypoglycemic, and potential anticancer properties, supporting gut health, blood sugar control, heart health, and immunity (Rahman & Banu, 2025).	Stir-fry sulur, chips, cake.	Interventions for gut health, hypoglycemic diets, and anti-inflammation, development of healthy *C. esculenta* products.
Diplazium esculentum	Terpenoid, saponin, phytosterol	Antioxidant, antimicrobial, anti-diabetic, anti-inflammatory (Singh, 2025), antiurolithiatic (Hoque Mollah et al., 2025).	Pancake (Baranggan & Adlaon, 2024), nugget, soup, stir-fries, salad, dried powder, pickles	Anti-diabetes & anti-inflammatory intervention, daily source of antioxidants through salads, soups, vegetable nuggets, and dried powder, and diet to prevent kidney stones.
Rorippa indica	Terpenoid, phytosterol, saponin	Anticancer (Drozdowska et al., 2020; Malabed et al., 2022; Melim et al., 2022).	Salad, clear soup	Anti-cancer dietary interventions, especially from the Brassicaceae family and consume fresh (salad) or clear soup.

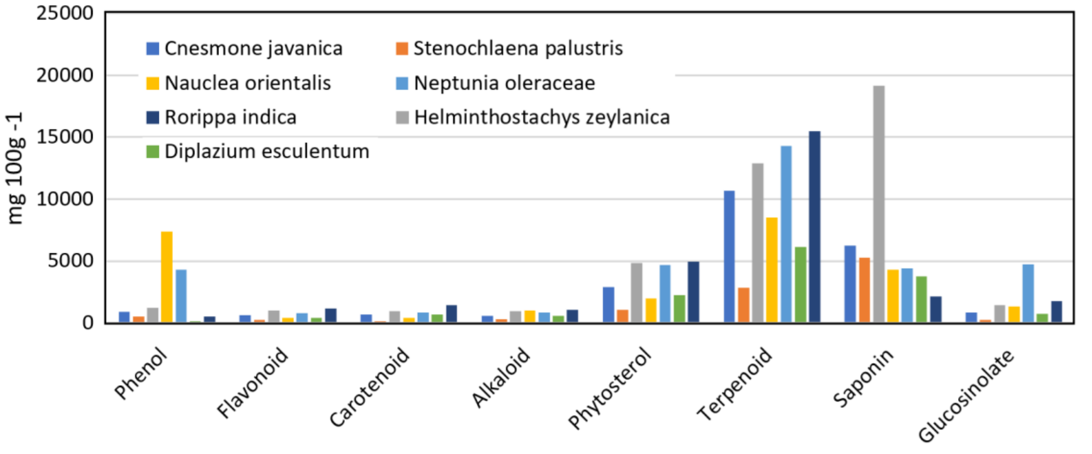

Figure 1. Phytochemical of leafy vegetables.

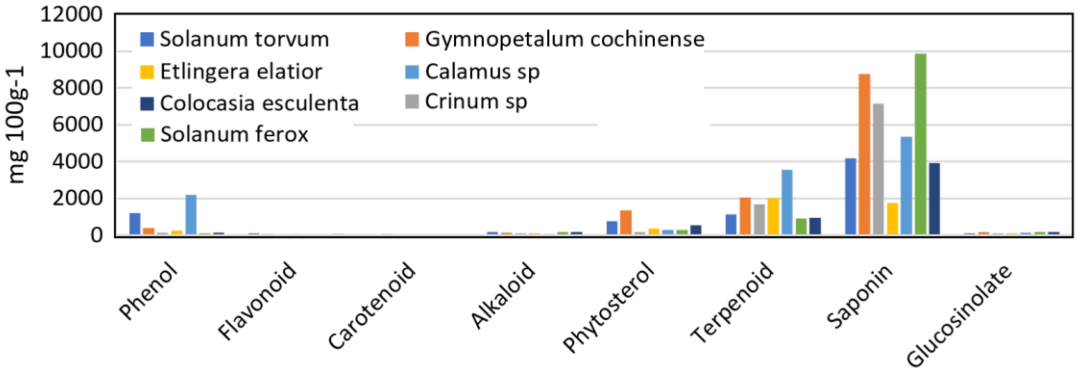

Figure 2. Phytochemical of non-leafy vegetables.

Sustainable cultivation of local vegetables is also a proposed strategy to reduce pressure on wild populations by developing agroforestry and paludiculture for *S. palustris*, *Calamus* sp. and *H. zeylanica*, and crop rotation systems to maintain populations. Cultivation training for communities is also a strategy to reduce the exploitation of natural habitats. Nutrition and culinary education based on local foods is also important to ensure that dietary interventions are in line with community tastes and eating habits, through functional food campaigns at the village level, training in low-oil cooking using local vegetables, and integration into schools, health posts, and agricultural extension services.

4. Conclusions

N. orientalis, *N. oleracea*, and *R. indica* are promising functional foods because they are rich in antioxidants and anti-inflammatory compounds. *R. indica* and *D. esculentum* stand out for their carotenoid content, which supports vitamin A intake. *N. oleracea*, *H. zeylanica*, and *D. esculentum* contain significant amounts of phytosterols and saponins, which may help lower cholesterol and support heart health. In addition, *N. oleracea*, *R. indica*, and *H. zeylanica* had high levels of glucosinolates and terpenoids, giving them strong anticancer potential.

Understanding the link between phytochemicals and health benefits in these species can help design more targeted dietary interventions. This information also has the potential to be used in the development of dietary intervention packages for specific groups, such as breastfeeding mothers, people with diabetes, populations at risk of cancer, and communities in areas prone to anemia. Sustainable dietary intervention models can be implemented through the diversification of local vegetable consumption and the development of processed products tailored to local cultures and preferences.

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Author contributions
HENCC: investigation, formal analysis, interpreting the data, writing-original draft, visualization, supervision; WK: investigation, interpreting the data, resources; KVA: resources, investigation, project administration; SP: investigation, interpreting the data, writing-original draft, resources; AF: data curation, writing: review & editing; ID: data curation, interpreting the data, writing: review & editing.

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