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REVIEW: POTENTIAL ANTIOXIDANT ACTIVITY OF INDONESIAN LOCAL TUBERS AND THE IMPACT OF PROCESSING TECHNIQUES

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ABSTRACT

Indonesia is endowed with a wide diversity of local tubers that hold untapped potential as functional food sources. Tubers such as purple and orange sweet potatoes, taro (*Colocasia esculenta*), yam (*Dioscorea spp.*), gadung (*Dioscorea hispida*), suweg (*Amorphophallus paeoniifolius*), and gembili (*Dioscorea esculenta*) are rich in phytochemicals such as flavonoids, phenolic acids, anthocyanins, and carotenoids. These compounds exhibit strong antioxidant activities which are linked to their capability to scavenge free radicals, thus potentially preventing oxidative stress-related diseases. However, the bioactivity and stability of these antioxidants are significantly influenced by food processing techniques. Thermal treatments such as boiling, steaming, and baking may degrade thermolabile compounds like anthocyanins, while other processes such as fermentation and ultrasonic-assisted extraction have been shown to increase the extractability and bioavailability of phenolic compounds. This review compiles and analyzes recent scientific findings on antioxidant content in local Indonesian tubers and evaluates how various processing methods affect their efficacy. Furthermore, it discusses the relevance of these findings for the development of functional foods and nutraceuticals based on indigenous crops.

1. Introduction

Oxidative stress is a major biological phenomenon caused by the accumulation of reactive oxygen species (ROS), which can damage lipids, proteins, and DNA, leading to chronic diseases such as cancer, cardiovascular disorders, diabetes, and neurodegenerative conditions (Pham-Huy et al., 2008). Antioxidants, both enzymatic and non-enzymatic, are crucial in neutralizing ROS and maintaining oxidative balance in human cells. In recent years, there has been a surge of interest in dietary antioxidants derived from natural sources, primarily due to the health risks associated with synthetic antioxidants like butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA), which have been reported to exhibit carcinogenic potential under certain conditions (Shahidi & Zhong, 2010). Consequently, the search for potent natural antioxidants has led researchers to explore underutilized plant resources, including tuber crops.

Indonesia is home to a wide range of indigenous tubers that are traditionally consumed by local communities. These include purple and orange sweet potatoes (*Ipomoea batatas L.*), taro (*Colocasia esculenta*), yam (*Dioscorea spp.*), gembili (*Dioscorea esculenta*), gadung (*Dioscorea hispida*), and suweg (*Amorphophallus paeoniifolius*). These tubers are not only rich in complex carbohydrates and dietary fiber but also contain substantial amounts of polyphenolic compounds, flavonoids, tannins, saponins, and carotenoids, many of which possess proven antioxidant activity (Franková et al., 2022; Rizkia et al, 2014). Among these, purple sweet potato stands out due to its high anthocyanin content, a class of water-soluble pigments that have been linked to antioxidant, anti-inflammatory, and anti-carcinogenic properties (Czank et al., 2013). Orange sweet potato, on the other hand, is a well-established source of beta-carotene, a provitamin A compound with high antioxidant potential (Laurie et al., 2012). Taro and other *Dioscorea* species contain total phenolic content (TPC) ranging from 100–400 mg GAE/100 g, depending on species and processing (Purwaningsih et al., 2020).

Despite their rich phytochemical profile, the utilization of these tubers as functional food ingredients remains limited. One reason is the variability in antioxidant activity due to postharvest and processing conditions. Thermal processes like boiling, steaming, and baking may degrade heat-sensitive compounds such as anthocyanins and vitamin C. Conversely, fermentation has been shown to increase total phenolic content by releasing bound phenolics through enzymatic action (Hur et al., 2014). Similarly, ultrasound-assisted extraction (UAE) can enhance extraction yield and antioxidant recovery without excessive thermal degradation (Chemat et al., 2017).

Given these conditions, it is critical to understand both the intrinsic antioxidant potential of local tubers and the extrinsic impact of processing techniques to optimize their application in food products and nutraceuticals. This review aims to : Provide a scientific overview of the phytochemical composition and antioxidant activity of selected Indonesian tubers; Compare findings from recent studies using established antioxidant assays (DPPH, FRAP, ABTS); Analyze the effect of common and emerging processing techniques on antioxidant retention; Discuss the implications of these findings for the development of health-oriented functional foods.

2. Methods

2.1 Literature Search Strategy

Scientific literature was gathered from electronic databases including PubMed, Google Scholar, ScienceDirect, and Scopus using combinations of keywords such as: *"Indonesian tubers antioxidant"*, *"bioactive compounds in purple sweet potato"*, *"effect of processing on antioxidant activity"*, *"thermal and non-thermal food processing techniques"*, and *"phenolic retention in traditional tubers."* Only peer-reviewed articles published between 2012 and 2024 were included in this review. Preference was given to studies that:

1. Analyzed antioxidant content in tubers grown or studied in Indonesia
2. Used standard antioxidant activity assays such as DPPH, ABTS, or FRAP
3. Included comparison before and after processing

Inclusion criteria:

1. Articles focused on local Indonesian tubers (e.g., purple/orange sweet potato, taro, gadung, gembili, suweg)
2. Studies that reported both phytochemical composition and antioxidant activity
3. Research that evaluated impact of at least one processing method

2.2 Data Extraction and Analysis

From each selected article, the following data were extracted:

1. Tuber species and variety
2. Bioactive compound(s) reported
3. Assay used (e.g., DPPH, FRAP, ABTS)
4. IC_{50} or antioxidant values
5. Processing method applied (if any)
6. Impact on antioxidant activity

The extracted data were tabulated and qualitatively analyzed to identify patterns in antioxidant behavior before and after processing. Quantitative data such as IC values were compared across tuber types and processing treatments to identify significant trends.

3.Results and Discussions

3.1. *Bioactive compounds in local indonesian tubers*

Local Indonesian tubers are not only staple sources of carbohydrate but also significant reservoirs of health-promoting phytochemicals. The diversity in bioactive compounds among these tubers particularly phenolics, flavonoids, anthocyanins, carotenoids, and saponins underpins their antioxidant potential. The concentration and type of these compounds vary based on species, cultivar, growing conditions, and postharvest handling (Laurie et al., 2012).

3.1.1. *Purple sweet potato* (*Ipomoea batatas* L)

This tuber is renowned for its high anthocyanin content, particularly cyanidin-3-glucoside and peonidin derivatives, which are responsible for its deep violet color. Anthocyanins are potent water-soluble antioxidants with mechanisms involving free radical scavengin, metal chelation, lipid peroxidation inhibition (Czank et al., 2013). In a study by Franková et al. (2022), purple sweet potato extract demonstrated a DPPH IC_{50} of 37.5 ppm, categorizing it as a strong antioxidant. Additionally, anthocyanins from this tuber have shown anti-inflammatory and anti-cancer properties in vitro (Wang et al., 2010).

Table 1. Bioactive compounds and antioxidant activities of selected Indonesian local tubers

Tuber Species	Dominant Bioactive Compounds	Concentration (range)	Antioxidant Assay	Activity Value	Reference
Purple sweet potato (*Ipomoea batatas* L.)	Anthocyanins (cyanidin-3-glucoside), flavonoids	Anthocyanins: 100–450 mg/100g FW	DPPH	IC_{50} = 37.5 ppm	Franková et al., 2022
Orange sweet potato	β-Carotene, vitamin C	β-Carotene: 6–12 mg/100g FW	FRAP	2× FRAP increase after steaming	Haryoto et al., 2023
Taro (*Colocasia esculenta*)	Phenolic acids, flavonoids	TPC: 150–350 mg GAE/100g DW	DPPH	IC_{50} = 152.6 ppm	Purwaningsih et al., 2020
Gembili (*Dioscorea esculenta*)	Tannins, flavonoids, saponins	TPC: ~320 mg GAE/100g	DPPH	High scavenging activity	Prayoga et al., 2025
Gadung (*Dioscorea hispida*)	Diosgenin, phenolics	TPC: 250–400 mg GAE/100g	DPPH	IC_{50} = 4,395 µg/mL	Susanti et al., 2022
Suweg (*Amorphophallus paeoniifolius*)	Flavonoids, alkaloids, oxalates	TPC: ~180 mg GAE/100g	DPPH	Moderate activity	Firman et al., 2016
Bawang Dayak (*Eleutherine palmifolia*)	Flavonoids, eleutherin, naphthoquinones	TPC after fermentation: ↑30%	DPPH	IC_{50} = 28,689 µg/mL	Fitriansyah, 2023
Binahong tuber (*Anredera cordifolia*)	Flavonoids, saponins	TPC: not specified	ABTS	178.6 mg/L	Rizkia et al, 2014

FW = fresh weight
DW = dry weight
TPC = total phenolic content (expressed as gallic acid equivalents, GAE)
$\mathbf{IC_{50}}$ = concentration needed to inhibit 50% of free radicals
FRAP = ferric reducing antioxidant power

3.1.2. *Orange sweet potato* (*Ipomoea batatas* L)

Orange-fleshed sweet potatoes are rich in β-carotene, a provitamin A carotenoid. β-Carotene has been shown to scavenge singlet oxygen, act as a chain-breaking antioxidant, be converted into retinol in the human body (Laurie et al., 2012). The β-carotene content in OSP can reach 6–12 mg/100g FW, which increases in bioaccessibility after steaming due to cell wall softening (Haryoto et al., 2023). This tuber is not only an antioxidant source but also crucial in combating vitamin A deficiency.

3.1.3. *Taro* (*Colocasia esculenta*)

Taro is traditionally consumed in many parts of Indonesia. It contains polyphenols, flavonoids, and mucilage compounds. Phenolic content in taro corms varies between 150–350 mg GAE/100g DW depending on variety and location (Purwaningsih et al., 2020). While less pigmented than purple or orange sweet potatoes, taro's antioxidant activity is still relevant, especially when minimally processed.

3.1.4. Gembili (*Dioscorea esculenta*)

This lesser-known yam is rich in flavonoids, tannins, and saponins, with reported antioxidant activity comparable to purple sweet potatoes (Prayoga et al., 2025). Its phenolic profile includes quercetin, kaempferol, and gallic acid derivatives, contributing to its DPPH scavenging activity. Moreover, its resistant starch content offers added health benefits such as glycemic control and prebiotic effects.

3.1.5. *Gadung* (*Dioscorea hispida*)

Despite its traditional stigma due to dioscorine toxicity, detoxified gadung tubers are edible and rich in diosgenin, a steroidal saponin with significant antioxidant and anti-inflammatory properties (Susanti et al., 2022). Total phenolic content ranges from 200–

400 mg GAE/100g, with DPPH IC_{50} values as low as 4,395 µg/mL under optimized extraction conditions.

3.1.6. *Suweg* (*Amorphophallus paeoniifolius*)

Suweg is part of the aroid family and has been investigated for its alkaloid, flavonoid, and phenolic content. Though its antioxidant capacity is moderate compared to colored tubers, it is of interest for its fiber content and potential as a low-calorie functional food (Firman et al., 2016).

3.1.7. *Bawang Dayak* (*Eleutherine palmifolia*)

This unique tuber has been traditionally used for medicinal purposes. It contains eleutherin, naphthoquinones, and flavonoids. Fermented bawang dayak showed a significant increase in phenolic content and DPPH activity, indicating processing can enhance its functionality (Fitriansyah, 2023).

3.1.8. *Binahong tuber* (*Anredera cordifolia*)

Although more commonly known for its leaves, the tuber of binahong also contains flavonoids, saponins, and alkaloids. Its ABTS scavenging capacity was recorded at 178.6 mg/L, making it a candidate for further exploration (Rizkia et al, 2017).

Summary of bioactive compounds identified in several local tubers and their respective antioxidant activities shown in **Table 1**.

3.2. Methods of Antioxidant Evaluation

Evaluating the antioxidant capacity of tubers and their extracts is critical to determining their potential health benefits. In the reviewed studies, three primary in vitro antioxidant assays were most commonly employed: DPPH, FRAP, and ABTS. Each assay has a unique mechanism and measures different antioxidant properties.

3.2.1. DPPH assay

DPPH is a common abbreviation for the organic chemical compound 2,2-diphenyl-1-picrylhydrazyl. The DPPH method is the most widely used due to its simplicity, cost-effectiveness, and rapid results. It measures the capacity of antioxidants to donate hydrogen to a stable nitrogen-centered radical, DPPH. The change from deep violet (absorbance at 517 nm) to yellow indicates radical scavenging (Brand-Williams et al., 1995). The effectiveness is expressed as IC_{50}, where lower values indicate stronger antioxidant potential. Example: Purple sweet potato extract showed IC_{50} of 37.5 ppm (Franková et al., 2022). Caveat: Lipophilic antioxidants such as carotenoids are poorly detected by this assay.

3.2.2. FRAP assay

FRAP assay stands for Ferric Reducing Antioxidant Power Assay.The FRAP assay measures the ability of antioxidants to reduce ferric (Fe^3) to ferrous (Fe^2) in the presence of TPTZ (2,4,6-tripyridyl-s-triazine). The blue complex formed is quantified at 593 nm. It reflects reducing power, not direct radical scavenging. Example: Orange sweet potato extract exhibited a 2-fold increase in FRAP after steaming (Haryoto et al., 2023).

3.2.4. ABTS assay

ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) is a chemical compound used to observe various reaction. The ABTS assay uses the $ABTS^+$ radical cation, which reacts with antioxidants leading to decolorization. It is more versatile than DPPH as it can measure both hydrophilic and lipophilic antioxidants. Absorbance is measured at 734 nm. Example: Binahong tuber extract showed strong ABTS scavenging at 178.6 mg/L (Rizkia et al, 2014).

3.2.5. Assay selection considerations

Each method measures different aspects of antioxidant behavior (**Table 2**). DPPH and ABTS both assess radical scavenging, but ABTS is broader in compound detection. FRAP provides insight into the reducing power, which correlates with metal chelation and electron-donating capacity. In many cases, multiple assays are used in parallel to obtain a comprehensive antioxidant profile of the extract. For example, Purwaningsih et al. (2020) evaluated both DPPH and FRAP for taro extracts to compare radical scavenging and reducing potential.

3.3. Effects of Processing on Antioxidants

Processing plays a critical role in shaping the antioxidant capacity of tuber-derived food products. While traditionally considered a necessity for safety and palatability, modern understanding reveals that processing can act both as a destructive force and as a facilitator for the release and enhancement of bioactive compounds. The impact of a specific processing technique depends not only on its thermal intensity but also on the physicochemical characteristics of the tuber matrix and the inherent properties off the antioxidants involved.

Table 2. Comparison of common antioxidant activity assays used in tuber studies

Method	Principle	Measured Activity	Target Compounds	Advantages	Limitations	Example Application
DPPH (2,2-diphenyl-1-picrylhydrazyl)	Electron/ hydrogen donation to DPPH radical → color change (purple to yellow)	Radical scavenging capacity	Phenolics, flavonoids, anthocyanins	Simple, rapid, sensitive	Sensitive to light, pH; not suitable for lipophilic antioxidants	Purple sweet potato (Franková et al., 2022)
FRAP (Ferric Reducing Antioxidant Power)	Reduction of Fe^{3+}-TPTZ to Fe^{2+} (blue complex) at low pH	Reducing power	Phenolic acids, ascorbic acid	Quick and reproducible	Does not detect thiols or slow-reacting antioxidants	Orange sweet potato (Haryoto et al., 2023)
ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid))	$ABTS^{+}$ radical cation is reduced by antioxidants → absorbance loss	Radical scavenging	Both hydrophilic & lipophilic antioxidants	Suitable for both polar/non-polar samples	Requires pre-generation of radical; less specific	Binahong (Rizkia et al, 2014)

Table 3. Impact of thermal processing on antioxidant profile of selected tubers

Tuber	Process	Affected Compounds	Mechanism	Antioxidant Change	Reference
Purple sweet potato	Boiling (100°C, 15–20 min)	Anthocyanins	Thermal breakdown, pH sensitivity	↓ 20–50% anthocyanin, ↓ 30% DPPH activity	Franková et al., 2022
Orange sweet potato	Steaming (95–100°C, 20 min)	β-Carotene	Cell wall rupture improves bioaccessibility	↑ FRAP activity (2x)	Haryoto et al., 2023
Taro	Oven drying (60°C, 8 h)	Phenolics, flavonoids	Oxidation, enzyme inactivation	↓ TPC 25%, ↓ DPPH	Purwaningsih et al., 2020

Table 4. Comparison of drying methods on antioxidant retention

Method	Tuber	TPC Retention (%)	Notes	Reference
Oven drying (60°C)	Taro	~75%	Polyphenol oxidation likely	Purwaningsih et al., 2020
Sun drying (ambient, 48h)	Gadung	~63%	Exposure to oxygen and UV reduces stability	Susanti et al., 2022

In general, thermal processing such as boiling, steaming, and roasting can significantly alter the profile of antioxidants (**Table 3**). For instance, anthocyanins in purple sweet potatoes are highly sensitive to heat, leading to their degradation during boiling and oven drying. Studies by Franková et al. (2022) showed that boiling reduced anthocyanin content by up to 50%, with a corresponding 30% drop in DPPH radical scavenging activity. This degradation is linked to hydrolysis of glycosidic bonds and oxidative ring-opening reactions, which are exacerbated by high temperatures and prolonged exposure.

However, not all thermal effects are negative. In orange-fleshed sweet potatoes, moderate steaming has been shown to enhance the bioaccessibility of β-carotene, a fat-soluble antioxidant. The softening of the cell matrix allows carotenoids to be more easily released and absorbed in the digestive system. Haryoto et al. (2023) reported a twofold increase in FRAP values after steaming, indicating a potential functional benefit when the process is properly controlled.

Drying, particularly oven drying at 60°C or above, often results in partial oxidation and loss of phenolic compounds, especially when carried out under ambient oxygen conditions. However, freeze-drying has emerged as a superior method to retain phenolics and flavonoids due to the absence of heat and reduced oxidative stress during processing. Prayoga et al. (2025) demonstrated that gembili flour retained over 90% of its antioxidant capacity after freeze-drying, compared to significant losses in oven-dried samples. Summarizes comparison of drying methods on antioxidant retention shown in **Table 4**.

Fermentation offers a contrasting paradigm. Instead of degrading antioxidants, it enhances them by transforming complex, bound phenolics into simpler, more bioactive forms. Through enzymatic activity, particularly by lactic acid bacteria, compounds such as chlorogenic acid and quercetin glycosides can be released or synthesized. Fitriansyah (2023) observed that fermentation of bawang dayak tubers for 72 hours increased total phenolic content by 30% and significantly improved its IC_{50} value in DPPH assays. Similarly, fermented gadung tubers showed increased bioactivity attributed to enhanced release of diosgenin and other antioxidant-active metabolites (Susanti et al., 2022).

A more recent innovation is ultrasound-assisted extraction (UAE), which uses acoustic cavitation to rupture cell walls and improve mass transfer of antioxidants into solvents. UAE allows for efficient recovery of phenolic compounds at relatively low temperatures, preserving heat-sensitive components such as anthocyanins and vitamin C. In gadung tuber, UAE increased total phenolics by 1.5 times and improved radical scavenging capacity by 40% compared to conventional maceration methods (Susanti et al., 2022).

Taken together, these findings emphasize that processing should not merely be seen as a preservation step, but as an active modulator of functional quality. Optimizing processing parameters, temperature, duration, pH, and combination techniques can result in tuber-based ingredients that retain or even enhance their antioxidant capacity. Integrating these strategies with consumer preferences and scalable technologies is a critical next step in functional food innovation based on local Indonesian biodiversity.

3.4 Application and Functional Food Development

The transformation of indigenous Indonesian tubers into functional food products represents a promising strategy to improve public health, promote food sovereignty, and valorize local biodiversity. With their diverse profiles of phenolics, flavonoids, anthocyanins, and carotenoids, these tubers are not only nutritious but also bioactive-rich materials with the potential to modulate oxidative stress, inflammation, glycemic response, and immune function (Shahidi & Ambigaipalan, 2015).

To unlock this potential, processing techniques must be selected based on the stability and behavior of specific antioxidant compounds. For instance, **steaming and freeze-drying** are ideal for retaining anthocyanins in purple sweet potatoes, while **fermentation** enhances the release of phenolics in gadung and gembili. Modern extraction techniques like **ultrasound-assisted extraction (UAE)** provide scalable methods to concentrate bioactives into functional flours or nutraceutical ingredients (Chemat et al., 2017). Functional product development has already demonstrated viability: purple sweet potato flour has been incorporated into cookies and beverages as a natural colorant and antioxidant source (Franková et al., 2022); orange sweet potato puree enriched with β-carotene is used in baby foods targeting vitamin A deficiency (Laurie et al., 2012); and fermented gadung flour, detoxified and enriched with phenolics, is being trialed in gluten-free noodle formulations (Susanti et al., 2022). The details of functional food development opportunities from selected Indonesian tubers shown in **Table 5**.

Table 5. Functional food development opportunities from selected Indonesian tubers

Tuber (Scientific Name)	Main Bioactive	Optimal Processing	Product Application	Potential Health Claim	Reference
Purple sweet potato (*Ipomoea batatas* var. ungu)	Anthocyanins (cyanidin, peonidin)	Steaming + freeze-drying	Bread, cookies, beverages	Antioxidant, anti-inflammatory, cognitive support	Franková et al., 2022; Wang et al., 2010
Orange sweet potato (*I. batatas* var. oranye)	β-Carotene	Steaming, pureeing	Baby food, bars, noodles	Vision health, immune support	Haryoto et al., 2023; Rodríguez-Amaya, 2015
Gembili (*Dioscorea esculenta*)	Flavonoids, fiber	Boiling + drying	Crackers, high-fiber flour	Glycemic control, digestive health	Prayoga et al., 2025
Gadung (*Dioscorea hispida*)	Diosgenin, phenolic acids	Detox + fermentation + UAE	Gluten-free noodles, antioxidant powder	Hormonal balance, antioxidant	Susanti et al., 2022; Raju & Bird, 2006
Bawang Dayak (*Eleutherine palmifolia*)	Polyphenols, eleutherin	LAB fermentation	Extracts, capsules	Anti-inflammatory, traditional tonic	Fitriansyah, 2023

Challenges are remain for the standardization across varieties, preservation of bioactive compounds during shelf-life, and consumer acceptance. However, with growing demand for natural, plant-based functional foods, the strategic development of tuber-based products holds both health and economic value. The successful development of functional foods from local Indonesian tubers depends on aligning bioactive potential with appropriate processing and product formats. Continued research and collaboration between farmers, processors, and scientists can realize the dual goals of promoting public health and sustaining local food systems

4. Conclusion

Local Indonesian tubers such as purple and orange sweet potatoes, taro, gembili, gadung, suweg, and bawang dayak are proven sources of bioactive compounds with significant antioxidant potential. These tubers are rich in anthocyanins, phenolic acids, flavonoids, saponins, and carotenoids, which contribute to their ability to scavenge free radicals, modulate oxidative stress, and provide health benefits when consumed regularly.

The antioxidant activity of these tubers is strongly influenced by the method of processing. Thermal methods such as boiling and oven drying tend to degrade thermolabile compounds like anthocyanins, while gentle methods such as steaming can enhance the bioavailability of fat-soluble compounds like β-carotene. Non-thermal approaches, including fermentation and ultrasound-assisted extraction, have demonstrated the ability to increase the concentration and activity of phenolic compounds through enzymatic liberation and improved extraction efficiency.

From a functional food development perspective, these tubers offer diverse applications, from antioxidant-rich bakery products to gluten-free flours and nutraceutical extracts. However, their full potential remains underutilized due to challenges such as phytochemical variability, lack of processing standardization, compound instability, and limited clinical validation of health claims.

Future efforts should focus on developing optimized, tuber-specific processing protocols, establishing robust scientific validation through in vivo and clinical studies, and improving consumer education about the health benefits of tuber-based functional foods. With targeted investment in research, innovation, and value chain integration, local tubers can be transformed into high-impact health-promoting food products, contributing to nutrition security, economic empowerment, and biodiversity conservation in Indonesia and beyond.

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