Journal of Food Technology Research
2026 Vol. 13, No. 4, pp. 68-80
ISSN(e): 2312-3796
ISSN(p): 2312-6426
DOI: 10.18488/jftr.v13i4.5322
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Total phenolic content and antioxidant activity of Garcinia binucao fruit pulp

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Article History
Received: 14 January 2026
Revised: 7 September 2026
Accepted: 22 September 2026
Published: 28 October 2026

Keywords
Antioxidant activity
DPPH
FRAP
Garcinia binucao
Phenolic compounds.

ABSTRACT

Garcinia binucao, or batuan, is a Philippine native fruit widely utilized by locals as a souring agent in cuisines. However, its biochemical properties are still underexplored by research. Hence, this research examined the phenolic composition and antioxidant activity of its edible pulp, which served as the basis for the controlled analytical conditions. The process involved sourcing mature fruits from local markets in Samar, Philippines. These were dried, pulverized, and extracted with aqueous methanol. The analysis showed that there was a relatively high total phenolic content (30.35 mg GAE g^{-1}). However, there were lower levels of flavonoids (2.14 mg CE g^{-1}). This suggests that the component is relatively composed of non-flavonoid phenolics. The antioxidant evaluation revealed a strong ferric-reducing capacity (78.86%). Thus, there was moderate radical-scavenging activity (56.51%). This shows that electron-transfer mechanisms may play a more prominent role than hydrogen-atom transfer in the batuan matrix. However, these data are not considered representative of broader variability because the measurements were derived from a single composite extract. Nevertheless, these results demonstrate that G. binucao has phenolic constituents with antioxidant activity. This translates to the possibility of a natural source of bioactive compounds for food applications. Future studies involving similar sampling and compound-specific analyses are necessary to better define its functional properties and practical relevance.

Contribution/Originality: The research adds to the scarce literature on *G. binucao* by providing baseline data obtained under standardized conditions on its phenolic composition and antioxidant activity. The findings serve as a useful reference for future research and support its potential relevance in food and nutrition applications.

1. INTRODUCTION

One of the indigenous Philippine fruits known as a souring agent in traditional dishes is *Garcinia binucao*, or batuan. It has been used by locals for sinigang and various fish and vegetable dishes (Ancheta & Dizon, 2020; Ancheta et al., 2020). This fruit and other sour fruits are not just for culinary utilization. It influences food systems by regulating acidity, slowing oxidative reactions, and limiting microbial growth. While *G. binucao* has been an important ingredient in most local dishes, there is a scarcity of literature on biochemical and functional food research. Unlike other Garcinia species, such as *Garcinia mangostana* and *Garcinia cambogia*, it has not been widely explored in research. These fruits are known to be rich in xanthones, phenolic acids, and hydroxycitric acid, compounds associated with antioxidant and other bioactive properties (Kumatso & Sigge, 2024; Scalbert, Johnson, & Saltmarsh, 2005). Their well-documented phytochemical profiles have supported both nutraceutical development and broader commercial use.

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Given this context, the limited scientific information available for *G. binucao* is notable. It is believed that species of the same genus usually share the same secondary metabolite pathways.

Phenolic compounds are recognized for contributing to the antioxidant activity of plant-based foods (Prior, Wu, & Schaich, 2005; Rice-Evans, Miller, & Paganga, 1997). Their redox-active structures can donate electrons and hydrogen atoms, which stabilize reactive species and reduce oxidative damage (Recuenco, De Luna, Magallano, & Salamanez, 2020; Thaipong, Boonprakob, Crosby, Cisneros-Zevallos, & Byrne, 2006). Thus, phenolic-rich plant materials are extensively researched as natural alternatives to synthetic ones in food processing. This research particularly targets the improvement of shelf life and product stability (Prior et al., 2005; Scalbert et al., 2005). Thus, it is relevant to produce reliable data on the phenolic content and antioxidant behavior of underutilized fruits. It not only addresses data gaps from a nutritional standpoint but also supports food technology applications.

There are a number of indigenous fruits that are proven to possess measurable antioxidant activity in the Philippines (Recuenco et al., 2020). Still, current detailed and standardized data on the edible pulp of *G. binucao* are limited. Those that are available emphasize processing characteristics or general physicochemical properties rather than systematic phenolic profiling under controlled analytical conditions (Ancheta et al., 2020; Dormido, Anadon, Paracale, & Seniego, 2019). There is little discussion comparing the functional implications of *G. binucao's* biochemical position, which remains unclear.

This prompted the study to assess the phenolic composition and antioxidant activity of *G. binucao* fruit pulp using established analytical approaches. It sought to determine the total phenolic and flavonoid contents by evaluating antioxidant behavior using Ferric Reducing Antioxidant Power (FRAP) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) assays. Further, it sought to identify the dominant mechanism of antioxidant action. The study sought to clarify the functional relevance of this underutilized fruit and provide a basis for future studies on indigenous plant resources through the generated baseline data.

2. REVIEW OF LITERATURE

2.1. Bioactive and Phenolic Relevance of Garcinia Species

The Garcinia genus is known for its diverse secondary metabolites. They are usually associated with antioxidant and other biofunctional properties. They are associated with compounds that help with oxidative stress and inflammation in several experimental studies. These compounds include phenolic acids, flavonoids, bioflavonoids, benzophenones, and xanthones (Kumatso & Sigge, 2024; Santo et al., 2020; Schobert & Biersack, 2019). This provides a better explanation for why Garcinia fruits attract interest in food, nutraceutical, and medicinal research.

Garcinia mangostana has the greatest amount of available literature. It has received significant attention because of its xanthone-rich pericarp. Compounds such as α-mangostin are known for strong redox activity and free-radical quenching capacity (Kumatso & Sigge, 2024; Schobert & Biersack, 2019). That said, mangosteen fruit has become the most popular functional species of its genus, although phenolic and other antioxidant-related compounds are also found in its fruit tissues (Kumatso & Sigge, 2024; Santo et al., 2020). Thus, diverse Garcinia species may vary in terms of dominant bioactive compounds. Still, they share antioxidant-relevant chemical features.

In comparison to *G. mangostana*, *G. binucao* is less studied. Although it has been a common staple ingredient in Filipino households, the literature has focused on physicochemical properties, processing potential, and basic nutritional characteristics. Still, there are studies that have already identified its phenolics and demonstrated measurable ferric-reducing and radical-scavenging activity, although this is preliminary evidence. Further, many studies examine whole fruit or mixed fruit matrices rather than the edible pulp alone.

There is an existing and accepted imbalance in the literature. Pulp-specific data of *G. binucao* are limited in comparison to other Garcinia species, which are extensively profiled for their bioactive constituents. There is a need to establish standardized information on phenolic content and antioxidant behavior if the fruits being examined are an indigenous source of natural antioxidants and have the potential to be a functional food ingredient.

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Establishing standardized information on its phenolic content and antioxidant behavior is therefore necessary, especially if the fruit is to be evaluated more seriously as an indigenous source of natural antioxidants and as a potential ingredient for functional food development.

2.2. Antioxidant Assays and Cross-Fruit Comparability

FRAP and DPPH are in vitro methods commonly used to examine antioxidant activity in fruits. However, these assays are not capable of describing similar chemical processes. FRAP is utilized to check the electron-donating or reducing capacity of antioxidant compounds under acidic conditions. Meanwhile, DPPH measures the capacity of an extract to neutralize stable free radicals through electron transfer, with some electron-transfer contribution depending on the matrix and solvent system (Benzie & Strain, 1996; Brand-Williams, Cuvelier, & Berset, 1995). This results in variations in antioxidant values and the assays used.

Philippine studies on indigenous fruits have also demonstrated this variability. One study found that several phenolic-rich fruits display strong ferric-reducing activity, although their DPPH inhibition values differ across species (Recuenco et al., 2020). It revealed only a moderately significant correlation between total polyphenol content and DPPH activity in edible wild fruits. This implies that antioxidant response is influenced by compound type, matrix composition, and solvent behavior (Dormido et al., 2019). This means that antioxidant results from different fruits or studies should be compared with caution.

Solvent polarity, reaction time, and the accessibility of phenolic hydroxyl groups are mentioned to have affected radical-based assays. Therefore, there may be specificity in reducing power. Thus, DPPH is better considered under radical-quenching efficiency. These two different assays are considered to support each other instead of being treated interchangeably.

The diverse chemical composition of fruit phenolics suggests applying more than one assay. This is important for acidic Garcinia fruits, for which non-flavonoid phenolics may contribute strongly to reducing capacity while showing different levels of radical-scavenging activity. Thus, the combination of FRAP and DPPH allows a more balanced basis for interpreting the antioxidant behavior of *G. binucao* pulp.

3. EVIDENCE FROM UNDERUTILIZED AND PHILIPPINE INDIGENOUS FRUITS

Philippine studies are a good basis for examining the potential of underutilized crops as sources of phenolics and natural antioxidants. Recuenco et al. (2020) explained that several species, such as *G. binucao*, had considerable levels of phenolics following a screening of locally available species. Hence, *G. binucao* exhibits both ferric-reducing and radical-scavenging activity (Recuenco et al., 2020). These findings indicate variability in the presence of antioxidant compounds among species and diverse edible parts. They suggest that fruit-specific and tissue-specific data are necessary for more accurate characterization.

The study of Rondevaldova et al. (2024) supports the value of these underutilized and unseen species. They are considered possible sources of bioactive compounds (Rondevaldova et al., 2024). Moreover, it points to a recurring challenge in research. These factors, such as differences in extraction methods, reporting units, and assay types, often make direct comparisons difficult. These variations tend to limit the consistency of available data and create a barrier to a specific interpretation.

Existing literature on *G. binucao* has focused on processing strategies and physicochemical properties instead of functional profiling. Dormido et al. (2019) examined the development of a sensory evaluation of batuan powder (Ancheta et al., 2020; Dormido et al., 2019), while Ancheta and Dizon (2020) explored drying conditions to improve product quality (Ancheta & Dizon, 2020). These are examples of studies that, even though their findings are valuable, do not provide standardized measurements of phenolic content or antioxidant capacity specific to the pulp.

Earlier literature has noted that chemical analyses identified certain compounds. These include sterols and triglycerides in *G. binucao* fruit (Apak et al., 2007; Ragasa, Torres, Marasigan, & Shen, 2014). However, these studies

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did not quantitatively evaluate phenolic composition or antioxidant activity. Thus, information on the functional properties of edible pulp remains limited.

The literature states that there is a scarcity of detailed and standardized data on *G. binucao* pulp. Addressing this gap is necessary for nutritional assessment and food technology applications, specifically in areas where natural antioxidants are considered for production and shelf-life enhancement.

4. MATERIALS AND METHODS

4.1. Sample Collection and Experimental Design

The first step in sample collection was the purchasing of *G. binucao* from local markets during its peak season. This occurred between September and October. They were obtained from three different market batches over two weeks to ensure a well-represented sample. Each batch weighed around 2.0 to 2.5 kg. The total fresh fruit weighed 6.8 kg.

The external features used to include fruits in the batch were green peel color, firm pericarp, intact surface, and a fully developed fruit size ranging from 3.8 to 5.2 cm in diameter. Fruits that were yellowing, overripe, or damaged were excluded. Thirty fruits were randomly selected from the pooled batches for size and weight measurement, with an average fruit weight of 42.3 ± 5.6 g.

The pulp was manually separated from the fruit, pooled to create a composite sample, and oven-dried for further analysis. Thereafter, the dried pulp was pulverized and stored in airtight amber containers. The dried pulp was stored at −20 °C for no longer than seven days before extraction.

5. REPLICATION AND ANALYTICAL UNITS

The process was performed for the initial biochemical assessment. The objective was to generate baseline information on the phenolic composition and antioxidant activity of *G. binucao* fruit pulp. Those fruit batches that passed the checklist requirements were combined. They were pooled to generate a single composite sample. It served as the composite sample for the entire research. Exploratory studies of plant-driven materials used this approach for the purpose of establishing reference values rather than capturing variability (Prior et al., 2005; Thaipong et al., 2006).

The analyses were conducted using composite extracts under controlled laboratory conditions. Total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), and DPPH radical scavenging activity were determined following established antioxidant assessment procedures (Prior et al., 2005). Means and standard deviations were calculated with reference to laboratory measurements employed at the Central Analytical Services Laboratory (CASL).

The values produced are indicative estimates and must be interpreted as preliminary rather than statistically replicated measurements, given the use of a pooled sample. Hence, limitations restrict the examination of natural variations, as results may reflect factors such as maturity, environmental conditions, and seasonal differences. Moreover, research must include both biological and technical replication to provide a rigorous evaluation of phenolic accumulation and antioxidant behavior.

5.1. Methanolic Extraction and Total Phenolic Analysis

The *G. binucao* dried pulp sample was finely ground to create uniform samples before extraction. Around 1.0 grams of powdered material was extracted with 80% methanol under persistent agitation at room temperature. Methanol-water mixtures have commonly been used in analyses for phenolic extraction due to their efficacy in solubilizing a broad range of polyphenolic compounds (Do et al., 2014; Prior et al., 2005). These findings were expressed on a dry-weight basis relative to the mass of the sample.

The next phase involved filtering the extracts using Whatman No. 1 filter paper. This was done to remove insoluble materials. The clear filtrate was then used for analysis. The Folin–Ciocalteu method was used to determine

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the total phenolic content (Singleton & Rossi, 1965). It is a known colorimetric procedure in food antioxidant research (Prior et al., 2005). In brief, an aliquot of the extract was mixed with Folin–Ciocalteu reagent, followed by sodium carbonate to initiate the reaction. After incubation at room temperature for 30 minutes, absorbance was measured spectrophotometrically.

Phenolic content was quantified using a gallic acid calibration curve and expressed as milligrams of gallic acid equivalents per gram of dried sample (mg GAE g^{-1} DW).

5.2. Determination of Total Flavonoid Content

For this analysis, a single methanolic extract was used as the sample, obtained from a collection of pulp from selected G. binucao fruits. The total flavonoid content (TFC) was determined through the use of aluminum chloride colorimetry (Chang, Yang, Wen, & Chern, 2002). To determine the TFC of the extract, a portion was reacted with sodium nitrite, aluminum chloride, and sodium hydroxide, forming a pink chromophore that was measured spectrophotometrically at 510 nm. It has been shown that this test is an established procedure for the estimation of flavonoids (Kumatso & Sigge, 2024). The concentration of flavonoids was quantified using a catechin (or quercetin) calibration curve and reported in mg CE g^{-1}.

5.3. Ferric Reducing Antioxidant Power (FRAP) Assay

The antioxidant activity of samples was estimated by means of the ferric reducing antioxidant power (FRAP) method that quantifies the donating property of antioxidants (Benzie & Strain, 1996). The FRAP reagent was prepared fresh by combining acetate buffer, 2,4,6-tripyridyl-s-triazine (TPTZ) solution, and ferric chloride solution according to procedures for fruits (Schobert & Biersack, 2019).

The reaction mixture was incubated at 37 °C for 30 minutes, during which ferric (Fe^{3+}) ions were reduced to ferrous (Fe^{2+}) ions to form a blue ferrous-TPTZ complex. The absorbance value of the resulting solution was measured at 593 nm using a UV/visible spectrophotometer. The antioxidant activity of the samples was determined based on the ferrous sulfate calibration graph and calculated as the percentage activity or reduction capacity of the extract, taking into account generally accepted antioxidant determination practices (Benzie & Strain, 1996; Schobert & Biersack, 2019).

5.4. DPPH Radical Scavenging Assay

The DPPH assay was used to measure radical scavenging activity as per the method of Brand-Williams et al. (1995). Following the recommendation for fruit matrices (Schobert & Biersack, 2019) to avoid DPPH solution photodegradation, sample extracts were combined with a methanolic DPPH solution and incubated at room temperature in the dark. The sample extract's capacity to donate hydrogen atoms was determined spectrophotometrically by measuring the decrease in absorbance at 517 nm. The DPPH assay combines hydrogen-atom transfer and single-electron transfer antioxidant actions (Apak et al., 2007). The radical-scavenging activity was reported as a percentage inhibition relative to the control.

The author prepared and extracted the samples. All biochemical analyses and antioxidant assays were carried out at the Central Analytical Services Laboratory (CASL), University of the Philippines Los Baños (UPLB), Laguna.

5.5. Standards and Calibration

Standard curves for total phenolic content were created using gallic acid. Standard curves for total flavonoid content were created using catechin and quercetin. Standard curves for FRAP were created using ferrous sulfate, and DPPH radical scavenging assays followed standardized procedures for assessing antioxidants (Pietta, 2000). All standard curves were evaluated for linearity using regression analysis, since the linearity of standard curves is an important consideration for analyzing food antioxidants (Schobert & Biersack, 2019).

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6. RESULTS

6.1. Phenolic and Flavonoid Composition of Garcinia Binucao Pulp

The pulp of *G. binucao* showed a total phenolic content of 30.35 mg GAE g^{-1}, suggesting a relatively high presence of phenolic compounds within the fruit matrix. Phenolics are widely associated with antioxidant activity in plant-based foods due to their redox-active properties (Recuenco et al., 2020), and the level observed here is consistent with this functional role. Comparable results have been reported for other Philippine indigenous fruits, where *G. binucao* has been identified among those with relatively high phenolic content (Ragasa et al., 2014).

In comparison, total flavonoid content was much lower, at 2.14 mg CE g^{-1}. This indicates that flavonoids contribute only a small portion of the overall phenolic composition. While flavonoids are known for their antioxidant activity, they are often present in smaller amounts than other phenolic groups, particularly in sour fruit species (Kumatso & Sigge, 2024). Similar trends have been observed in other Garcinia species (Dormido et al., 2019) as well as in locally available acidic fruits (Ragasa et al., 2014). The difference between total phenolics and flavonoids suggests that the antioxidant profile of *G. binucao* pulp is likely influenced more by non-flavonoid compounds, such as phenolic acids and related constituents.

Antioxidant capacity measured using the FRAP assay was expressed as a percentage reducing activity following the method of Benzie and Strain (1996), providing an estimate of the electron-donating ability of the extract under the assay conditions. Table 1 presents the total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), and DPPH radical scavenging activity of *G. binucao* fruit pulp.

Table 1. Quantitative antioxidant profile of *Garcinia binucao* fruit pulp based on total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), and DPPH radical scavenging activity.

Parameter	Value	Unit*
Total Phenolic Content (TPC)	30.35 ± 0.14	mg GAE g^{-1}
Total Flavonoid Content (TFC)	2.14 ± 0.03	mg CE g^{-1}
Ferric Reducing Antioxidant Power (FRAP)	78.86 ± 0.15	% reducing activity
DPPH radical scavenging activity	56.51 ± 0.06	% inhibition

Note: * Values are expressed as mean ± standard deviation based on measurements conducted at the Central Analytical Services Laboratory (CASL), University of the Philippines Los Baños. Total phenolic content is expressed as milligrams of gallic acid equivalents per gram of dried sample (mg GAE g^{-1}), while total flavonoid content is expressed as milligrams of catechin equivalents per gram of dried sample (mg CE g^{-1}). FRAP values represent percentage reducing activity determined using the ferric reducing antioxidant power assay following (Benzie & Strain, 1996). DPPH activity is expressed as percentage radical scavenging inhibition following the method of Brand-Williams et al. (1995).

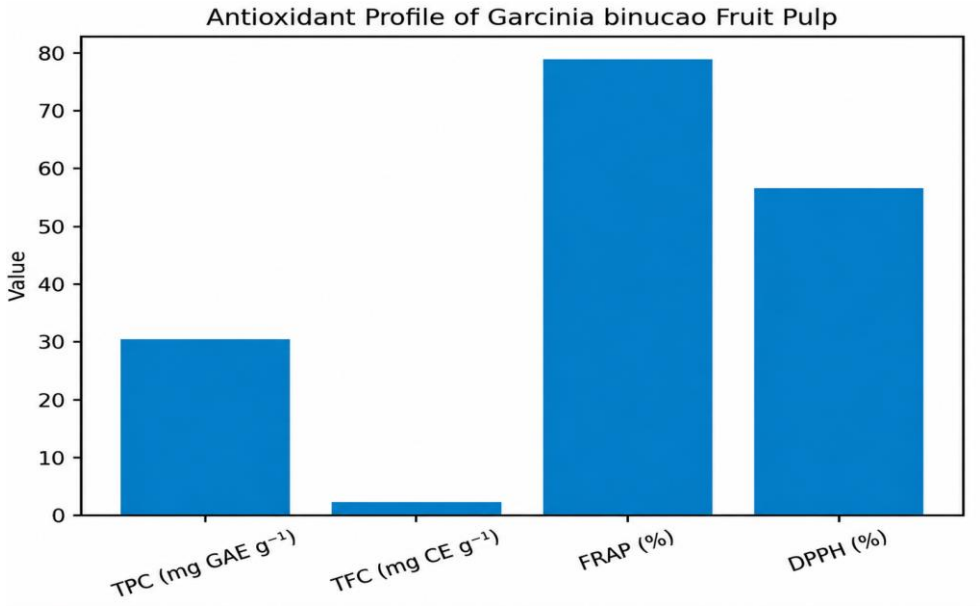


Figure 1. Total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), and DPPH radical scavenging activity of *Garcinia binucao* fruit pulp.

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Figure 1 illustrates the total phenolic content (TPC), total flavonoid content (TFC), ferric reducing antioxidant power (FRAP), and DPPH radical scavenging activity of *G. binucao* fruit pulp.

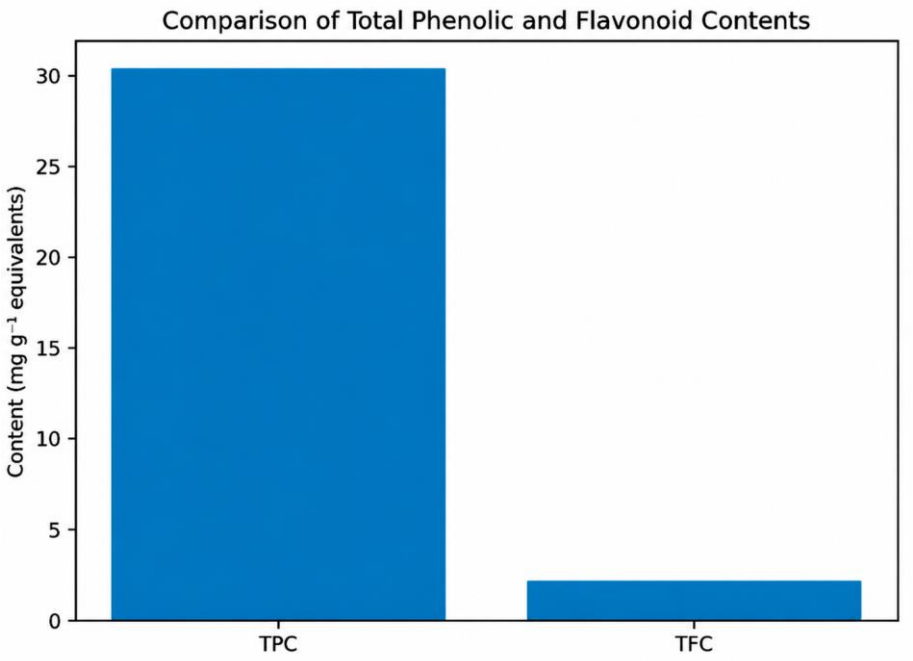


Figure 2. Comparison between total phenolic content (TPC) and total flavonoid content (TFC) of *Garcinia binucao* fruit pulp, illustrating the dominance of phenolic compounds over flavonoids.

Figure 2 compares the total phenolic content (TPC) and total flavonoid content (TFC) of *G. binucao* fruit pulp, showing that the TPC is higher than the TFC.

6.2. Antioxidant Activity and Mechanistic Implications

The evaluations of the antioxidant activity of the pulp of *G. binucao* via the FRAP and DPPH assays, which are complementary, provide a comprehensive evaluation. The FRAP assay demonstrated strong reducing activity of *G. binucao* pulp with a value of 78.86 ± 0.15%. This strong reducing activity indicates that the *G. binucao* pulp has the capacity to donate electrons and reduce ferric ions in solution. In the literature, this response in the FRAP assay has been observed in plant extracts with high phenolic content, particularly those that contain phenolic acids and redox-active compounds. The *G. binucao* pulp's reducing capacity in the FRAP assay appears to be attributed to the total phenolic content of the pulp.

The *G. binucao* pulp showed a DPPH radical inhibition of 56.51 ± 0.06%. This value indicates a strong capacity of the pulp to donate a hydrogen atom and neutralize a stable free radical (Brand-Williams et al., 1995). DPPH inhibition values of greater than 50% are generally considered to be indicative of significant antioxidant activity, further confirming that the extract contains free radical scavenging activity. Because the DPPH assay is based on hydrogen atom transfer and single-electron transfer, this DPPH activity demonstrates a phenolic composition with varying structural attributes and reactivity.

It means that the higher the FRAP response in comparison to DPPH inhibition, the more electron-transfer mechanisms are present in the fruit matrix. It is consistent with the known behavior of phenolic compounds. Those hydroxyl groups may readily participate in electron donation, with their effectiveness influenced by structural features such as the number and positions of these groups (Benzie & Strain, 1996; Del Rio et al., 2013; Kumatso & Sigge, 2024; Recuenco et al., 2020). This dominance shows that non-flavonoid phenolics are the core contributors to antioxidant activity in *G. binucao* pulp. Using both the DPPH and FRAP tests assesses antioxidant behavior comprehensively, as each method assesses different reactivities. It is common for a stronger FRAP response than DPPH activity to be

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reported in other systems rich in phenols and acids, such as those containing fruits. Other measured fruit systems with interfering compounds show stronger reducing-mediated activity rather than radical scavenging activity (Farombi & Owoeye, 2011; Pietta, 2000; Prior et al., 2005). The difference suggests that antioxidant behavior is affected by compound and matrix composition and is not inconsistent.

The results show that the radical scavenging activity of *G. binucao* is influenced not just by the presence of phenolic compounds but also by structural and positional variations of these compounds in the chemical environment of the fruit. Within the Garcinia genus, this profile supports its potential relevance as a phenolic-driven functional ingredient, similar to other species demonstrating high reducing ability and moderate radical scavenging activity.

6.3. Comparative Interpretation and Visualization

Figure 2 shows that, in *G. binucao*, the relationship between TPC and TFC shows a clearly higher level of phenolics than flavonoids. In many fruit systems, phenolic and phenolic-related compounds dominate the antioxidant system (Rice-Evans et al., 1997). Thus, the lower contribution of flavonoids, coupled with the dominant phenolic content, indicates that phenolic compounds drive antioxidant activity in this matrix.

A comparison of antioxidant assays shows an analogous trend. As depicted in Figure 3, the reducing activity as measured by the FRAP assay is greater than the radical scavenging capacity as measured by the DPPH assay. This suggests that the activity is more due to electron transfer than to hydrogen atom transfer. Such differences in assays have been reported for plant-derived antioxidants, and rather than indicating an inconsistency in results, they denote a complexity in the chemical behavior of the antioxidants (Schobert & Biersack, 2019).

6.4. Comparison with Other Tropical and Garcinia Fruits

When compared with other tropical and sour fruits, *G. binucao* appears to have a higher phenolic content. For other fruits in the region, such as tamarind (*Tamarindus indica*), calamansi (*Citrus microcarpa*), and kamias (*Averrhoa bilimbi*), literature suggests that the phenolic content is in the range of 5–25 mg GAE g^{-1} (Prior et al., 2005; Recuenco et al., 2020; Thaipong et al., 2006). *G. binucao* is higher than this range, indicating that this fruit may be richer in phenolic compounds. Similar findings for these fruits have been reported in the Philippines and in other studies in the region, providing additional support for this finding (Del Rio et al., 2013; Prior et al., 2005; Ragasa et al., 2014; Recuenco et al., 2020; Scalbert et al., 2005). The other species in the Garcinia genus also have similar findings; for example, *G. atroviridis* and *G. mangostana* both have phenolic-rich profiles and similar functional properties (Farombi & Owoeye, 2011; Kumatso & Sigge, 2024; Schobert & Biersack, 2019). The findings of this study for *G. binucao* place this species in a similar group and allow this species to potentially be an indigenous source of antioxidants for food and other related applications, as it has similar properties. Table 2 presents a comparison of the total phenolic content and antioxidant activity of *G. binucao* fruit pulp with those of selected tropical fruits and other Garcinia species reported in the literature.

Table 2. Comparative total phenolic content and antioxidant activity of *Garcinia binucao* and selected tropical and Garcinia fruits reported in the literature.

Species	Fruit part	TPC (mg GAE g^{-1})	Antioxidant assay(s)	Reference
Garcinia binucao	Fruit pulp	30.35 ± 0.14	FRAP, DPPH	Present study
Garcinia mangostana	Pericarp	20–60	DPPH, FRAP	Kumatso and Sigge (2024)
Garcinia atroviridis	Fruit	15–40	DPPH, FRAP	Kumatso and Sigge (2024)
Tamarindus indica	Pulp	5–25	DPPH	Prior et al. (2005)
Averrhoa bilimbi	Fruit	10–20	DPPH	Recuenco et al. (2020)

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Differences in values may reflect variation in fruit part analyzed, extraction solvent, and assay conditions.

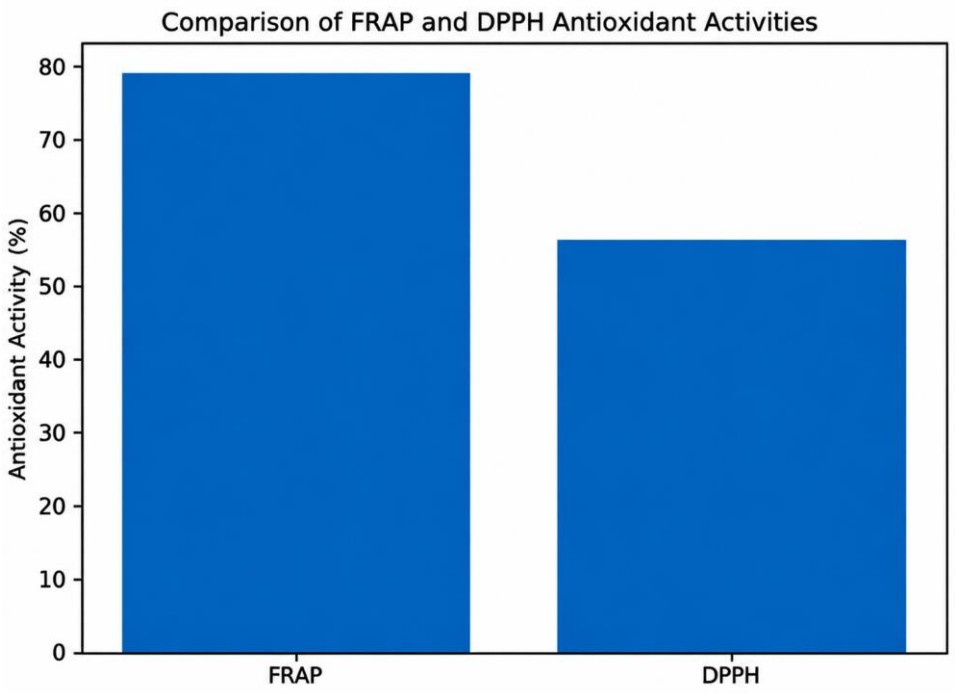


Figure 3. Ferric reducing antioxidant power (FRAP) and DPPH radical scavenging activity of *Garcinia binucao* fruit pulp, reflecting differences between electron-transfer and radical scavenging antioxidant mechanisms.

Figure 3 presents the FRAP and DPPH radical scavenging activities of *G. binucao* fruit pulp, demonstrating its antioxidant activity as assessed using two assays based on different reaction mechanisms.

It should be noted that variations in reported total phenolic content and antioxidant activity across studies may be influenced by differences in extraction solvent, fruit part analyzed, maturity stage at harvest, and assay protocols, which should be carefully considered when making direct quantitative comparisons among tropical and Garcinia fruits (Apak et al., 2007; Kumatso & Sigge, 2024; Prior et al., 2005; Thaipong et al., 2006).

6.5. Influence of Acidic Matrix and Ecological Factors

G. binucao pulp is highly acidic, and the primary constituents of organic acids in the pulp are citric and malic acids (Do et al., 2014; Quevedo, Laurena, & Merca, 2013; Ragasa et al., 2014). The stability of phenolics may be associated with the high acidity of the pulp. The reduction of phenolic oxidation is probably associated with the acidic environment of *G. binucao*. This decrease may have been induced by the reduction of both enzymatic and non-enzymatic oxidation of phenolics (Apak et al., 2007; Pietta, 2000; Rice-Evans et al., 1997). From a practical standpoint, this may help retain antioxidant activity throughout extraction, processing, and storage. Previous experiments with batuan highlighted that higher acidity retarded the process of oxidative degradation, which may suggest higher stability in the processed product (Ancheta et al., 2020; Dormido et al., 2019; Prior et al., 2005). Given this, the fruit matrix is likely to assist in the retention of redox-active compounds.

The stability of the biochemical matrix may be further affected by the environment. High tropical sunlight, high humidity, and a combination of other variables considered as stressors can result in high phenolic production in plants (Farombi & Owoeye, 2011; Lattanzio, Lattanzio, & Cardinali, 2006; Schobert & Biersack, 2019). Among these stressors, oxidative and microbial factors may be most influential in forming protective compounds. The *G. binucao* results are in line with this theory (Del Rio et al., 2013; Scalbert et al., 2005).

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6.6. Functional Food and Product Development Implications

This suggests that *Garcinia binucao*'s phenolic content and strong reducing capacity may have practical value beyond traditional culinary use. Phenolic-rich plant ingredients are increasingly seen as alternatives to synthetic antioxidants in the food processing sector. This responds to a growing demand for clean-label products (Prior et al., 2005; Scalbert et al., 2005). The antioxidant profile observed in the study suggests considerable applications in systems where oxidative stability is pertinent. As such, they may be considered for use in beverages, plant-based condiments, and powdered ingredients.

In addition, the fruit's naturally acidic composition may enhance the stability of these bioactive compounds during processing and storage. Studies on batuan-derived products indicate that acidity can contribute to improved shelf life, especially under drying conditions (Ancheta et al., 2020; Dormido et al., 2019). When combined with its phenolic composition, this feature may allow the fruit to function not only as a flavoring agent but also as a source of natural preservatives.

From a broader perspective, *G. binucao* represents an underutilized indigenous resource with characteristics comparable to more widely studied Garcinia species (Kumatso & Sigge, 2024; Schobert & Biersack, 2019). Expanding its use in food systems could support local innovation and small-scale processing while diversifying functional food ingredients. However, further work is needed to standardize processing methods and ensure consistency before such applications can be fully realized.

6.7. Methodological Considerations and Future Research Directions

While the results point to promising antioxidant properties, several limitations should be considered. The use of a pooled composite sample means that the data do not reflect variation associated with differences in maturity, location, or seasonal conditions, factors that are known to influence phenolic accumulation in fruits (Prior et al., 2005; Thaipong et al., 2006). As a result, the findings are best viewed as indicative rather than representative of broader population trends.

Another point to consider is the use of FRAP and DPPH assays, which provide overall measures of antioxidant behavior but do not identify the specific compounds involved. Previous studies on Garcinia species have shown that different phenolic groups, including xanthones and phenolic acids, can vary in their biological activity (Farombi & Owoeye, 2011; Schobert & Biersack, 2019). Without compound-level analysis, it is difficult to determine which constituents are primarily responsible for the observed effects.

Future research would benefit from incorporating replicated sampling across different harvest periods and locations to better capture natural variability. More detailed chemical characterization using techniques such as HPLC or LC–MS would also help identify key antioxidant compounds and clarify their roles. In addition, studies focusing on processing, storage, and formulation could provide insight into how these compounds behave in real food systems.

These approaches would allow a more comprehensive evaluation of *G. binucao* and support its potential development as a functional food ingredient grounded in reproducible scientific evidence.

7. CONCLUSION

The research suggests preliminary biochemical insights into the phenolic composition and antioxidant behavior of *G. binucao* fruit pulp. The findings emphasized that its pulp has a relatively high level of total phenolic compounds. This is supplemented by measurable antioxidant activity in both FRAP and DPPH assays. The stronger response was seen in the FRAP assays. This was interpreted to indicate that the antioxidant system is largely governed by electron-transfer mechanisms, a pattern known to be significantly related to phenolic acid-rich fruit matrices. These findings align with the idea that *G. binucao* fruit pulp has inherent biochemical compounds that are significant to oxidative stability.

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The data broadly contribute to the scarce literature on underutilized Philippine indigenous fruits. They posit the possibility of *G. binucao* as a natural antioxidant source. They provide the needed baseline for understanding its functional properties. However, caution must be exercised in interpreting the data, as they do not yet constitute established evidence in food systems. Nevertheless, they situate the species within the wider group of phenolic-rich tropical fruits. Recent years have seen increased interest in plant-driven antioxidants. These seek to improve nutritional and technological pursuits, such as preliminary characterization, which is increasingly pertinent.

8. LIMITATIONS OF THE STUDY

This research has limitations based on its findings. First, the pooled composite sample limits the ability to account for natural variation arising from environmental conditions, fruit maturity, or geographic origin. Thus, these values must be given an interpretation that is indicative rather than representative of the population-level characteristics.

Second, the utilization of FRAP and DPPH assays solely provides a general measure of antioxidant activity. Hence, it limits the identification of individual bioactive compounds. This restricts a more specific understanding of the mechanisms underlying the observed activity because of the absence of compound-specific profiling. Moreover, bioavailability, toxicity, and performance under actual food processing conditions were not assessed. This limits direct translation into applied food systems.

These suggest that the research findings should be considered preliminary and interpreted with caution.

9. POLICY IMPLICATIONS

Several policy perspectives are being considered in terms of practical considerations for these findings. The observed antioxidant capacity suggests that *G. binucao* could be explored as a locally sourced substitute for synthetic antioxidants, specifically in small- to medium-scale food processing sectors. This aligns with persistent efforts to establish clean-label ingredients and reduce reliance on artificial additives.

Moreover, the biochemical potential of *G. binucao* underpins its value as an underutilized indigenous resource. It can strengthen local value chains through integration, potentially providing economic opportunities for farmers or rural communities where the fruit is available. Hence, this could support broader visions aligned with agricultural diversification and sustainable resource objectives.

The findings suggest a link to nutrition-oriented programs. They encourage the utilization of locally available, bioactive-rich staples. Incorporating *G. binucao* into food and nutrition strategies may pave the way for dietary diversification. Moreover, it stimulates the promotion of cultural food systems. It underscores the necessity for persistent investment in the scientific investigation of native produce, including those that remain underexplored in biochemical and functional food research.

Funding: This study received no specific financial support.
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study. Both authors have read and agreed to the published version of the manuscript.
Disclosure of AI Use: The authors used an AI-assisted language tool (ChatGPT, OpenAI, GPT-5.3) for minor language editing and improve clarity. All content was carefully reviewed, revised, and approved by the authors.

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