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Research Article

Unveiling the Phytochemical Richness of Guatemalan *Spondias*: Comparative Analysis of Phenolics, Flavonoids and Antioxidant Potential

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ABSTRACT

Jocote fruits, derived from *Spondias purpurea* and *Spondias mombin*, are widely consumed in Guatemala and are traditionally valued for their nutritional and medicinal properties. Previous studies conducted in other regions highlight their richness in vitamins and phenolic constituents with potential health benefits. This study evaluated the flavonoid composition, total phenolic content, and antioxidant capacity of nine varieties of the two *Spondias* species collected from distinct regions of Guatemala to assess their potential as nutraceutical resources. Antioxidant activity was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay, while total phenolics were quantified by the Folin–Ciocalteu method. Flavonoids and related phenolic compounds were profiled using HPLC-DAD, with compound identification based on retention time comparison with analytical standards. Extracts from the Corona, Tronador, and Rax Ux varieties of *S. purpurea* and the Jobo and Quinin varieties of *S. mombin* exhibited the strongest antioxidant activity, with IC_{50} values ranging from 6.19 to 7.96 mg/L. Across the samples, p-coumaric acid and rutin were the most frequently detected phytochemicals (present in 14 samples), followed by quercetin (detected in 13 of the 15 samples). These findings demonstrate that Guatemalan jocote fruits possess a variety of bioactive flavonoids and phenolic compounds, supporting their classification as nutraceutical candidates due to their strong antioxidant potential. Further pharmacological and cytotoxicity studies are recommended to elucidate additional health-related benefits and broaden their potential applications in nutraceutical development.

Keywords: *Spondias purpurea*; *Spondias mombin*; polyphenols; *p*-coumaric acid; rutin; quercetin; nutraceutical

1. INTRODUCTION

Guatemala hosts a vast diversity of plant species, many of which remain underexplored despite their potential agro-industrial and nutraceutical value. A significant proportion of these native resources remain underutilized due to limited scientific information regarding their nutritional properties and secondary metabolite profiles (Pérez et al., 2012). Among the

culturally important yet insufficiently studied fruits is the *jocote*, the common name for the fruits of *Spondias purpurea* and *Spondias mombin* (Anacardiaceae), widely consumed across the country (Miller & Schaal, 2005).

The genus *Spondias* comprises approximately 18 species distributed throughout tropical regions worldwide and is known for producing diverse bioactive secondary metabolites. *S. purpurea* and *S. mombin* are small, fruit-bearing trees native to the dry tropical forests of Mexico and Central America. Their fruits aromatic red or yellow drupes are consumed fresh, traded in local markets, and processed into jams, beverages, fermented products, wines, sweets, and ice creams (dos Santos et al., 2023; Elufioye et al., 2018). In Guatemala, *S. purpurea* varieties are abundant and widely cultivated, prized for their superior flavor compared to *S. mombin*, although wild *S. mombin* persists in regions such as Petén where it remains largely undomesticated. Previous studies have shown that *Spondias* fruits possess notable vitamin content and exhibit multiple biological activities, including antibacterial, antifungal, larvicidal, antioxidant, anti-ulcer, hepatoprotective, anti-inflammatory, and anticancer effects (Sameh et al., 2018; Aráujo et al., 2012). Various plant parts are used in traditional medicine to manage conditions such as diabetes, anemia, malaria, diarrhea, inflammatory disorders, and gastritis. These properties are attributed to diverse classes of secondary metabolites particularly polyphenols such as quercetin, ellagic acid, and chlorogenic acid (dos Santos et al., 2023).

Flavonoids, one of the key polyphenolic groups present in *Spondias*, are widely studied due to their structural diversity, abundance in plant tissues, and broad biological activities. Their potent antioxidant capacity results from the presence of phenolic hydroxyl groups, which enable effective metal chelation and free radical scavenging (Turatbekova et al., 2023; Salihu and Salleh, 2023; Kadir et al., 2023; Escamilla et al., 2009; Tarahovsky et al., 2014). Flavonoids demonstrate therapeutic potential in conditions such as atherosclerosis, ischemic heart disease, and cancer and exhibit anti-diabetic, anti-inflammatory, antibacterial, antiviral, cytotoxic, and lipid-lowering effects (Hasnat et al., 2024). Consequently, they have wide applications in the food, cosmetic, and pharmaceutical industries (Dias et al., 2021). In *Spondias* species, flavonoids and phenolic acids have been consistently linked to their strong antioxidant activity (Sameh et al., 2018). Compounds such as rutin, quercetin, and ellagic acid have been reported in *S. mombin* (Ribeiro et al., 2022; Aráujo et al., 2012), while studies on *S. purpurea* have identified quercetin and kaempferol derivatives, including quercetin 3-O-rutinoside and kaempferol 3-O-rutinoside, particularly in the pulp and fruit peel (Adorno et al., 2020; Engels et al., 2012). Despite the widespread consumption of *jocote* fruits in Guatemala, comprehensive information on the diversity and abundance of flavonoids and phenolic compounds in the country's varieties remains scarce. This gap limits the valorization of *jocote* as a potential source of nutraceuticals and value-added products.

The present study aims to characterize the major flavonoids in the pulp of diverse *S. purpurea* and *S. mombin* varieties from different regions of Guatemala and to determine their total phenolic content and antioxidant capacity. These findings will provide insight into the nutraceutical potential of Guatemalan *jocote* fruits and support future efforts to develop value-added products derived from this widely consumed native resource.

2. MATERIALS AND METHODS

2.1. Sample Preparation

Fruits from different varieties of *S. purpurea* and *S. mombin* were collected from sites across the western, eastern, and northern departments of Guatemala, along with one comparative sample (SP04) of *S. mombin* sourced from Honduras and marketed in Guatemala. For each location, a minimum of 2 kg of fully ripe fruits were harvested. Samples were

transported in clearly labeled sacks to the laboratory for processing. The pulp was separated manually from the fruits and dried in a food dehydrator (Presto) for 24 h. The Honduran sample (SP04) was included as a reference to contextualize and compare the phytochemical profiles of Guatemalan material.

2.2. Extraction of Samples for Antioxidant Activity and Total Phenolic Content

For each sample, 5.0 g of dried pulp or peel were thoroughly mixed with 5 g of reagent-grade sand. The mixture was ground using a mortar and pestle, transferred to a 50 mL Falcon tube, and extracted with 30.0 mL of methanol. The suspension was vigorously shaken, allowed to stand for 24 h, and centrifuged. The resulting supernatant was transferred to Petri dishes and evaporated to dryness at room temperature in a fume hood. The dried extracts were collected and stored in labeled vials for subsequent antioxidant and total phenolic content assays.

2.3. Flavonoid Extraction for HPLC Analysis

Dried pulp or peel extracts (10.0 g) were placed in a 500 mL beaker, and 100 mL of boiling water were added. The mixture was vigorously stirred and allowed to cool to room temperature. Samples were then centrifuged for 30 min at 2000 rpm, after which the aqueous phase was separated and the remaining solids were discarded. Each aqueous extract was partitioned three times with 100 mL of ethyl acetate using 500 mL separatory funnels. The combined organic layers were concentrated to near dryness on a rotary evaporator (Heidolph). The residues were transferred to 1.5 mL vials using 1.0 mL ethyl acetate washings to ensure complete recovery. Final solvent removal was achieved using a centrifuge concentrator (Vacufuge Plus, Eppendorf), and the mass of the recovered solid was recorded to calculate extraction yield. Samples were labeled and stored under refrigeration until HPLC analysis.

2.4. Flavonoid Analysis by HPLC

Extract residues and analytical standards were dissolved in a 1:1 MeOH:H_2O mixture to a final concentration of approximately 1.0 mg/mL, followed by sonication. Prior to injection, solutions were filtered through 0.2 µm Millex-LG membrane filters (Millipore). Chromatographic separation was performed on an Agilent Infinity 1260 HPLC system equipped with a quaternary pump and a diode-array detector (1200 Series) operating between 200-600 nm. A Zorbax Eclipse Plus C18 column (100×4.6 mm, 3.5 µm) was used, with temperature control and data acquisition via ChemStation software. The method was adapted from Magiera & Zareba (2015). Detection wavelengths included 230, 254, 260, 285, and 310 nm. The mobile phase consisted of water with 0.1% formic acid (solvent A) and acetonitrile (solvent B), with a flow rate of 0.3 mL/min. The gradient program was as follows: 0-3 min: 98-2%, 3-11 min: 87-13%, 11-18 min: 80-20%, 18-24 min: 55-20%, 24-25 min: 20-100%, 25-28 min: 0%, 28-29 min: 0-98%, and 29-35 min: 98-2%. Flavonoids were identified based on retention times and UV-visible spectra compared to ten authenticated phenolic and flavonoid standards (2,5-dihydroxybenzoic acid, caffeic acid, p-coumaric acid, rutin, ellagic acid, taxifolin, kaempferol-3-O-rutinoside, quercetin, and 3-hydroxy-6-methoxy-1-flavone; Merck), analyzed under identical chromatographic conditions.

2.5. Antioxidant Activity

A stock solution for the antioxidant assay was prepared by dissolving 0.1 g of dry extract in 5 mL of absolute methanol using a sonicator (Fisher Scientific FS20) for 30 min at 30-40

kHz (Salleh et al., 2014; Salleh et al., 2015). From this stock solution, a dilution series was prepared to obtain concentrations corresponding to dilution factors of 0.2, 0.4, 0.6, 0.8, and 1.0. These dilutions were generated by mixing 200, 400, 600, 800, and 1000 µL of the extract solution, respectively, with enough methanol to reach a final volume of 1 mL. A 500 µM DPPH (2,2-diphenyl-1-picrylhydrazyl) solution was prepared in methanol and acetate buffer (pH 5.5). For the assay, four types of reaction mixtures were prepared: a blank control, a control, an assay blank, and the assay samples. Each tube contained 3 mL of acetate buffer. Methanol volumes differed depending on the tube type: 6 mL for the blank control, 4.5 mL for the control, 5.7 mL for the assay blank, and 4.2 mL for the assay samples. For the control and assay samples, 1.5 mL of DPPH solution was added. Finally, 0.3 mL of the respective extract dilution was added to the assay blank and assay samples, whereas the blank control and control tubes contained no extract. All tubes were incubated at room temperature for 30 min, protected from light. Absorbance readings were recorded at 517 nm, and the percentage inhibition was calculated. A plot of extract concentration (X-axis) versus absorbance (Y-axis) was used to obtain the linear regression equation and correlation coefficient (R^2). Antioxidant activity was expressed as the IC_{50} value the concentration of extract required to inhibit 50% of DPPH absorbance (Sharma & Bhat, 2008; Vasco et al., 2008).

2.6. Determination of Total Phenolic Content

An aliquot of 500 µL of the methanolic extract obtained from *jocote* pulp was mixed with 3.75 mL of Folin-Ciocalteu reagent (Merck), previously diluted 1:10 with distilled water. The mixture was allowed to stand at 22 °C for 5 min, after which 3.75 mL of an aqueous sodium bicarbonate solution (60 mg/L) was added. The reaction was permitted to proceed for 90 min at room temperature, and the absorbance was then measured at 725 nm. Total phenolic content was quantified using gallic acid (Sigma-Aldrich, ≥98% purity) as a calibration standard, and results were expressed as gallic acid equivalents (GAE) (Salleh and Ahmad, 2016; Salleh et al., 2016).

3. RESULTS AND DISCUSSION

A total of 15 *Spondias* fruit samples were collected from diverse regions of Guatemala, representing six varieties of *S. purpurea* (Tronador, Dulce, Corona, Amarillo, De Verano, and Rax Ux) and two varieties of *S. mombin* (Jobo and Quinin). One additional sample (SP04), the Colorado variety of *S. purpurea* originating from Honduras but marketed in Guatemala, was included as a comparative control. The sampling locations spanned the departments of Quiché, San Marcos, Sololá, Retalhuleu, Jutiapa, and Petén, with altitudes ranging from 14 to 1,599 m. These geographical details are summarized in Table 1, and representative fruits from four varieties are shown in Figure 1.

Table 1. Field data from *Spondias* spp. fruit collections in different locations in Guatemala

Code	Species	Variety	Location	Geographic coordinates/Altitude
SP01	*S. purpurea*	Jocote Dulce	Pachalum, Quiché	N 14° 55’ 33.38’’ O 90° 39’ 50.11’’1,240 msnm
SP02	*S. purpurea*	Jocote Amarillo	San Marcos	--
SP03	*S. purpurea*	Jocote De Corona	Panajachel, Sololá	N 14° 44’ 37.13’’ O 91° 09’ 16.25’’1,589 msnm
SP04	*S. purpurea*	Jocote Colorado	Honduras	--
SP05	*S. purpurea*	Jocote de Corona	La Máquina, Retalhuleu	N 14° 12’ 29.11’’ O 91° 40’ 34.25’’14 msnm

SP06	*S. purpurea*	Jocote De Verano	Comapa, Aldea Estanzuela, Jutiapa	N 14° 06’ 45.97’’ O 89° 54’ 53.64’’1,254 msnm
SP07	*S. purpurea*	Jocote Tronador	San Cristobal Ixcanal II, Comapa, Jutiapa	N 14° 08’ 16.70’’ O 89° 56’ 22.00’’1,294 msnm
SP08	*S. purpurea*	Jocote De Corona	Quesada, Jutiapa	N 14° 17’ 36.12’’ O 89° 53’ 50.79’’905 msnm
SP09	*S. purpurea*	Jocote Rax Ux	Santiago Atitlán, Sololá	N 14° 38’ 24.18’’ O 91° 13’ 45.97’’1,599 msnm
SP10	*S. purpurea*	Jocote De Corona	Santiago Atitlán, Sololá	N 14° 38’ 24.18’’ O 91° 13’ 45.97’’1,599 msnm
SP11	*S. purpurea*	Jocote Rax Ux	Santiago Atitlán, Sololá	N 14° 38’ 24.18’’ O 91° 13’ 45.97’’1,599 msnm
SP12	*S. purpurea*	Jocote De Corona	Santiago Atitlán, Sololá	N 14° 38’ 24.18’’ O 91° 13’ 45.97’’1,599 msnm
SP13	*S. purpurea*	Jocote De Corona	La Brea, Quesada, Jutiapa	N 14° 20’ 06.67’’ O 90° 04’ 10.22’’1,310 msnm
SM01	*S. mombin*	Jocote Quinín	San Francisco, Petén	N 16° 49’ 16.90’’ O 89° 55’ 17.30’’211 msnm
SM02	*S. mombin*	Jocote Jobo	San Francisco, Petén	N 16° 51’ 15.60’’ O 89° 55’ 24.10’’189 msnm

Figure 1. Fruits (jocotes): A: *Spondias purpurea,* Colorado variety; B*; Spondias mombin*, Quinin variety; C: *Spondias purpurea*, Tronador variety and D: *Spondias purpurea* Corona variety.

The retention times of 10 phenolic and flavonoid standards analyzed by HPLC are presented in Table 2. Retention times ranged from 9.844 min for 2,5-dihydroxybenzoic acid to 23.888 min for 3-hydroxy-6-methoxy-1-flavone. The closest elution was observed between p-coumaric acid and rutin (0.313 min); however, the chromatographic resolution and UV-Vis spectral differences were sufficient to ensure reliable identification in the fruit extracts.

Analysis of the methanolic extracts revealed clear differences among *Spondias* varieties in flavonoid diversity, antioxidant capacity, and total phenolic content (Table 3). The sample with the highest number of identified phenolic compounds was SP07 (Tronador variety, *S. purpurea*; 10 compounds). This was followed by SP11 (Rax Ux, *S. purpurea*; 8 compounds), and by SP12, SP13, and SM02, which each contained seven phenolic constituents. Across all

samples, the most frequently detected compounds were p-coumaric acid and rutin (14 samples each) and quercetin (13 samples). In contrast, 2,5-dihydroxybenzoic acid and kaempferol were detected only in SP11, indicating unique chemical features in this specific variety.

Table 2. Retention times of standards of flavonoids and phenolic compounds obtained by HPLC

No.	Retention time tR (minutes)	Substance
1	9.844	2,5-dihydroxybenzoic acid
2	11.306	Caffeic acid
3	13.461	p-cumaric acid
4	13.774	Rutin
5	14.234	Ellagic acid
6	15.064	Taxifolin
7	15.374	Kaempferol-3-O-rutinoside
8	19.556	Quercetin
9	20.434	Kaempferol
10	23.888	3-hydroxi-6-methoxy-1-flavone

Table 3. Identification of flavonoids and phenolic compounds, antioxidant capacity and total phenolic content of pulp and peel extracts from jocote fruits from different regions of Guatemala

Codes	Flavonoids	IC_{50} (mg/mL)	TPC (mg/mL GA*)
SP01	*p*-coumaric acid, rutin, taxifolin, kaempferol-3-O-rutinoside, kaempferol-3-O-rutinoside, quercetin	14.37 ± 0.38	0.137 ± 0.00
SP02	Caffeic acid, *p*-coumaric acid, rutin, ellagic acid, taxifolin	15.84 ± 0.50	0.246 ± 0.02
SP03	*p*-coumaric acid, rutin, quercetin, 3-hydroxy-6-methoxy-1-flavone	36.69 ± 0.90	0.114 ± 0.03
SP04	rutin, ellagic acid, quercetin, kaempferol, 3-hydroxy-6-methoxy-1-flavone	16.15 ± 0.02	0.130 ± 0.01
SP05	*p*-coumaric acid, rutin, ellagic acid, quercetin, 3-hydroxy-6-methoxy-1-flavone	13.57 ± 0.59	0.123 ± 0.02
SP06	*p*-coumaric acid, rutin, ellagic acid, quercetin, 3-hydroxy-6-methoxy-1-flavone	10.00 ± 0.01	0.152 ± 0.02
SP07	2,5-dihydroxybenzoic acid, caffeic acid, *p*-coumaric acid, rutin, ellagic acid, taxifolin, kaempferol-3-O-rutinoside, quercetin, kaempferol, 3-hydroxy-6-methoxy-1-flavone	7.96 ± 0.24	0.214 ± 0.02
SP08	*p*-coumaric acid, rutin, ellagic acid, kaempferol-3-O-rutinoside, quercetin, 3-hydroxy-6-methoxy-1-flavone	16.62 ± 0.02	0.080 ± 0.01
SP09	*p*-coumaric acid, rutin, ellagic acid, kaempferol-3-O-rutinoside, 3-hydroxi-6-methoxy-1-flavone.	9.33 ± 0.03	0.127 ± 0.05
SP10	Caffeic acid, *p*-coumaric acid, rutin, taxifolin, Kaempferol-3-O-rutinoside, quercetin, 3-hydroxy-6-methoxy-1-flavone	28.41 ± 0.04	0.090 ± 0.02
SP11	Caffeic acid, *p*-coumaric acid, rutin, ellagic acid, taxifolin, kaempferol-3-O-rutinoside, quercetin, 3-hydroxy-6-methoxy-1-flavone	8.97 ± 0.08	0.258 ± 0.03
SP12	2,5-dihydroxybenzoic acid, *p*-coumaric acid, rutin, ellagic acid, quercetin, kaempferol, 3-hydroxy-6-methoxy-1-flavone	6.19 ± 0.07	0.379 ± 0.01
SP13	Caffeic acid, *p*-coumaric acid, rutin, ellagic acid, kaempferol-3-O-rutinoside, quercetin, 3-hydroxy-6-methoxy-1-flavone	14.65 ± 0.04	0.146 ± 0.02
SM01	Caffeic acid, *p*-coumaric acid, taxifolin, quercetin, 3-hydroxy-6-methoxy-1-flavone	6.76 ± 0.08	0.341 ± 0.03
SM02	Caffeic acid, *p*-coumaric acid, rutin, ellagic acid, kaempferol-3-O-rutinoside, quercetin, 3-hydroxy-6-methoxy-1-flavone	6.60 ± 0.01	0.276 ± 0.01
BHT	-	0.22 ± 0.24	0.228 ± 0.03
BHA	-	0.10 ± 0.60	0.249 ± 0.02

GA: Gallic acid; BHT: Butylated hydroxy toluene; BHA: Butylated hydroxy anisole; SP: *S. purpurea*; SM: *S. mombin*

These findings align with reports from other countries, where p-coumaric acid, rutin, and quercetin are consistently documented in *S. purpurea* and *S. mombin* (Sameh et al., 2018; Ogunro et al., 2023; dos Santos et al., 2023). UV spectra for selected polyphenols are shown in Figure 2, confirming identity through characteristic absorption profiles. The bioactivity relevance of these compounds is notable: p-coumaric acid induces apoptosis in colon cancer cells via ROS–mitochondrial mechanisms and exhibits antioxidant, antimicrobial, and immunosuppressive activities (Jaganathan et al., 2013; Boz, 2015; Pragasam et al., 2012). Rutin is known to reverse multidrug resistance in breast cancer cells and has strong antioxidant properties, while quercetin demonstrates antiviral potential against HSV-1 and broad therapeutic value (Iriti et al., 2017; Ordaz et al., 2018; Martínez et al., 2002). In addition, 3-hydroxy-6-methoxy-1-flavone and ellagic acid were present in 13 and 11 samples, respectively, providing further evidence of the phytochemical richness of Guatemalan *Spondias* fruits.

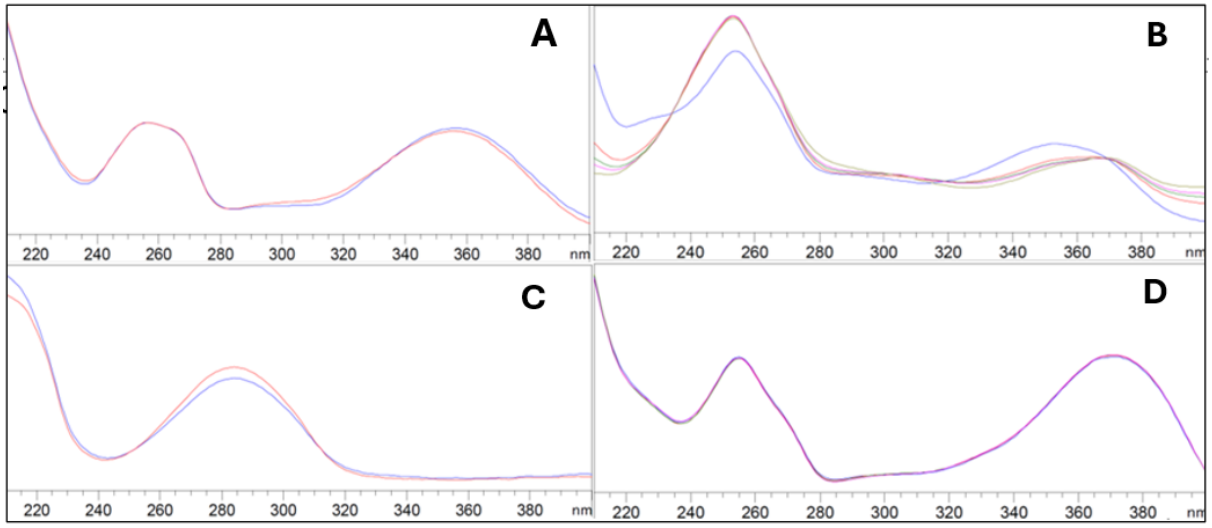

Figure 2. UV spectra of rutin (**A**) at 13.79 min in Rax ux variety; ellagic acid (**B**) at 14.246 min from Honduras; taxifolin (**C**) at 15.084 min from Quinin variety; and quercetin (**D**) at 18.581 min from Quinin variety

Antioxidant activity, expressed as IC_{50} values for DPPH scavenging, and total phenolic content (GAE). The strongest antioxidant activity was observed in samples SP12 (Corona, *S. purpurea*; 6.19 ± 0.07 mg/mL), SM02 (Jobo, *S. mombin*; 6.60 ± 0.01 mg/mL), SM01 (Quinin, *S. mombin*; 6.76 ± 0.08 mg/mL), and SP07 (Tronador, *S. purpurea*; 7.96 ± 0.24 mg/mL). These samples generally contained the highest total phenolic contents (0.214 - 0.379 mg/mL), reinforcing the strong relationship between phenolic concentration and antioxidant capacity. However, none of the natural samples surpassed the synthetic antioxidants BHT and BHA, which showed IC_{50} values of 0.22 and 0.10 mg/mL, respectively.

The Honduran sample (SP04) exhibited phenolic and antioxidant values comparable to Guatemalan samples, validating its use as a commercial control benchmark. The chemical diversity–activity relationship was generally consistent: samples with a higher number of identified flavonoids tended to exhibit lower IC_{50} values (higher antioxidant activity). Nonetheless, certain exceptions highlight the limitations of targeted profiling. For instance, SM01 possessed only five identified flavonoids but exhibited strong antioxidant activity (IC_{50} = 6.76 ± 0.08 mg/mL), likely attributable to its high total phenolic content (0.341 ± 0.03 mg/mL). Conversely, SP10 contained seven phenolic compounds but displayed a moderate antioxidant response, possibly due to its relatively low total phenolic content. The antioxidant activities observed for *Spondias* pulp in this study were lower than the values reported when whole fruits (pulp + peel) are analyzed (Elufioye et al., 2018), a difference consistent with literature establishing that peels generally contain higher polyphenol concentrations than pulps

(Rodrigues et al., 2024; Lasota et al., 2024). Nevertheless, the phenolic content values obtained here align well with the antioxidant activity trends and confirm the health-promoting potential of *Spondias* polyphenols.

Overall, the results indicate that both *S. purpurea* and *S. mombin* fruits from Guatemala possess significant nutraceutical potential. Samples with total phenolic contents above 0.200 mg/mL consistently showed strong antioxidant capacity, suggesting a synergistic contribution of flavonoids and related phenolic constituents. Because *jocote* is commonly consumed with its peel, the combined phytochemical load of the fruit is likely even greater in practice. These findings reinforce the potential of *Spondias* fruits as candidates for the development of natural, non-toxic therapeutic agents against degenerative diseases, as suggested in previous studies (Ogunro et al., 2023).

4. CONCLUSION

This study highlights the significant nutraceutical potential of *S. purpurea* and *S. mombin* fruits from Guatemala. The Tronador, Corona, and Rax Ux varieties of *S. purpurea* exhibited the greatest diversity of flavonoids and the highest total phenolic contents, which strongly contributed to their superior antioxidant activities. Likewise, the Jobo and Quinin varieties of *S. mombin* demonstrated noteworthy phytochemical richness and antioxidant capacity, supporting their value for future domestication and crop improvement efforts in northern Guatemala. Overall, the consistent presence of key bioactive compounds particularly p-coumaric acid, rutin, and quercetin reinforces the relevance of these fruits as promising sources of natural antioxidants. Further studies should investigate additional pharmacological properties, including anti-inflammatory, antimicrobial, and cytoprotective effects, to fully assess their potential applications as nutraceuticals. Expanding the analysis to other *Spondias* varieties and quantifying their phenolic and flavonoid profiles will provide a more comprehensive understanding of the health-promoting potential of this important native fruit.

Conflict of Interest
The authors declare that they have no conflicts of interest,

Author Contribution Statement
Max Samuel Mérida-Reyes: Conceptualization, methodology, investigation; Juan Francisco Pérez-Sabino: Conceptualization, methodology, data curation, supervision, writing original draft, review, editing. Antonio Ribeiro da Silva: Conceptualization, methodology, supervision. Pedro Pablo Molina Jauregui: Data curation, investigation, writing original draft

Data Availability Statement
The data supporting the results of this study are available from the corresponding author upon request.

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