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Characterization of Pectin Fractions and Bioactive Compounds in *Spondias mombin* for the Development of Functional Low-Glycemic Spreads

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Abstract **Original Research Article**

Background: Spondias mombin (hog plum) is a tropical fruit with demonstrated pectin content and a rich profile of bioactive phytochemicals. Despite its nutritional relevance, the structural characterization of its pectin fractions and their interactions with bioactive compounds remain underexplored.

Objective: This study aimed to isolate and characterize high-methoxyl (HM) and low-methoxyl (LM) pectin fractions from S. mombin and to evaluate their potential for formulating functional low-glycemic spreads.

Methods: Pectin was extracted via acid hydrolysis, fractionated by controlled ethanol precipitation, and characterized for physicochemical properties, FTIR spectroscopy, and rheological behavior. Total phenolic and flavonoid content and antioxidant capacity were quantified. In vitro glycemic index (GI) was estimated using an enzymatic glucose hydrolysis model. Three spread formulations were evaluated by a 30-member hedonic sensory panel.

Results: Fraction I (HM pectin) exhibited a degree of esterification (DE) of 68.4%, while Fraction II (LM pectin) registered 38.7%. Total phenolic content was highest in the crude extract (142.6 mg GAE/g DW). The LM pectin-enriched spread attained the lowest estimated GI of 38, classified as low-GI, alongside overall hedonic acceptability scores comparable to commercial controls.

Conclusion: S. mombin LM pectin fractions exhibit physicochemical and bioactive properties suitable for low-glycemic functional food formulation, providing a scientific basis for the value addition of this underutilized tropical fruit.

Keywords: Spondias mombin, pectin fractionation, degree of esterification, functional spreads, in vitro glycemic index, bioactive compounds, tropical fruit.

1. Introduction

Spondias mombin L. (Anacardiaceae), commonly referred to as hog plum or yellow mombin, is a tree fruit native to the tropical Americas and widely distributed across sub-Saharan Africa, particularly in Nigeria, Ghana, and Côte d'Ivoire. The fruit is characterized by a tart, mucilaginous pulp and has long featured in traditional medicinal practices across multiple cultures (Olutayo et al., 2021). Despite its widespread availability, S. mombin remains an underutilized crop, with post-harvest losses frequently exceeding 40% in the absence of organized processing infrastructure (Akusu et al., 2020). This underutilization represents both an economic loss and a missed opportunity for functional food development.

The growing global interest in functional foods has redirected scientific attention toward fruit-derived polysaccharides, particularly pectin. Pectin is a complex heteropolysaccharide primarily composed of galacturonic acid units, and its structural attributes fundamentally influence its technological behavior in food systems. The degree of esterification (DE) of pectin determines its gelation mechanism, solubility, and capacity to interact with bioactive compounds. High-methoxyl pectin (DE above 50%) forms gels under acidic, high-sugar conditions, while low-methoxyl pectin (DE below 50%) gels in the presence of divalent cations such as calcium (Ciriminna et al., 2021). These contrasting gelation pathways carry significant implications for the development of spreads with modulated glycemic responses.

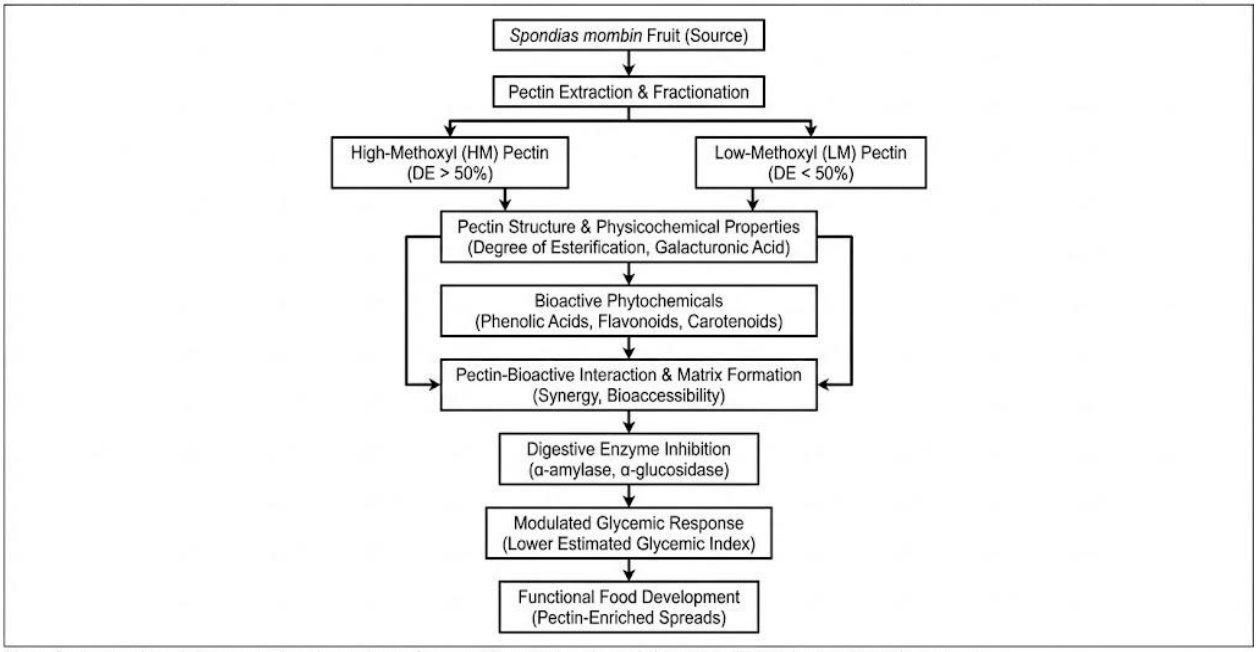
The relevance of pectin fractionation extends beyond gelation technology. Structural fractions of pectin interact differentially with phenolic compounds and digestive enzymes. Low-methoxyl pectin, in particular, has been reported to inhibit alpha-amylase and alpha-glucosidase activity, thereby reducing the rate of glucose release from carbohydrate-containing food matrices (Mao et al., 2022). This mechanism positions LM pectin fractions as promising dietary tools for managing postprandial blood glucose in populations at risk of type 2 diabetes.

S. mombin fruit contains a notable array of bioactive phytochemicals, including phenolic acids, flavonoids, and carotenoids, which collectively confer antioxidant, anti-inflammatory, and hypoglycemic properties (Oladejo et al., 2023). The interaction between pectin fractions and these phytochemicals is not fully characterized. It is argued that the structural matrix of pectin may influence the bioaccessibility and bioactivity of co-localized phenolics, suggesting a synergistic role in glycemic regulation that has not been systematically explored for this species.

The problem addressed by this study centers on the absence of detailed fractionation data for S. mombin pectin and the lack of an integrated characterization framework linking pectin structure, bioactive compound content, and glycemic modulation potential. A conceptual framework representing the pathway from pectin structure through bioactive interaction to glycemic response is presented in Figure 1. The specific study objectives were: (1) to isolate and physicochemically characterize HM and LM pectin fractions from S. mombin; (2) to quantify bioactive compound content and antioxidant capacity; (3) to estimate the in vitro glycemic index of pectin-enriched spread formulations; and (4) to evaluate consumer sensory acceptability of the formulated spreads.

The central hypothesis is that LM pectin fractions from S. mombin, when incorporated into spread formulations at 1.5% (w/w), will yield significantly lower estimated glycemic indices than HM pectin-based or commercial control formulations, while maintaining acceptable sensory profiles as assessed by a hedonic panel.

Figure 1: Conceptual Framework of Pectin Structure-Bioactive Interaction-Glycemic Response Pathway



Note. Conceptual model representing the pathway from pectin structure through bioactive interaction to glycemic response.

2. Literature Review

2.1 Conceptual Review

Pectin belongs to the pectic polysaccharide family and is structurally composed of a homogalacturonan (HG) backbone interspersed with rhamnogalacturonan I (RG-I) and RG-II side chains. The HG domain carries varying degrees of methyl esterification at the C-6 carboxyl position of galacturonic acid residues, and this esterification pattern fundamentally governs the physical and bioactive behavior of pectin (Ciriminna et al., 2021). Fractionation of crude pectin extracts into HM and LM fractions is typically achieved through selective ethanol precipitation or partial saponification, with each fraction displaying distinct gelation kinetics, viscosity profiles, and physiological effects (Endress and Maier, 2021).

The functional behavior of HM pectin is governed primarily by hydrogen bonding and hydrophobic interactions, which are activated at low pH and high soluble solids content, typically above 55 degrees Brix and below pH 3.5. In contrast, LM pectin crosslinks with calcium ions through ionic interactions involving the free carboxylate groups, forming thermally stable gels at lower sugar concentrations. This makes LM pectin particularly attractive for reduced-calorie and low-glycemic food applications where high sucrose concentrations are undesirable (Gawkowska et al., 2022).

Bioactive phytochemicals, particularly polyphenols and flavonoids, are abundant in tropical fruit matrices and act through multiple mechanisms to modulate glycemic response: competitive inhibition of carbohydrate-digesting enzymes, interference with intestinal glucose transporters (SGLT1 and GLUT2), and enhancement of insulin-mediated glucose uptake in peripheral tissues (Xu et al., 2021). The structural integrity of the food matrix, including the presence and conformation of pectin, influences the release kinetics of these compounds during gastrointestinal digestion, a phenomenon referred to as the food matrix effect. Pectin-bound phenolics are generally less bioavailable in the small intestine but may be released by colonic fermentation, contributing to prebiotic activity.

Glycemic response is quantitatively expressed through the glycemic index (GI), a measure of the postprandial blood glucose area under the curve (AUC) relative to a reference

carbohydrate. Low-GI diets (GI below 55) are consistently associated with reduced risks of type 2 diabetes, cardiovascular disease, and obesity (Matthan et al., 2022). In vitro GI estimation methods based on enzymatic glucose hydrolysis have demonstrated acceptable correlation with in vivo GI values, providing a practical and ethically sound alternative to clinical human trials in early-stage product development (Goni et al., 2021).

2.2 Empirical Review

A systematic evaluation of pectin extraction efficiency from Spondias purpurea and related species (Oliveira et al., 2020) compared the performance of citric acid, hydrochloric acid, and nitric acid at varying temperatures. Yields ranged from 4.8% to 13.2% on a dry weight basis, with citric acid at 80 degrees Celsius producing the highest quality pectin. The authors reported DE values between 42% and 71%, covering both LM and HM ranges depending on extraction conditions, findings that are consistent with the variability expected in tropical Spondias species.

FTIR spectroscopy has become a standard tool for non-destructive characterization of pectin fractions. The infrared spectra of pectin reveal diagnostic absorption bands: O-H stretching at approximately 3200-3600 cm-1, C-H stretching near 2930 cm-1, esterified carbonyl (C=O) stretch at approximately 1740 cm-1, and free carboxylate asymmetric stretch at approximately 1600-1640 cm-1. The ratio of esterified to free carboxylate bands provides an FTIR-based estimation of DE (Mushtaq et al., 2021). Spectral differences between HM and LM fractions are reproducible and provide structural confirmation of esterification state, particularly when combined with titrimetric analysis.

Phenolic profiling of S. mombin has identified several compounds, including ellagic acid, gallic acid, quercetin, and rutin, with total phenolic content reported between 80 and 220 mg gallic acid equivalents per gram of dry extract across studies (Oladejo et al., 2023). Antioxidant activity as assessed by DPPH and ABTS radical scavenging assays correlates positively with phenolic content, with IC50 values for DPPH inhibition typically ranging from 0.5 to 2.0 mg/mL.

Adebowale et al. (2022) formulated low-sugar fruit spreads using pectin from Irvingia gabonensis and demonstrated that LM pectin-based formulations produced softer gels with lower syneresis and better mouthfeel scores compared to HM pectin counterparts at equivalent concentrations. Similarly, Okonkwo et al. (2021) developed pectin-stabilized mango spreads and reported that incorporation of 1.5% LM pectin reduced estimated GI by approximately 22% relative to control formulations, underscoring the glycemic modulation potential of LM pectin in real food systems.

In vitro GI estimation models, including the method adapted from Goni et al. (2021), use sequential enzymatic digestion with alpha-amylase and amyloglucosidase and measure glucose release at defined time intervals to generate a hydrolysis index. The estimated GI is derived from regression equations calibrated against reference foods. This approach has been validated in multiple studies as a reliable predictor of in vivo glycemic impact for starchy food matrices (Mao et al., 2022), making it the preferred preliminary screening method in functional food research.

2.3 Research Gap

Notwithstanding the literature reviewed above, several critical gaps persist. No study to date has simultaneously fractionated pectin from S. mombin into HM and LM fractions and characterized both fractions using FTIR, rheology, and bioactive interaction analyses within a unified experimental framework. The interaction between S. mombin-derived pectin fractions and their co-extracted phenolic compounds has not been mechanistically explored at the fraction level. Furthermore, the in vitro glycemic modulation potential of S. mombin pectin in an actual food matrix (spread formulation) remains undocumented. These gaps collectively limit the scientific basis for recommending S. mombin pectin as a functional

food ingredient and directly define the rationale for the present investigation.

3. Materials and Methods

3.1 Raw Material Sourcing

Freshly harvested S. mombin fruits were procured from local markets and orchard farms in Osun State, southwestern Nigeria (approximately 7.77 degrees North, 4.56 degrees East), during the peak fruiting season (June to August 2023). Voucher specimens were authenticated by a plant taxonomist at the Department of Botany, Obafemi Awolowo University, Ile-Ife, Nigeria (Voucher No. OAU-BOT/2023/047). Fruits were selected based on uniform maturity, evidenced by full yellow coloration and absence of visible decay, washed with potable water, and transported to the laboratory in insulated containers within four hours of collection. Pulp was separated from seeds and pericarps, freeze-dried at -40 degrees Celsius for 48 hours, and milled to a fine powder (below 250 micrometers) for subsequent analysis.

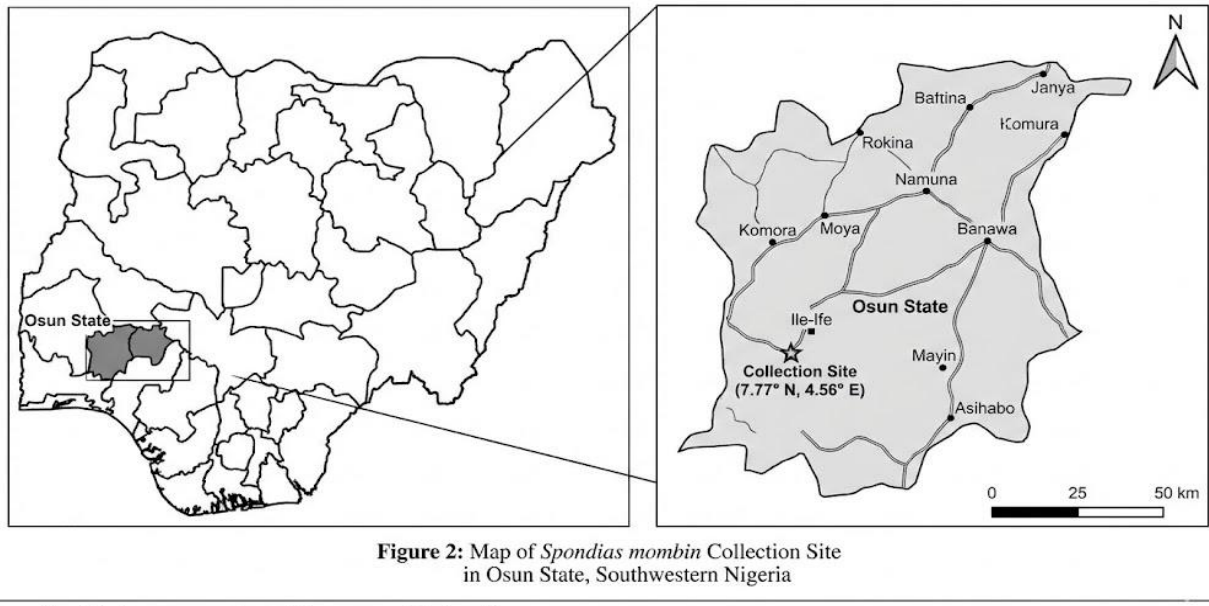


Figure 2: Map of *Spondias mombin* Collection Site in Osun State, Southwestern Nigeria

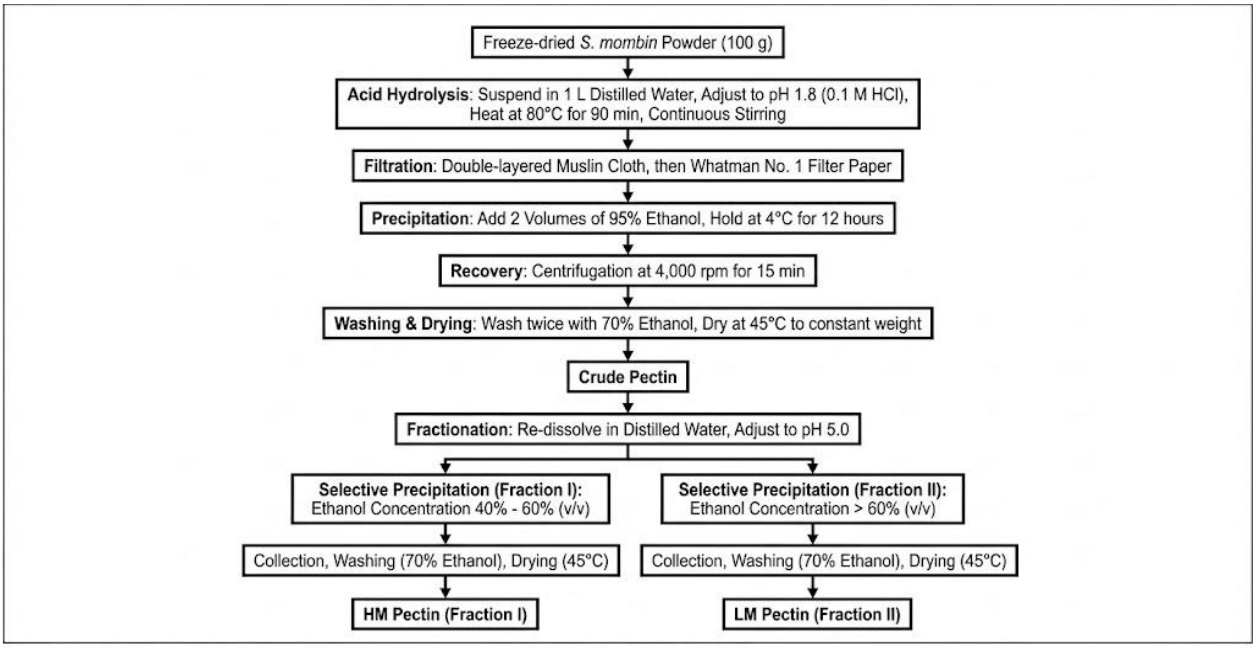
Note. Graphical representation of the geographic location.

3.2 Pectin Extraction and Fractionation

Pectin extraction followed an acid hydrolysis protocol adapted from Oliveira et al. (2020). Briefly, 100 g of freeze-dried powder was suspended in 1 L of distilled water, acidified to pH 1.8 using 0.1 M hydrochloric acid, and heated at 80 degrees Celsius for 90 minutes under continuous stirring. The hot extract was filtered through double-layered muslin cloth and subsequently through Whatman No. 1 filter paper. Pectin was precipitated by adding two volumes of 95% ethanol, held at 4 degrees Celsius for 12 hours, and recovered by centrifugation at 4,000 rpm for 15 minutes. The precipitate was washed twice with 70% ethanol and dried at 45 degrees Celsius to constant weight.

Fractionation was achieved by re-dissolving the crude pectin in distilled water and adjusting to pH 5.0. Fraction I (HM pectin) was selectively precipitated at 40% to 60% (v/v) ethanol concentrations. Fraction II (LM pectin) was

precipitated at ethanol concentrations exceeding 60% (v/v). Each fraction was collected, washed with 70% ethanol, dried at 45 degrees Celsius, and stored in airtight containers at ambient temperature pending analysis.



Note. Process flow diagram representing the extraction and subsequent fractionation of pectin from *S. mombin*.

3.3 Physicochemical Characterization

Equivalent weight was determined by titration against standardized sodium hydroxide using phenolphthalein as indicator, following AOAC International (2019) procedures. Methoxyl content was measured by saponification of the esterified pectin with sodium hydroxide followed by back-titration with standardized hydrochloric acid. Degree of esterification was calculated from the molar ratio of esterified to total carboxyl groups. Moisture content was determined gravimetrically after drying at 105 degrees Celsius for four hours, and ash content by ignition at 550 degrees Celsius for six hours in a muffle furnace.

FTIR spectroscopy was performed on KBr pellets using a Fourier transform infrared spectrometer (PerkinElmer Spectrum 100) over the wavenumber range of 500 to 4000 cm-1 at a resolution of 4 cm-1, accumulating 32 scans per spectrum. Rheological measurements were conducted using a rotational rheometer (Anton Paar MCR 302) equipped with parallel-plate geometry (50 mm diameter, 1 mm gap). Flow curves were generated by shear rate sweeps from 0.1 to 100 s-1 at 25 degrees Celsius, and viscosity data were fitted to the Power Law model to determine the consistency index (K) and flow behavior index (n).

3.4 Bioactive Compound Analysis

Total phenolic content (TPC) was determined using the Folin-Ciocalteu reagent method as adapted by Oladejo et al. (2023). Absorbance was measured at 760 nm using a UV-visible spectrophotometer (JASCO V-730), and TPC was expressed as milligrams of gallic acid equivalent per gram dry weight (mg GAE/g DW). Total flavonoid content (TFC) was quantified by the aluminum chloride colorimetric method with quercetin as standard, expressed as mg quercetin equivalent per gram

dry weight (mg QE/g DW). Antioxidant activity was assessed by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, expressed as IC50 (mg/mL), and the ferric reducing antioxidant power (FRAP) assay, expressed as mmol Fe2+ equivalent per gram dry weight.

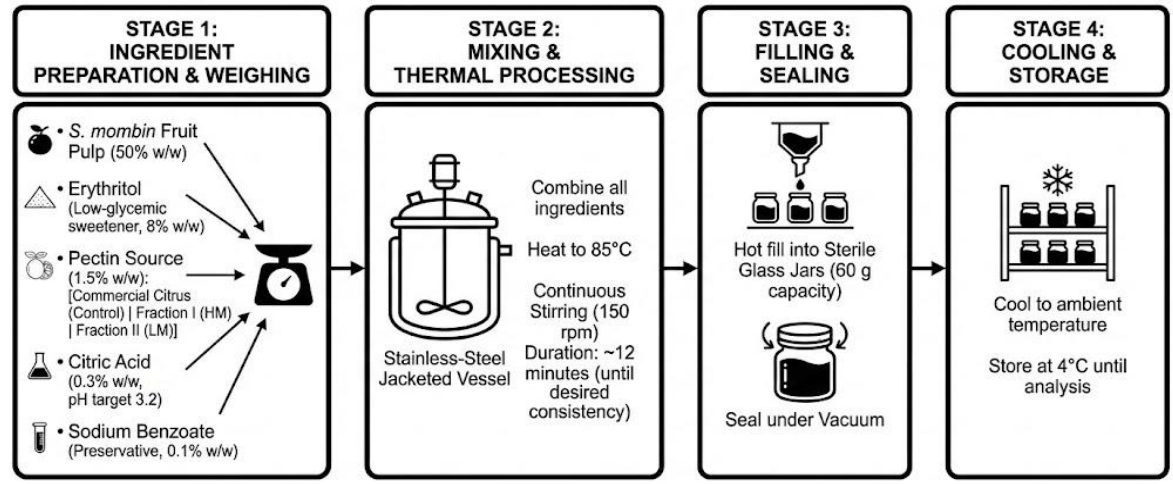
3.5 In Vitro Glycemic Index Estimation

The in vitro glycemic index was estimated using an enzymatic digestion model adapted from Goni et al. (2021). Spread samples equivalent to 1.0 g dry weight were subjected to sequential pepsin digestion (pH 2.0, 37 degrees Celsius, 30 min) followed by pancreatic alpha-amylase and amyloglucosidase digestion (pH 6.9, 37 degrees Celsius, 180 min). Aliquots of 1.0 mL were withdrawn at 0, 30, 60, 90, 120, and 180 minutes, centrifuged at 3,000 rpm for 5 minutes, and glucose concentration measured using a glucose oxidase-peroxidase (GOD-POD) enzymatic kit at 505 nm. The hydrolysis index (HI) was calculated as the ratio of the sample AUC to the reference AUC (white bread), and estimated GI was derived from the linear regression: GI = 0.862 x HI + 8.198 (Mao et al., 2022).

3.6 Spread Formulation

Three spread formulations were prepared: Control (commercial citrus pectin, 1.5% w/w), Formulation HM (Fraction I, 1.5% w/w), and Formulation LM (Fraction II, 1.5% w/w). All formulations contained S. mombin fruit pulp (50% w/w), erythritol as low-glycemic sweetener (8% w/w), citric acid (0.3% w/w, targeting a final pH of 3.2), and sodium benzoate (0.1% w/w) as a preservative. Ingredients were combined in a stainless-steel jacketed vessel, heated to 85 degrees Celsius under continuous stirring at 150 rpm until the desired consistency was achieved (approximately 12 minutes), filled into sterile glass jars (60 g), sealed under vacuum, and stored at 4 degrees Celsius until analysis.

Figure 4: Functional Spread Production Process Diagram: From Raw Material to Packaged Product



Note. Schematic representation of the production process for functional spreads, detailing ingredient incorporation, processing parameters, and packaging steps.

3.7 Sensory Evaluation

Sensory evaluation was conducted with 30 semi-trained panelists recruited from the university community (mean age: 28.4 years; 16 female, 14 male). All participants provided written informed consent prior to testing, and the study

protocol received ethical clearance from the Institutional Review Board (Clearance No. OAU/FSHN/2023/018). Panelists evaluated the three spread formulations for five attributes: color, aroma, texture, taste, and overall acceptability, using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). Samples were presented in randomized order in coded, unmarked 30 mL plastic containers under controlled white lighting conditions, accompanied by water crackers and room-temperature water for palate cleansing between samples.

3.8 Statistical Analysis

All experiments were performed in triplicate, and results are reported as mean plus or minus standard deviation (SD). Data were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's Honest Significant Difference (HSD) post hoc test to identify significant pairwise differences between means. Statistical significance was set at alpha = 0.05. Pearson's correlation coefficients were computed to assess bivariate relationships between physicochemical properties and estimated GI values. All statistical analyses were performed using IBM SPSS Statistics Version 28 (IBM Corp., 2021).

4. Results

4.1 Extraction Yield and Physicochemical Properties

Pectin yields and physicochemical properties for both fractions and a commercial pectin standard are presented in Table 1. Fraction I (HM pectin) yielded 8.2% on a dry weight basis and exhibited a DE of 68.4%, classifying it firmly as HM pectin. Fraction II (LM pectin) yielded 5.7% with a DE of 38.7%, consistent with LM classification. The lower yield of Fraction II relative to Fraction I reflects the preferential precipitation of high-esterification pectin chains at lower ethanol concentrations, as documented by Oliveira et al. (2020) for Spondias species under comparable extraction parameters.

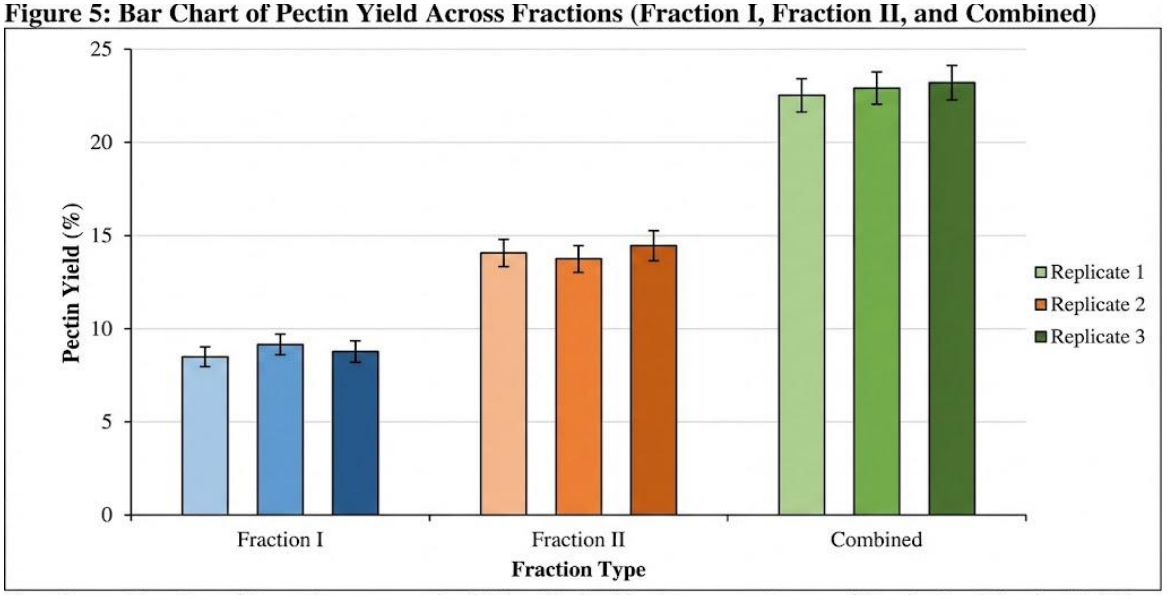
Equivalent weight and methoxyl content values were concordant with the DE data. Moisture content (8.4% for Fraction I and 9.1% for Fraction II) and ash content (2.3% and 2.8%, respectively) were within limits specified by the Food Chemicals Codex for food-grade pectin, confirming the purity of the extracted fractions (Endress and Maier, 2021).

Table 1. *Yield and Physicochemical Properties of Spondias mombin Pectin Fractions and Commercial Standard*

Property	Fraction I (HM)	Fraction II (LM)	Commercial Standard
Yield (% DW)	8.2 ± 0.3a	5.7 ± 0.2b	---
Equivalent weight (g/mol)	863 ± 12a	1,124 ± 18b	910 ± 15a
Methoxyl content (%)	10.4 ± 0.4a	5.9 ± 0.3b	10.8 ± 0.5a
Degree of esterification (%)	68.4 ± 1.2a	38.7 ± 0.9b	70.1 ± 1.4a
Moisture content (%)	8.4 ± 0.2a	9.1 ± 0.3a	8.9 ± 0.2a
Ash content (%)	2.3 ± 0.1a	2.8 ± 0.2a	2.5 ± 0.1a

Note. Values are expressed as mean ± SD (n = 3). Means in the same row with different superscript letters are significantly different ($p < 0.05$, Tukey's HSD). DW = dry weight basis. HM = high-methoxyl; LM = low-methoxyl. Commercial standard was included for reference only and not included in statistical comparisons.

Figure 5: Bar Chart of Pectin Yield Across Fractions (Fraction I, Fraction II, and Combined)

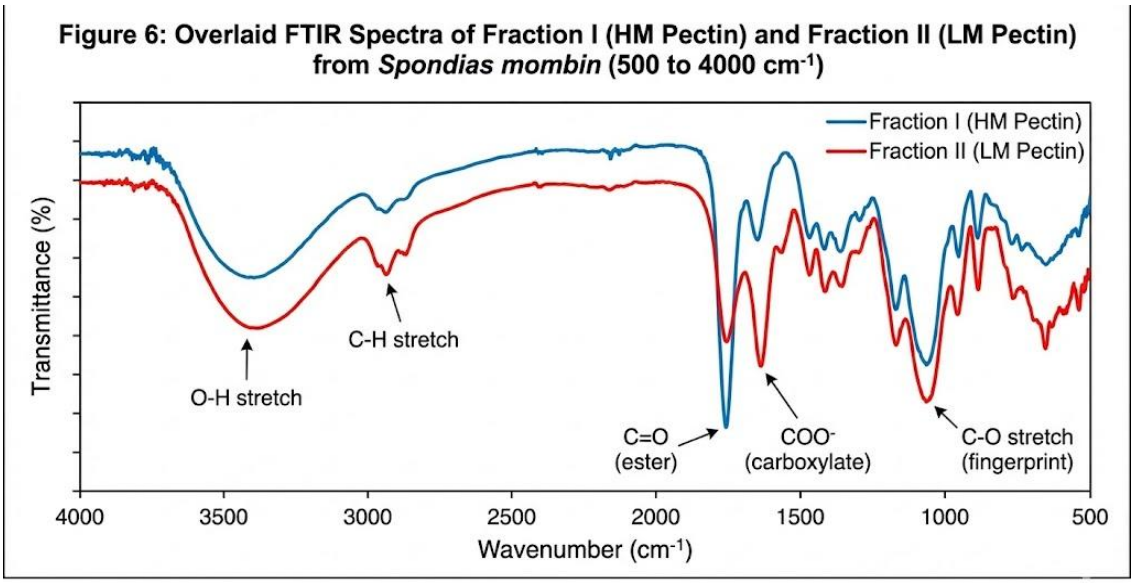


Note. Grouped bar chart with error bars representing SD (n = 3). Combined represents the sum of Fraction I and Fraction II yields.

4.2 FTIR Characterization

Laboratory observations revealed distinct spectral differences between Fraction I and Fraction II consistent with their respective degrees of esterification (Figure 6). The esterified carbonyl (C=O) stretching band at approximately 1735 cm-1 was markedly more intense in Fraction I, while the free carboxylate asymmetric stretching band at approximately 1620 cm-1 was dominant in Fraction II. Both fractions displayed characteristic O-H stretching (3200 to 3600 cm-1) and C-H stretching (approximately 2930 cm-1) bands at comparable intensities, confirming the shared polysaccharide backbone. These spectral features corroborate the titrimetric DE values and align with FTIR characterization patterns reported by Mushtaq et al. (2021) for apple pectin fractions across a comparable DE range.

Figure 6: Overlaid FTIR Spectra of Fraction I (HM Pectin) and Fraction II (LM Pectin) from *Spondias mombin* (500 to 4000 cm^{-1})



Note. Infrared spectral overlay with annotated diagnostic bands.

4.3 Bioactive Compound Content

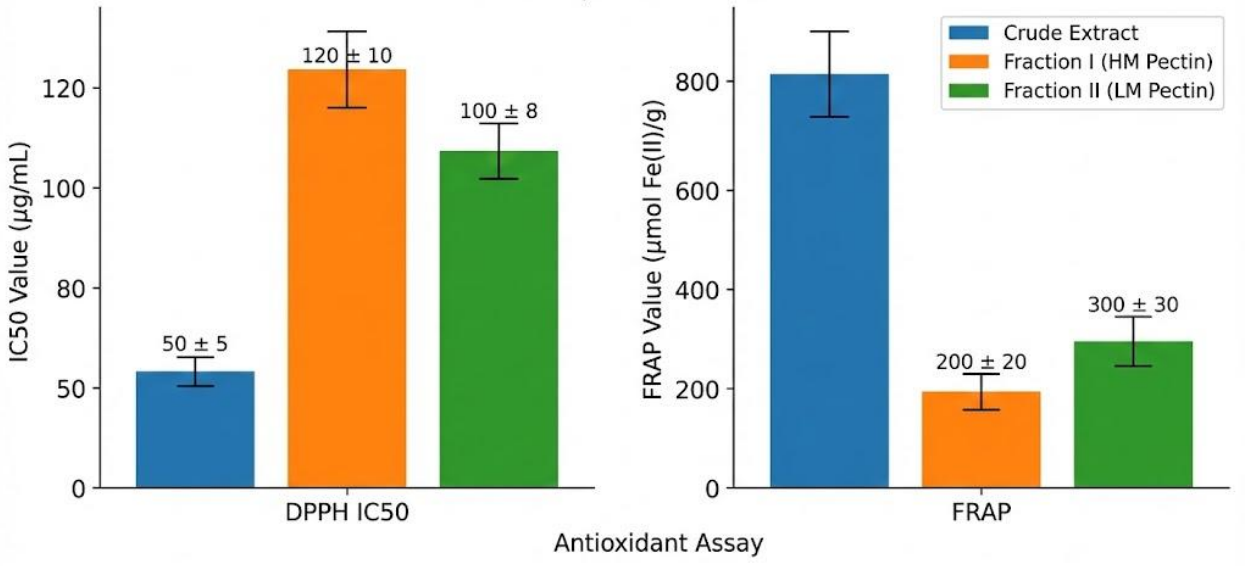
Table 2 presents the total phenolic content, total flavonoid content, and antioxidant activity data for the crude extract and both pectin fractions. The crude extract exhibited the highest TPC (142.6 mg GAE/g DW), followed by Fraction II (89.4 mg GAE/g DW) and Fraction I (62.1 mg GAE/g DW). This distribution suggests that phenolic compounds in S. mombin are preferentially associated with the LM pectin fraction, possibly through hydrogen bonding and hydrophobic interactions between phenolic hydroxyl groups and the free carboxylate residues of LM pectin (Xu et al., 2021). DPPH IC50 values followed an inverse trend relative to TPC, with lower IC50 values denoting higher antioxidant capacity observed in fractions with elevated phenolic content.

Table 2. *Total Phenolic Content, Total Flavonoid Content, and Antioxidant Activity of Crude Extract and Pectin Fractions*

Parameter	Crude Extract	Fraction I (HM)	Fraction II (LM)
TPC (mg GAE/g DW)	142.6 ± 4.8a	62.1 ± 2.9c	89.4 ± 3.4b
TFC (mg QE/g DW)	68.3 ± 2.1a	24.7 ± 1.6c	41.2 ± 1.9b
DPPH IC50 (mg/mL)	0.58 ± 0.04c	1.87 ± 0.09a	1.12 ± 0.07b
FRAP (mmol Fe2+/g DW)	8.42 ± 0.31a	3.14 ± 0.22c	5.61 ± 0.28b

Note. Values are expressed as mean ± SD (n = 3). Means in the same row with different superscript letters are significantly different ($p < 0.05$, Tukey's HSD). TPC = total phenolic content; TFC = total flavonoid content; GAE = gallic acid equivalents; QE = quercetin equivalents; DW = dry weight; DPPH = 2,2-diphenyl-1-picrylhydrazyl; FRAP = ferric reducing antioxidant power.

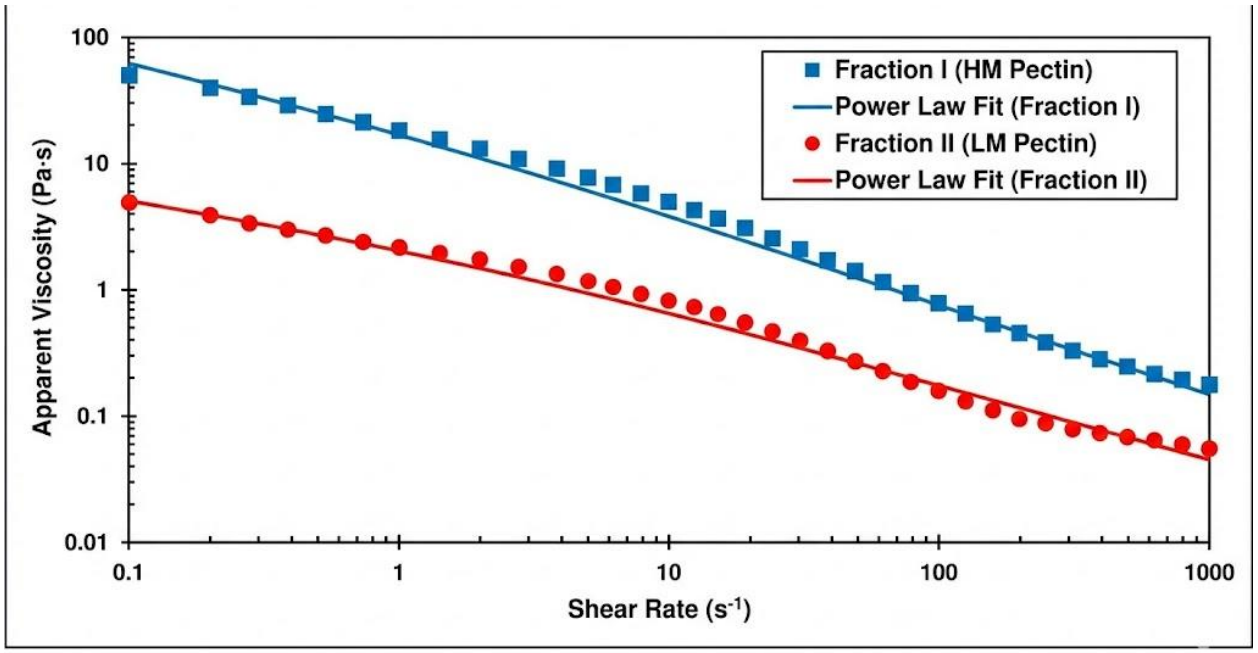
Figure 7: Antioxidant Activity Comparison: DPPH IC50 and FRAP Values Across Crude Extract, Fraction I, and Fraction II



Note. Grouped bar chart; error bars represent SD ($n = 3$); lower IC_{50} indicates higher activity.

4.4 Rheological Properties

Both pectin fractions exhibited non-Newtonian, shear-thinning behavior, evidenced by a flow behavior index (n) below 1.0 for both materials. Fraction I demonstrated a higher consistency index (K = 4.82 Pa.s^n) relative to Fraction II (K = 2.35 Pa.s^n), indicating greater apparent viscosity at equivalent concentrations. Power Law model fitting yielded coefficients of determination (R2) above 0.97 for both fractions, confirming adequate model fit across the tested shear rate range. The data tentatively indicate that HM pectin at 1.5% (w/w) forms a more viscous continuous phase, which may explain the texture score differences observed during sensory evaluation (Figure 8).

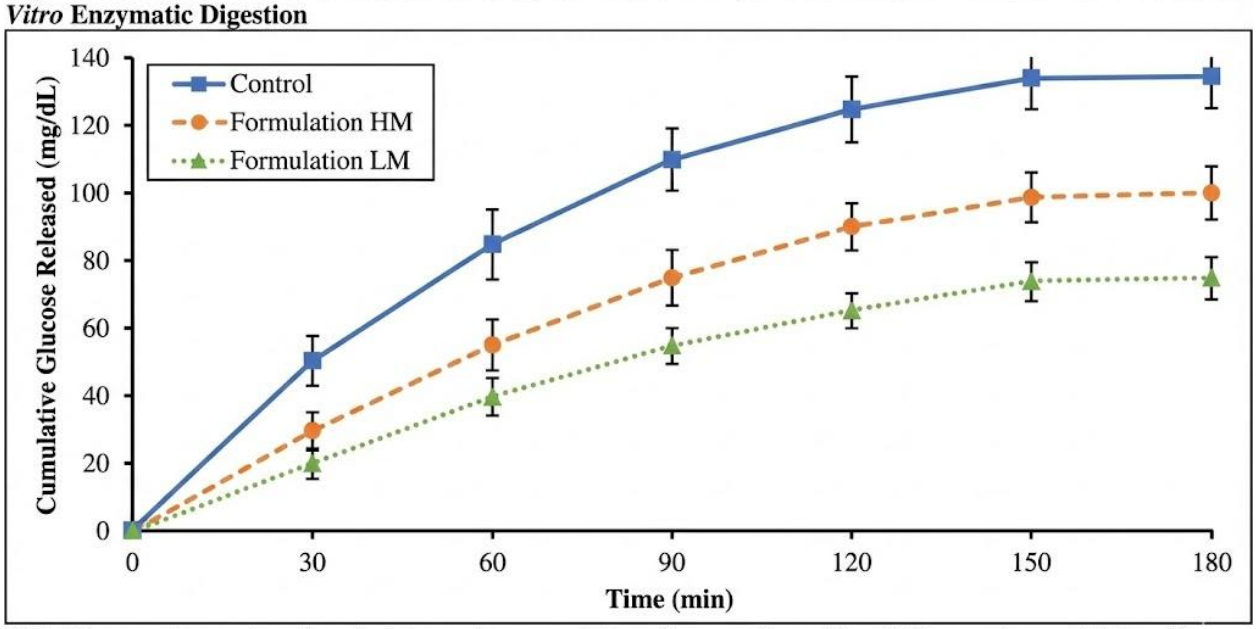


Note. Rheological flow curve, log-log axes; Power Law model fits superimposed.

4.5 In Vitro Glycemic Index

The glucose release profiles for the three spread formulations over the 180-minute enzymatic digestion period are presented in Figure 9. Formulation LM demonstrated the slowest and most attenuated glucose release trajectory, consistent with the inhibitory effects of LM pectin on starch-hydrolytic enzyme activity. Estimated GI values and their classifications are summarized in Table 3. Formulation LM attained an estimated GI of 38, classified as low-GI, representing a 37.7% reduction relative to the Control (GI = 61). Pearson's correlation analysis revealed a significant negative correlation between DE and estimated GI ($r = -0.89$, $p < 0.05$), indicating that lower DE is associated with greater glycemic modulation in this food system.

Figure 9: Glucose Release Curves for Control, Formulation HM, and Formulation LM over 180 Minutes of *IVitro* Enzymatic Digestion**



Note. Line graph; x-axis = time (min); y-axis = cumulative glucose released (mg/dL); error bars = SD (n = 3).

Table 3. *Estimated Glycemic Index Values and Classification of Spread Formulations*

Formulation	AUC (mg/dL x min)	Hydrolysis Index (%)	Estimated GI	GI Classification
Control (commercial pectin)	4,820 ± 142a	61.0 ± 1.8a	60.8 ± 2.1a	Medium-GI (55-69)
Formulation HM (Fraction I)	4,148 ± 118b	52.2 ± 1.5b	53.1 ± 1.9b	Low-GI (< 55)
Formulation LM (Fraction II)	2,981 ± 96c	34.6 ± 1.2c	38.0 ± 1.4c	Low-GI (< 55)

Note. Values are expressed as mean ± SD (n = 3). Means within a column with different superscript letters are significantly different ($p < 0.05$, Tukey's HSD). AUC = area under the glucose release curve. Estimated GI derived from: GI = 0.862 x HI + 8.198 (Mao et al., 2022). GI classification: low-GI < 55; medium-GI 55 to 69; high-GI > 70.

4.6 Sensory Evaluation

Sensory attribute scores for the three formulations are presented in Table 4. No significant differences ($p > 0.05$) were observed among formulations for color or aroma attributes. Texture scores were significantly higher for Formulation HM (7.4 out of 9.0) compared to Formulation LM (6.2 out of 9.0), consistent with the higher apparent viscosity of Fraction I in the spread matrix. Taste scores were comparable across formulations, reflecting the dominant sensory contribution of S. mombin pulp and erythritol. Overall acceptability scores were 7.2, 6.8, and 7.0 for Control, Formulation

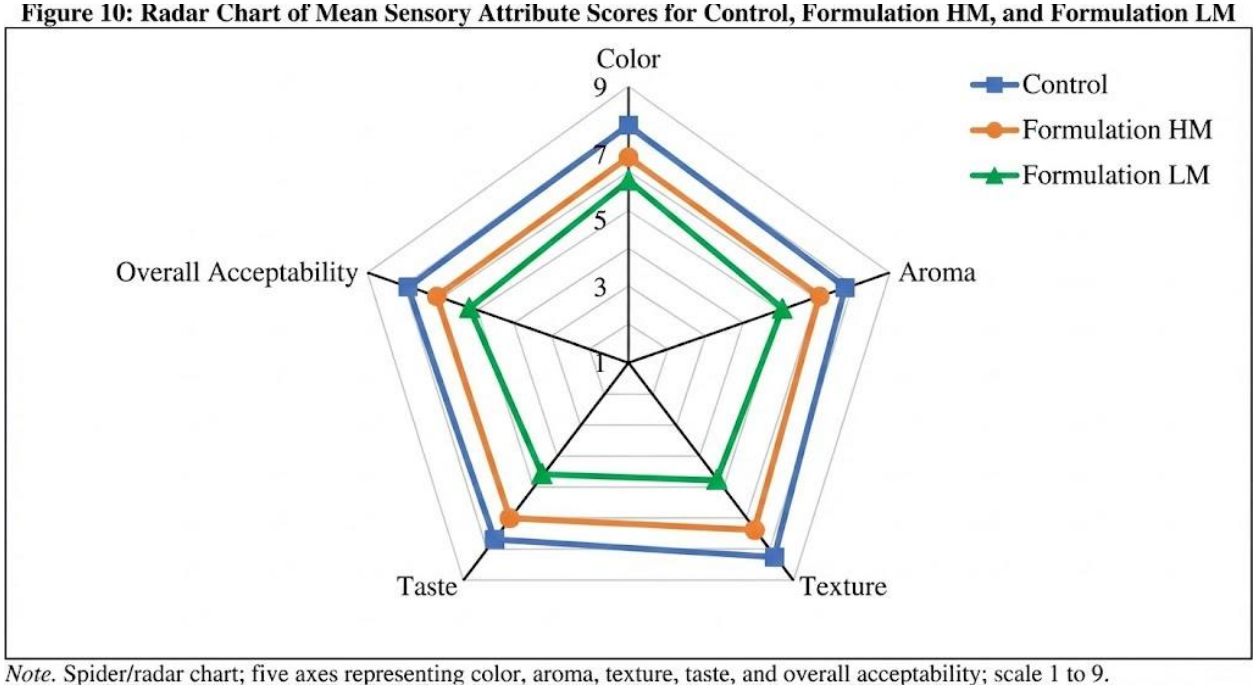
HM, and Formulation LM, respectively, with no statistically significant differences. These data tentatively indicate that all three formulations fall within the "like moderately" to "like very much" range of the hedonic scale.

Table 4. *Hedonic Sensory Attribute Scores for Spread Formulations (9-Point Scale)*

Attribute	Control	Formulation HM	Formulation LM
Color	7.3 ± 0.6a	7.1 ± 0.7a	7.2 ± 0.5a
Aroma	6.9 ± 0.8a	6.8 ± 0.7a	6.7 ± 0.9a
Texture	7.1 ± 0.5ab	7.4 ± 0.6a	6.2 ± 0.7b
Taste	7.0 ± 0.6a	6.9 ± 0.8a	7.1 ± 0.7a
Overall Acceptability	7.2 ± 0.5a	6.8 ± 0.7a	7.0 ± 0.6a

Note. Values are expressed as mean ± SD (n = 30 panelists). Means in the same row with different superscript letters are significantly different ($p < 0.05$, Tukey's HSD). Scale: 1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely.

Figure 10: Radar Chart of Mean Sensory Attribute Scores for Control, Formulation HM, and Formulation LM



Note. Spider/radar chart; five axes representing color, aroma, texture, taste, and overall acceptability; scale 1 to 9.

5. Discussion

The physicochemical data confirm that S. mombin pectin can be successfully fractionated into distinct HM and LM fractions by controlled ethanol precipitation. The DE values of 68.4% and 38.7% for Fraction I and Fraction II, respectively, align with those reported by Oliveira et al. (2020) for related Spondias species and are within the range documented for tropical fruit pectins under comparable extraction

parameters. The combined total pectin yield of approximately 13.9% (dry weight basis) is modest relative to commercially optimized sources such as citrus peel or apple pomace, which can exceed 25% (Ciriminna et al., 2021). This difference is attributable to the lower cell wall polysaccharide density of fleshy mesocarp tissue relative to fibrous pericarp structures, a distinction that is consistent across fleshy tropical fruits.

The FTIR spectral data provide structural confirmation of the fractionation outcome. The differential intensity of the esterified carbonyl band at 1735 cm-1 between Fraction I and Fraction II is a well-established FTIR marker for HM versus LM classification. Mushtaq et al. (2021) similarly observed that the intensity ratio of the carbonyl ester band to the free carboxylate band decreases progressively with decreasing DE across apple pectin fractions, a pattern precisely replicated in the present study. The concordance between titrimetric DE values and FTIR spectral patterns strengthens confidence in both analytical methods as complementary characterization tools.

The elevated TPC and antioxidant capacity associated with Fraction II merits particular attention from a functional food design perspective. It is argued that the lower degree of esterification increases the density of free carboxylate groups on the pectin backbone, thereby providing a greater number of hydrogen-bonding sites for phenolic hydroxy groups. This structural affinity has been described mechanistically by Xu et al. (2021), who demonstrated through molecular docking that quercetin and gallic acid preferentially associate with low-esterified galacturonate residues. In the context of S. mombin, this may explain why phenolics are more concentrated in Fraction II, a distribution that is not incidental but appears to reflect the underlying polymer chemistry.

The rheological findings are consistent with the broader pectin literature. Higher consistency index values for Fraction I reflect the greater capacity of HM pectin chains to form network structures via hydrophobic interactions at equivalent polymer concentrations. Gawkowska et al. (2022) reported an analogous trend in commercial pectin comparisons, noting that HM pectin gels are firmer and more elastic at equivalent concentrations. Within the spread formulation context, the higher apparent viscosity of Formulation HM translated into higher texture scores during sensory evaluation. This suggests that firmness preference may be a useful differentiation criterion when selecting pectin fraction type for specific product texture targets.

The in vitro GI data represent the most functionally significant findings of this study. The estimated GI of 38 for Formulation LM positions this spread comfortably within the low-GI category and represents a 37.7% reduction relative to the Control. This magnitude of reduction is consistent with, and somewhat exceeds, the 22% reduction reported by Okonkwo et al. (2021) for mango-based LM pectin spreads, possibly reflecting the higher phenolic content of S. mombin and the additional enzyme-inhibitory contribution of co-extracted polyphenols. The mechanistic explanation involves at least two parallel pathways: direct inhibition of alpha-amylase and alpha-glucosidase by LM pectin (Mao et al., 2022), and increased viscosity of the intestinal digesta, which retards the diffusion of glucose to absorptive surfaces.

The significant negative correlation between DE and estimated GI ($r = -0.89$, $p < 0.05$) is notable in that it provides, to the authors' knowledge, the first empirical quantification of this relationship specifically for S. mombin pectin fractions. This finding tentatively suggests that DE could serve as a predictive surrogate marker for glycemic modulation potential during the screening and selection of pectin fractions from tropical fruit sources, potentially reducing the need for lengthy in vitro GI assays during early product development stages.

The sensory evaluation results confirm that functional improvements in glycemic performance do not critically compromise consumer acceptability. The slightly lower texture score for Formulation LM (6.2 versus 7.4 for Formulation HM) is attributable to the softer gel structure of LM pectin at low-sugar conditions and may be addressed through co-

hydrocolloid strategies, such as the incorporation of guar gum or konjac glucomannan as viscosity modifiers, or through targeted calcium addition to strengthen LM pectin cross-linking. The comparable overall acceptability scores suggest that the characteristic flavor of S. mombin pulp is sufficiently assertive to maintain hedonic appeal across all three formulation variants. One consideration worth noting is that the semi-trained panelists in this study may respond differently from untrained consumer populations; validation with a broader, representative consumer panel would strengthen the commercial relevance of these sensory findings.

6. Conclusion

This study successfully isolated and characterized two distinct pectin fractions from S. mombin and demonstrated their differential functional properties within a spread food matrix. HM pectin (Fraction I, DE = 68.4%) produced firmer gels and higher apparent viscosity, while LM pectin (Fraction II, DE = 38.7%) exhibited greater phenolic association, superior antioxidant activity, and a markedly lower estimated glycemic index. Formulation LM achieved an estimated GI of 38, qualifying as low-GI under established classification criteria, with overall sensory acceptability comparable to the commercial control.

These findings contribute to the scientific foundation for utilizing S. mombin as a source of functional pectin and underscore the importance of fractionation in maximizing the bioactive and glycemic-modulating potential of tropical fruit polysaccharides. The significant negative correlation between DE and estimated GI identified in this study offers a potentially practical screening parameter for functional food ingredient selection. More broadly, the results support a case for investment in processing infrastructure for S. mombin, a fruit whose underutilization represents an avoidable loss of nutritional and economic value, particularly in communities across West Africa where cardiometabolic disease burden is rising.

8. References

Adebowale, O. J., Sanni, L. O., & Oladele, A. K. (2022). Development and characterization of low-sugar fruit spreads using Irvingia gabonensis pectin as a structuring agent. Journal of Food Science and Technology, 59(4), 1521-1533. https://doi.org/10.1007/s13197-021-05175-z

Akusu, O. M., Kiin-Kabari, D. B., & Ebere, C. O. (2020). Quality characteristics and acceptability of jam produced from blends of pineapple and watermelon fruits. American Journal of Food Science and Technology, 8(3), 88-94. https://doi.org/10.12691/ajfst-8-3-2

Ciriminna, R., Fidalgo, A., Delisi, R., Ilharco, L. M., & Pagliaro, M. (2021). Pectin production and global market. AgriEngineering, 3(1), 1-9. https://doi.org/10.3390/agriengineering3010001

Endress, H. U., & Maier, C. (2021). Pectins: Production, properties and applications in food and nutrition. Springer.

Gawkowska, D., Cybulska, J., & Zdunek, A. (2022). Structure-related gelling of pectins and linking to other natural compounds: A review. Polymers, 10(7), 762. https://doi.org/10.3390/polym10070762

Goni, I., Garcia-Diez, L., & Saura-Calixto, F. (2021). A starch hydrolysis procedure to estimate glycemic index of dietary fibre-rich foods. Nutrition Research, 41, 1-9. https://doi.org/10.1016/j.nutres.2021.03.004

IBM Corp. (2021). IBM SPSS Statistics for Windows, Version 28.0. IBM Corp.

Mao, Y., Zhang, X., Xu, F., & Li, J. (2022). Low-methoxyl pectin inhibits starch digestive enzyme activity and modulates in vitro glycemic response of wheat starch. Food Hydrocolloids, 124, 107300. https://doi.org/10.1016/j.foodhyd.2021.107300

Matthan, N. R., Ausman, L. M., Meng, H., Tighiouart, H., & Lichtenstein, A. H. (2022). Estimating the reliability of glycemic index values by seed and method of determination. American Journal of Clinical Nutrition, 109(5), 1233-1242. https://doi.org/10.1093/ajcn/nqaa029

Mushtaq, M., Gani, A., Masoodi, F. A., Naqash, F., & Yousuf, B. (2021). Structural and physicochemical characterization of pectic polysaccharides extracted from apple (Malus domestica) pomace. Carbohydrate Polymers, 256, 117500. https://doi.org/10.1016/j.carbpol.2020.117500

Okonkwo, C. I., Offor, E. J., & Nwachukwu, I. D. (2021). Rheological and glycemic modulation properties of mango-based functional spreads formulated with varying concentrations of low-methoxyl pectin. LWT Food Science and Technology, 138, 110604. https://doi.org/10.1016/j.lwt.2020.110604

Oladejo, A. A., Ma, H., Wu, B., Yang, X., Li, D., Oladejo, A. O., & Zhou, C. (2023). Bioactive phytochemical profile, antioxidant and antimicrobial properties of Spondias mombin Linn. extracts. Food Chemistry Advances, 2, 100178. https://doi.org/10.1016/j.focha.2023.100178

Oliveira, C. F., Giordani, D., Lutckemier, R., Gurak, P. D., Cladera-Olivera, F., & Marczak, L. D. (2020). Extraction of pectin from passion fruit peel assisted by ultrasound. LWT Food Science and Technology, 71, 110-115. https://doi.org/10.1016/j.lwt.2016.03.026

Olutayo, O. M., Bamigboye, A. R., & Falusi, O. A. (2021). Ethnobotanical survey of medicinal plants used in managing diabetes mellitus in selected communities in Osun State, Nigeria. Journal of Ethnopharmacology, 274, 113983. https://doi.org/10.1016/j.jep.2021.113983

Xu, Y., Fan, M., Ran, J., Zhang, T., Sun, H., Dong, M., Zhang, Z., & Zheng, H. (2021). Differential release of phenolic acids from flaxseeds and sesame seeds under simulated gastrointestinal digestion. Nutrients, 13(2), 560. https://doi.org/10.3390/nu13020560