

Mangrove-Derived Bioactive Compounds as Potential Functional Food Ingredients for Metabolic Health: A Scoping Review

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ABSTRACT

Mangrove plants contain phenolics, flavonoids, tannins, terpenoids, limonoids, dietary fiber, and other metabolites that may influence oxidative stress, carbohydrate digestion, glycemic regulation, lipid metabolism, inflammation, and gut-derived metabolic signaling. However, their use as functional food ingredients requires evidence extending beyond chemical antioxidant assays. This scoping review mapped primary studies published from 2017 to 2026 on mangrove-derived extracts, fractions, isolated compounds, powders, and food-compatible preparations relevant to metabolic health and functional food development. The review followed JBI methodology and PRISMA-ScR guidelines. Consistent with scoping review protocols, no formal risk-of-bias appraisal was performed. Literature searches across PubMed/MEDLINE and ScienceDirect identified 194 records (182 and 12, respectively). The evidence base clustered into glycemic control, lipid and hepatic regulation, oxidative and inflammatory modulation, and food-translation pathways. The identified literature was predominantly preclinical, comprising in vitro and animal models, with no human intervention studies identified. Notably, in obese rats, *Bruguiera gymnorhiza* fruit flour increased glucagon-like peptide-1 (GLP-1) levels from 6.12 to 14.67 pg/mL and reduced total cholesterol from 191.95 to 109.13 mg/dL after 28 days ($p < 0.001$). Although mangrove-derived materials show promising preclinical potential for functional food applications, clinical evidence remains absent. Standardized food-grade processing, safety assessments, bioaccessibility testing, realistic dose translation, and human intervention trials are required before definitive health claims can be supported.

INTRODUCTION

Metabolic disorders, including type 2 diabetes, obesity, dyslipidaemia, and related hepatic and inflammatory disturbances, share mechanisms such as postprandial hyperglycaemia, insulin resistance, oxidative stress, chronic inflammation, and altered lipid metabolism. These pathways have increased interest in plant-derived bioactives as potential components of functional foods for metabolic-health support^{1,2}.

Mangrove plants are promising but underdeveloped sources of such ingredients. Species within *Rhizophora*, *Avicennia*, *Sonneratia*, *Bruguiera*, *Xylocarpus*, *Ceriops*, and *Nypa* contain polyphenols, flavonoids, tannins, terpenoids, limonoids, phytosterols, dietary fibre, and related compounds that may influence metabolic pathways³. However, most mangrove studies remain

preclinical, and evidence from human metabolic intervention studies is lacking. Moreover, positive antioxidant or enzyme-inhibition results alone do not establish functional-food value; translation also requires food-compatible processing, chemical standardization, realistic dietary exposure, safety, bioaccessibility, and acceptable food-matrix performance.

Accordingly, this scoping review mapped evidence published from 2017 to 2026 on mangrove plant-derived materials relevant to metabolic health and functional-food development. It aimed to identify the taxa, plant parts, preparations, metabolic targets, and experimental models studied; assess the translational maturity of the evidence; and identify key gaps that should be addressed before clinical or food-product application.

MATERIALS AND METHODS

Review design and reporting framework

This scoping review was conducted using the Joanna Briggs Institute (JBI) methodological guidance for scoping reviews and reported in accordance with the PRISMA extension for scoping reviews (PRISMA-ScR)^{4,5}. A formal review protocol was not prospectively registered. The review procedures were developed in accordance with JBI methodological guidance and PRISMA-ScR. The review question was framed using the population-concept-context approach: experimental or biological systems relevant to metabolic health (population); mangrove plant-derived bioactive compounds, extracts, fractions, powders, fermented preparations, or food ingredients (concept); and laboratory, animal, human, or food-product studies in any geographic setting (context). The objective was to map the range, characteristics, and translational maturity of the evidence rather than estimate a pooled effect; therefore, meta-analysis was not planned.

Eligibility criteria

Eligible studies were peer-reviewed original research articles published between 1 January 2017 and 21 September 2026 that investigated taxonomically identified mangrove plant materials or preparations and reported outcomes relevant to metabolic health or functional-food translation. Eligible outcomes included glycaemic control, lipid metabolism, oxidative stress, inflammation, obesity-related markers, SCFAs, incretin or satiety hormones, hyperuricaemia, digestive-enzyme inhibition, and processing-related bioactivity. Reviews, editorials, conference abstracts without extractable data, microorganism-only studies, environmental studies without health-relevant outcomes, and studies limited to unrelated antimicrobial, anticancer, or other non-metabolic endpoints were excluded.

Information sources and search strategy

PubMed/MEDLINE and ScienceDirect were searched for studies published between 1 January 2017 and 21 September 2026. The PubMed search was executed on 21 September 2026 and retrieved 182 records. The Boolean strategy combined mangrove genera with terms describing bioactive constituents and metabolic outcomes: (Rhizophora OR Sonneratia OR Avicennia OR Bruguiera OR Ceriops OR Xylocarpus OR Aegiceras OR Lumnitzera OR Excoecaria OR Nypa) AND (bioactive OR phytochemical* OR polyphenol* OR phenolic* OR flavonoid* OR tannin* OR terpenoid* OR extract* OR fraction* OR compound* OR "functional food" OR nutraceutical*) AND (antioxidant* OR antidiabetic OR diabetes OR hyperglyc* OR glucose OR glycemic OR insulin OR obesity OR metabolic OR dyslipid* OR lipid* OR inflammation OR "oxidative stress" OR "alpha-glucosidase" OR "alpha-amylase" OR steatosis OR microbiota). The publication-date limit was 1 January 2017 through 2026.

ScienceDirect was used as a supplementary database to increase sensitivity for food-chemistry and metabolic studies. Two complementary searches were conducted: (1) mangrove AND (bioactive OR phytochemical OR extract) AND (antioxidant OR antidiabetic OR "metabolic health"); and (2) "mangrove" AND (extract OR phytochemical OR bioactive) AND (antidiabetic OR hypoglycemic OR hypolipidemic OR "alpha-glucosidase" OR "alpha-amylase" OR obesity OR glucose OR lipid OR cholesterol OR triglyceride). Twelve additional candidate records were retained from these targeted searches for detailed eligibility assessment. Backward citation searching of relevant reviews and eligible primary papers was also used to verify potentially relevant studies. Because the ScienceDirect search was supplementary and several reports overlapped with PubMed-indexed evidence, duplicate consolidation was performed at the article level during detailed eligibility assessment.

Study selection and data charting

Records were screened in two stages. Title and abstract screening excluded 68 PubMed records: 34 involved mangrove-associated microorganisms or other non-plant sources, 19 were outside the metabolic-health/functional-food scope, and 15 were non-original publications. The remaining 114 PubMed records and 12 ScienceDirect candidates proceeded to detailed eligibility assessment (n=126). Of these, 107 were not retained: 46 were duplicate or overlapping reports, 21 involved ineligible sources or materials, 15 had insufficient metabolic relevance, 5 reported ineligible outcomes, 3 were non-original publications, and 17 contained insufficient information to establish eligibility. Nineteen primary studies were included in the final evidence synthesis.

Two reviewers independently screened titles/abstracts and full texts, with disagreements resolved by consensus. Zotero supported citation management and duplicate checking. Data charting captured study characteristics, exposure details, quantitative outcomes, and translational limitations.

Formal risk-of-bias appraisal was not undertaken because the review aimed to map evidence, although study design and evidence type were considered during interpretation.

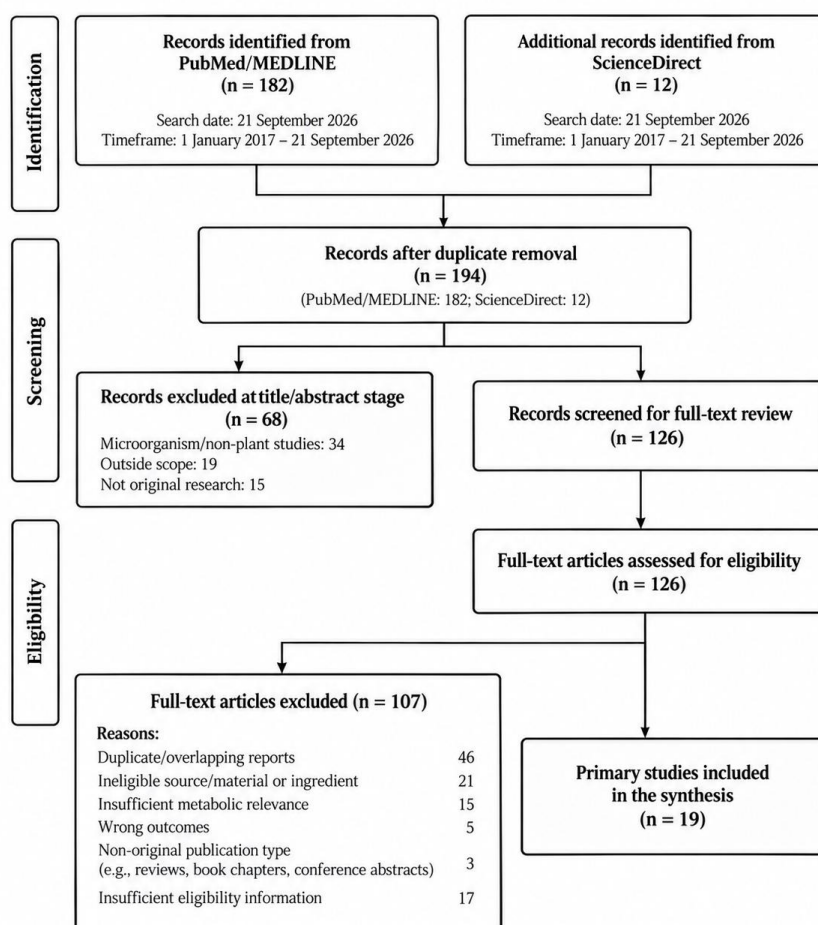


Figure 1. PRISMA-ScR-style flow diagram of study identification, screening, eligibility assessment, and inclusion.

RESULTS

Study selection

PubMed/MEDLINE identified 182 records; 68 were excluded at title/abstract screening (34 non-plant/microorganism studies, 19 outside scope, and 15 non-original publications). The remaining 114 records plus 12 ScienceDirect candidates underwent detailed eligibility assessment (n=126). Of these, 46 were duplicate/overlapping reports, 21 had ineligible sources/materials, 15 insufficient metabolic relevance, 5 ineligible outcomes, 3 non-original publication types, and 17 insufficient eligibility information. Nineteen studies were included in the final synthesis.

Evidence landscape

The evidence base was broad but predominantly preclinical, including chemical profiling, enzyme inhibition, and rodent models of metabolic dysfunction. Studies most frequently involved *Rhizophora*, *Avicennia*, *Xylocarpus*, *Sonneratia*, *Bruguiera*, and *Nypa*. Food-oriented evidence was less common but included fruit flour, vinegar, aqueous extracts, and subcritical-water processing, while no human metabolic intervention studies were identified.

Key primary studies

Study	Country	Species/material	Model/preparation	Main metabolic or translational finding	Main limitation
Andrade-Cetto et al., 2017 ⁶	Mexico	<i>Rhizophora</i> mangle bark/cortex	STZ–nicotinamide diabetic rats; 4 groups, n=6/group; extract 90 mg/kg, twice daily, 42 d	Chronic hypoglycaemic and hypolipidaemic effects; cinchonains, catechin-related compounds, epicatechin, lyoniside and nudiposide identified	Medicinal bark extract; no food-matrix study
Yusoff et al., 2017 ⁷	Malaysia	<i>Nypa fruticans</i> vinegar	STZ-diabetic rats, n=6/group; 250, 500, 1000 mg/kg twice daily for 12 d; RIN-5F cells	Stimulated insulin secretion and improved glycaemic endpoints	Fermented product is food-relevant, but dose translation remains uncertain
Mesquita et al., 2018 ⁸	Brazil	<i>Rhizophora</i> mangle polyphenolic material	High-fat-diet obese mice	Improved insulin-resistance and fatty-liver-related outcomes	Preclinical; formulation and bioavailability not established
Das et al., 2019 ⁹	India	<i>Xylocarpus granatum</i> bark	STZ-diabetic mice, n=5/group; 100 or 200 mg/kg/day, 30 d	Reduced hyperglycaemia and oxidative-stress complications; alpha-glucosidase-related activity reported	Bark and extract context; safety/food suitability unresolved

Study	Country	Species/material	Model/preparation	Main metabolic or translational finding	Main limitation
Das et al., 2019 ¹⁰	India	Avicennia officinalis bark	STZ-diabetic mice; 200 mg/kg plus enzyme/antioxidant assays	Lowered glucose, total cholesterol and triglycerides; inhibited alpha-amylase and alpha-glucosidase; antioxidant activity	Strong mechanistic link but non-food-grade medicinal extract
Chiavaroli et al., 2020 ¹¹	Côte d'Ivoire / multinational laboratory study	Rhizophora racemosa leaf/bark	Multiple extraction methods/solvents; in vitro chemical and enzyme assays	Chemical profiling with antioxidant, alpha-amylase and alpha-glucosidase inhibition	Assay heterogeneity; no in vivo confirmation
Abu Zeid & Al Jaghthmi, 2020 ¹²	Saudi Arabia	Rhizophora mucronata and Avicennia marina leaves	STZ-diabetic rats; 8 groups, n=15/group; 400 mg/kg/day for 6 weeks	Glucose, insulin and lipid profiles improved; <i>R. mucronata</i> produced stronger antidiabetic/hypolipidaemic responses than <i>A. marina</i> or their combination	High animal dose; no food prototype
Olanipekun et al., 2020 ¹³	India	Xylocarpus granatum stems	Isolated compounds; α -glucosidase assay	Corniculatolide C showed α -glucosidase inhibition with $IC_{50} = 24.8 \mu M$	Compound-level evidence only; no whole-food, digestion or in vivo evidence
Wu et al., 2021 ¹⁴	China	Sonneratia apetala leaves/branches	PO+hypoxanthine hyperuricaemic mice; 7 d	Reduced serum uric acid, creatinine and BUN; inhibited hepatic XOD and improved oxidative/inflammatory indices; related work reports doses 25–100 mg/kg	Relevant metabolic model, but not directly diabetes/obesity

Study	Country	Species/material	Model/preparation	Main metabolic or translational finding	Main limitation
Mitra et al., 2022 (15)	Bangladesh	Avicennia alba leaves	Alloxan-diabetic mice; 200, 400, 500 mg/kg, followed to 15 d	At 400 mg/kg, glucose fell from 385.25 ± 3.27 to 285.10 ± 2.96 mg/dL; dose-dependent reduction; significant at higher doses	Laboratory solvent and broad pharmacological screening
Amalia et al., 2022 ¹⁶	Indonesia	Bruguiera gymnorhiza fruit flour	28 obese male Wistar rats; n=7/group; 2 or 4 g/200 g BW/day, 28 d	4-g dose: GLP-1 $6.12 \rightarrow 14.67$ pg/mL, PYY $26.40 \rightarrow 413.72$ pg/mL, TC $191.95 \rightarrow 109.13$ mg/dL, TG $133.99 \rightarrow 84.86$ mg/dL, IL-6 $171.12 \rightarrow 81.52$ pg/mL, all $p < 0.001$	One of the strongest whole-food/functional-food models; human confirmation absent
Choi et al., 2022 ¹⁷	Republic of Korea	Nypa fruticans plant material	RSM/ANN extraction optimization; ethanol 0–100%, 6–24 h, 40–60°C	Optimized antioxidant activity and phenolic/flavonoid recovery. Optimal: 57.6% ethanol, 19.0 h, 51.3°C; DPPH 62.5%, CUPRAC 41.95 μ M, FRAP 48.39 μ M, TPC 143.6 mg GAE/g, TFC 166.8 CAE/g	Useful process evidence; metabolic efficacy not directly tested
Audah et al., 2022 ¹⁸	Indonesia	Sonneratia caseolaris leaves	In vitro phytochemical, DPPH and antimicrobial assays	High antioxidant potential and phytochemical characterization. DPPH IC_{50} 4.25 ± 3.05 ppm, compared with ascorbic acid 5.25 ± 0.59 ppm; flavonoid fraction reported at 12.4%	Chemical antioxidant endpoint only; no direct metabolic or in vivo outcome

Study	Country	Species/material	Model/preparation	Main metabolic or translational finding	Main limitation
Biswas et al., 2023 ¹⁹	Bangladesh	Ceriops decandra root	OGTT in mice, n=5/group; 250 or 500 mg/kg; enzyme assays	Both doses significantly lowered glucose at 60–90 min; α -amylase IC ₅₀ 2.58 mg/mL for <i>C. decandra</i> vs acarbose 0.90 mg/mL	Acute/short-term pharmacological model; root harvesting and high extract dose constrain food translation
Gayen et al., 2024 ²⁰	India	Bruguiera cylindrica bark	HFD/STZ rats, n=6/group; 200 or 400 mg/kg/day, 28 d; enzyme assays	At 400 mg/kg, glucose 414.33→104.66 mg/dL by day 28; at 200 mg/kg 428.63→212.20 mg/dL; HbA1c 6.35% and 7.33%, respectively, vs 9.64% diabetic control	Pharmacological bark extract; relatively high doses; no food-grade formulation
Wonggo et al., 2024 ²¹	Indonesia	Sonneratia alba fruit	Subcritical-water extract	100 C/10 min optimized extract; flavonoids 23.33 mg QE/g, tannins 1.24 mg TAE/g, antioxidant IC ₅₀ 62.38 ppm; explicitly proposed as functional food	Highly food-compatible processing but metabolic efficacy remains untested

Study	Country	Species/material	Model/preparation	Main metabolic or translational finding	Main limitation
Razali et al., 2025 ²²	Malaysia	Nypa fruticans vinegar	HFD + low-dose STZ T2DM rats; 250, 500, 1000 mg/kg/day for 28 d	1000 mg/kg improved biochemical abnormalities and HOMA- β , preserved pancreatic islets/hepatocytes, stimulated incretin signalling and modulated SGLT1; diabetes induction altered outcomes significantly ($p=0.026$ for weight)	Fermented food-derived material, but very high experimental dose and no clinical trial
Kartikaningsih et al., 2025 ²³	Indonesia	Sonneratia caseolaris leaves	Various aqueous extraction media; DPPH, TPC/TFC, LC-HRMS	Distilled-water extract antioxidant IC ₅₀ 89.29 $\pm$ 0.06 mg/mL; methanol extract 63.72 $\pm$ 1.27 mg/mL; TEMPO, choline and betaine identified	Food-compatible water extraction, but only chemical/in silico evidence; safety, sensory and metabolic efficacy need testing
Khatun et al., 2026 ²⁴	Bangladesh	Rhizophora mucronata	STZ-diabetic mice, n=5/group; fractions 200 mg/kg/day for 7 d	Dichloromethane and ethyl-acetate fractions reduced glucose by 60.73% and 52.17%, respectively, vs glibenclamide 71.5%; antioxidant IC ₅₀ 12.18 and 11.70 μ g/mL	Organic-solvent fractions; pharmacological not food-grade evidence; short treatment duration

Carbohydrate digestion and glycaemic control

Carbohydrate-digesting enzymes were among the most frequently investigated metabolic targets. *Avicennia officinalis* bark extract inhibited both α -amylase and α -glucosidase, while administration of the parent extract at 200 mg/kg in streptozotocin-induced diabetic mice was associated with reductions in blood glucose and improvements in lipid-related parameters¹⁰. *Rhizophora racemosa* extracts also showed α -amylase and α -glucosidase inhibitory activity, although potency varied according to extraction solvent and method¹¹. At the compound level, corniculatolide C isolated from *Xylocarpus granatum* stems inhibited α -glucosidase with an IC_{50} of 24.8 μ M¹³. In diabetic mice, *X. granatum* bark extract at 200 mg/kg reduced blood glucose from approximately 324 to 218 mg/dL and was accompanied by reductions in triglycerides and total cholesterol¹⁹.

Animal studies provided a stronger bridge from enzyme inhibition to physiological relevance. Repeated administration of *Rhizophora mangle* cortex extract produced chronic hypoglycaemic and hypolipidaemic effects in STZ-nicotinamide diabetic rats⁶. Aqueous leaf extracts of *R. mucronata* and *A. marina*, administered at 400 mg/kg/day for six weeks, improved serum glucose, insulin, and lipid profiles in diabetic rats¹². *Nypa fruticans* vinegar was particularly relevant because it represented a food-associated fermented matrix rather than a conventional medicinal extract. In STZ-diabetic rats, aqueous vinegar extract at 500 and 1000 mg/kg reduced blood glucose from 16.43 to 8.35 mmol/L and from 16.95 to 7.35 mmol/L, respectively, while the 1000 mg/kg dose also reduced triglycerides to 34.32 ± 3.78 mg/dL compared with 69.03 ± 2.31 mg/dL in diabetic controls⁷. More recent work in a high-fat-diet/low-dose-STZ model further suggested modulation of incretin signalling, HOMA- β , DPP4-related pathways, and jejunal SGLT1 expression following *N. fruticans* vinegar administration²².

Lipid metabolism, hepatic outcomes, and obesity-related signalling

Several studies extended the evidence beyond glycaemic control. *Rhizophora mangle* polyphenolic preparations were associated with improved insulin resistance and fatty-liver-related outcomes in high-fat-diet obese mice⁸. *Avicennia officinalis* bark extract also improved total cholesterol and triglycerides in diabetic mice¹⁰, while aqueous extracts of *R. mucronata* and *A. marina* at 400 mg/kg/day for six weeks improved lipid profiles in streptozotocin-induced diabetic rats¹². These findings support multi-target metabolic activity, although most preparations were concentrated extracts whose exposure cannot be directly equated with dietary intake.

The most translational obesity study identified in the review used *Bruguiera gymnorhiza* fruit flour rather than a purified extract. In obese Wistar rats, supplementation for 28 days at 4 g/200 g body weight/day increased GLP-1 from 6.12 to 14.67 pg/mL and PYY from 26.40 to 413.72 pg/mL, while total cholesterol decreased from 191.95 to 109.13 mg/dL and triglycerides from 133.99 to 84.86 mg/dL. IL-6 also decreased from 171.12 to 81.52 pg/mL, with all reported changes reaching $p < 0.001$, alongside increases in caecal short-chain fatty acids¹⁶. These findings provide comparatively strong

whole-food evidence linking a mangrove fruit matrix with gut fermentation, satiety signalling, lipid regulation, and systemic inflammation; however, confirmation in human studies is still lacking.

Oxidative stress and inflammatory modulation

Antioxidant activity was one of the most frequently reported supporting outcomes across the included studies. DPPH, ABTS, FRAP, CUPRAC, and related radical-scavenging assays consistently demonstrated reducing capacity in *Rhizophora*, *Avicennia*, *Sonneratia*, *Nypa*, *Ceriops*, and other mangrove taxa^{11,17,18,21,23,24}. For example, the ethanol extract of *Sonneratia caseolaris* leaves showed a DPPH IC₅₀ of 4.25 ± 3.05 ppm, whereas subcritical-water extract of *S. alba* fruit showed an antioxidant IC₅₀ of 62.38 ppm under the optimized condition of 100°C for 10 min^{11,17,18,21,23,24}. These values indicate substantial chemical antioxidant activity, but direct comparison across studies should be interpreted cautiously because assay conditions, solvents, units, and extract composition differed.

Stronger evidence was provided by studies that combined antioxidant-related endpoints with physiological or inflammatory outcomes. In diabetic or obese animal models, mangrove-derived preparations were associated with improvements in oxidative-stress markers, metabolic parameters, histological changes, or systemic inflammatory responses^{8–10,12,16,22}. In the *B. gymnorhiza* fruit-flour study, IL-6 decreased from 171.12 to 81.52 pg/mL after 28 days of supplementation at 4 g/200 g body weight/day ($p < 0.001$), alongside improvements in lipid and satiety-related outcomes²⁵. However, antioxidant capacity measured by chemical assays should be interpreted as supportive rather than definitive evidence of metabolic protection, because these assays do not establish bioavailability, tissue exposure, or clinically meaningful antioxidant effects.

Food-compatible processing and functional-food translation

Food-oriented studies showed emerging potential for translating mangrove materials into functional ingredients. Optimized extraction of *Nypa fruticans* yielded high phenolic and flavonoid contents under conditions of approximately 57.6% ethanol, 19 h, and 51.3°C, although metabolic efficacy was not tested¹⁷. Subcritical-water extraction of *Sonneratia alba* fruit at 100°C for 10 min produced 23.33 mg QE/g flavonoids, 1.24 mg TAE/g tannins, and an antioxidant IC₅₀ of 62.38 ppm²¹, while aqueous *S. caseolaris* extracts further supported food-compatible processing²³. However, translation to functional foods still requires validation of bioaccessibility, safety, processing stability, realistic serving size, and human efficacy^{26,27}.

DISCUSSION

A translational hierarchy of evidence

The mapped evidence can be organized into a conceptual translational framework progressing from chemical profiling and antioxidant assays to enzyme or cell-based evidence, animal metabolic models, and food-compatible preparations such as fruit flour, vinegar, and aqueous extracts. This

framework is descriptive rather than formally validated and helps distinguish discovery-stage findings from evidence closer to dietary application. Chemical antioxidant activity or low in vitro IC₅₀ values alone are insufficient to establish functional-food efficacy; stronger translation requires relevant metabolic effects, realistic exposure, food compatibility, safety, and ultimately human confirmation. No human metabolic intervention studies were identified.

Mechanisms linking mangrove bioactives with metabolic health

The included studies suggest several biologically plausible mechanisms through which mangrove-derived bioactives may contribute to metabolic effects. First, inhibition of α -amylase and α -glucosidase may reduce the rate of carbohydrate hydrolysis and may contribute to lower postprandial glucose exposure. Second, polyphenols, tannins, terpenoids, and related metabolites may influence oxidative-stress and inflammatory pathways that are implicated in insulin resistance and metabolic tissue injury. Third, the improvements in hepatic and circulating lipid parameters reported for *Rhizophora mangle*, *Avicennia officinalis*, *R. mucronata/A. marina*, and *Bruguiera gymnorhiza* are consistent with a potential effect on lipid metabolism, although the underlying molecular pathways were not fully established^{6,10,12,16}. Fourth, the increase in SCFAs, GLP-1, and PYY following *B. gymnorhiza* fruit-flour supplementation, together with incretin- and glucose-transporter-related findings for *Nypa fruticans* vinegar, suggest a potential gut-metabolic mechanism involving fermentation products, satiety signalling, and intestinal glucose handling^{26,22}.

These mechanisms are not mutually exclusive and should be interpreted as hypothesis-generating rather than causally established pathways. For example, a polyphenol- and fibre-rich preparation could potentially influence carbohydrate digestion, gut fermentation, inflammatory signalling, and metabolic regulation through multiple interacting processes. However, the included studies generally did not demonstrate a complete causal sequence from standardized bioactive exposure to molecular target engagement and clinically meaningful metabolic outcomes. Future studies should therefore integrate chemical characterization, digestion and bioaccessibility assessment, mechanistic biomarkers, and validated metabolic outcomes to test these proposed pathways more directly.

Why antioxidant activity should be treated as supporting evidence

Antioxidant assays such as DPPH, ABTS, FRAP, and CUPRAC are useful for screening and process optimization but should be interpreted as supporting rather than definitive evidence of metabolic benefit, because they reflect chemical reactivity under controlled conditions rather than bioaccessibility, systemic exposure, or clinically meaningful effects. Antioxidant findings are therefore most informative when supported by biologically relevant outcomes, such as oxidative-stress biomarkers, inflammation, histology, or metabolic responses.

Dose translation, bioaccessibility, and matrix effects

Dose translation remains a major limitation because several animal studies used concentrated extracts at exposures unlikely to be achieved through normal food consumption. Human-equivalent-dose calculations do not fully account for absorption, metabolism, microbial conversion, or food-matrix interactions. Bioaccessibility should therefore be assessed as an intermediate step between composition and biological efficacy, for example using standardized in vitro digestion methods such as INFOGEST^{28,29}. Future studies should also evaluate how processing and matrix interactions affect the release, stability, and activity of mangrove-derived bioactives.

Extraction technology and standardization

Extraction and processing methods influence both bioactivity and feasibility for food application. Studies on *N. fruticans* and *S. alba* illustrate the potential of optimized and food-compatible extraction, while fermentation may offer an additional route for functional beverage development^{17,21,29}. Future studies should report reproducible processing conditions and establish botanical identity, chemical fingerprints, quantified marker compounds, and validated functional assays to ensure batch consistency and support translation into standardized food ingredients.

Safety, antinutrients, and coastal contaminants

Safety evidence was limited across the included studies, which focused mainly on bioactivity and metabolic outcomes rather than comprehensive food-safety assessment. Antinutrient exposure, repeated-dose toxicity, contaminant burden, and tolerable intake were rarely evaluated, so the long-term safety of concentrated mangrove-derived ingredients remains uncertain.

Potential concerns regarding heavy metals, petroleum-derived pollutants, pesticides, microbial hazards, and other contaminants are largely inferred from the broader coastal-food literature rather than directly demonstrated in the included mangrove studies³⁰. These should therefore be treated as precautionary considerations requiring direct verification. Antinutrients such as tannins should also be quantified because high exposure may affect astringency, protein digestibility, and mineral availability.

Sustainability and benefit sharing

Sustainability was not a primary outcome of the included studies; however, it is an important consideration for the future development of mangrove-derived functional-food ingredients. Materials obtained from bark and roots may raise greater ecological concerns because harvesting can damage or kill plants, whereas fruits, controlled renewable leaf harvest, and processing side-streams may offer more sustainable alternatives. Future studies should therefore consider harvest intensity, regeneration potential, source traceability, and the involvement of coastal communities when evaluating promising mangrove-derived ingredients. Benefit-sharing may also be relevant where traditional knowledge or locally used mangrove foods contribute to product development.

Limitation

A limitation of the review process was that the historical detailed-screening log did not preserve mutually exclusive numerical exclusion categories, which prevented retrospective separation of duplicate or overlapping reports from specific full-text exclusion reasons. In addition, formal risk-of-bias or methodological quality appraisal was not undertaken, consistent with the evidence-mapping purpose of this scoping review.

Research priorities

Future research should prioritize: (1) standardized food-grade ingredients with authenticated sourcing, contaminant and antinutrient assessment; (2) realistic dose, digestion, bioaccessibility, and food-matrix validation; and (3) controlled human intervention studies using clinically relevant metabolic outcomes. Sustainability, sensory acceptability, and scalable processing should be integrated throughout product development. The research focus should shift from demonstrating antioxidant activity toward establishing which standardized and safe mangrove-derived ingredients produce reproducible metabolic benefits.

Translational framework for mangrove-derived functional ingredients

Level	Question	Minimum evidence	Current status	Priority
1. Identity	What exactly is the material?	Voucher, origin, plant part, maturity, harvest metadata	Inconsistent	Taxonomic and harvest standards
2. Composition	What does it contain?	Yield, fingerprint, quantified markers, nutrients/antinutrients	Moderate for selected taxa	Reference standards and batch limits
3. Function	Does it affect a metabolic target?	Controls, dose-response, orthogonal assays	Common but heterogeneous	Reproducible multi-assay validation
4. Food feasibility	Does activity survive processing and digestion?	Food-grade processing, stability, INFOGEST, matrix and sensory tests	Scarce but emerging	Prototype development
5. Safety	Is intended intake safe?	Contaminants, antinutrients, toxicity, tolerance	Insufficient	Repeated-dose and contaminant data

Level	Question	Minimum evidence	Current status	Priority
6. Human benefit	Does it improve a clinical metabolic outcome?	Controlled human trial with standardized product	Not established	Dose-finding and efficacy trials

CONCLUSION

Mangrove-derived bioactive materials show promising preclinical potential for metabolic-health-oriented functional-food development, particularly through effects related to glycaemic regulation, lipid metabolism, oxidative and inflammatory pathways, and gut-metabolic signalling. However, the current evidence remains dominated by in vitro and animal studies, with limited information on standardized food-grade processing, bioaccessibility, realistic dietary exposure, safety, and no established human metabolic efficacy. Future research should therefore prioritize standardized and food-compatible preparations, direct safety and contaminant assessment, digestion and bioaccessibility studies, realistic dose translation, and well-designed human intervention trials before firm health claims or broader functional-food applications can be justified.

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