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Coastal Foods with Functional Potential from the Riau Islands, Indonesia: Nutritional Value, Bioactive Compounds, and Research Gaps

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ABSTRACT

Coastal food resources in the Riau Islands, Indonesia, may contribute to dietary quality and functional food development. However, evidence regarding their nutritional value, bioactive compounds, and health relevance remains fragmented. This narrative review aimed to map the existing evidence on nine locally relevant coastal foods and identify research gaps. PubMed, ScienceDirect, and Taylor & Francis Online were searched for studies published between 2016 and 2026, supplemented by Google Scholar and citation searching. The review focused on stingless bee honey, gonggong (*Laevrombus turturella*), mangrove crab (*Scylla* spp.), mangrove apple (*Sonneratia caseolaris*), brown seaweed (*Sargassum* spp.), sea cucumber (*Holothuria scabra*), ikan biang (*Ilisha elongata*), betel leaf (*Piper betle*), and ikan parang-parang (*Chirocentrus dorab*). Thirty primary studies, comprising seven identified through database searches and 23 through supplementary searches, were synthesized according to functional pathways, levels of biological validation, geographical relevance, and stages of translation. Three studies published before 2016 were retained because of the limited availability of recent evidence. Two major pathways were identified: bioactive-oriented potential associated with phenolic compounds, polysaccharides, peptides, and saponins, and nutrient-oriented potential associated with protein, essential amino acids, minerals, and unsaturated fatty acids. Antioxidant and antimicrobial activities were the most frequently reported biological activities. None of the included primary studies evaluated outcomes in animals or humans. However, supporting reviews indicated limited evidence from animal studies for four commodities and identified only one small clinical trial involving a sea cucumber-derived bioactive compound rather than the whole food. Geographically specific evidence from the Riau Islands was strongest for gonggong. Overall, these coastal foods represent promising candidates for functional food development rather than clinically validated functional foods. Future research should prioritize the standardized characterization of locally sourced foods, assessment of processing methods and food safety, bioavailability studies, and well-designed human studies.

INTRODUCTION

Functional foods have received increasing attention because foods are recognized not only as sources of essential nutrients but also as potential contributors to health maintenance and disease prevention[1]. Bioactive food components, including phenolic compounds, flavonoids, carotenoids,

peptides, polysaccharides, and selected fatty acids, may influence physiological processes associated with oxidative stress, inflammation, and metabolic regulation. However, the presence of bioactive compounds or biological activity demonstrated in laboratory assays does not necessarily establish a clinically meaningful health benefit[2]. The development of evidence-based functional foods therefore requires a progression from nutritional and compositional characterization to the evaluation of biological activity, bioavailability, safety, and ultimately human health outcomes[1,3].

Coastal ecosystems provide a diverse range of food resources derived from marine, estuarine, mangrove, and coastal terrestrial environments. In addition to supplying macronutrients and micronutrients, these resources may contain biologically active constituents such as phenolic compounds, sulfated polysaccharides, peptides, collagen, and polyunsaturated fatty acids[4]. Marine algae, mollusks, fish, crustaceans, echinoderms, and mangrove plants have therefore attracted increasing interest as potential sources of functional food ingredients[4–6]. Their nutritional and bioactive characteristics, however, may vary according to species, geographical origin, environmental conditions, harvesting practices, and processing methods, which determines whether reported biological activities can be translated into meaningful food-based applications.

The Riau Islands Province, located at the maritime crossroads of western Indonesia, is characterized by an extensive archipelagic landscape and strong dependence on coastal and marine resources. Its marine, estuarine, mangrove, and island-associated ecosystems support a wide variety of locally consumed foods, and seafood, seaweeds, mangrove-derived plants, mollusks, and crustaceans form part of the region's food systems and cultural practices. This ecological and culinary diversity provides an important basis for exploring locally available foods as sources of nutrients and bioactive compounds. Nevertheless, their functional potential should be evaluated on the strength, consistency, and geographical relevance of the available scientific evidence rather than solely on traditional use or nutritional reputation.

Within this regional context, nine coastal and island-associated foods are of particular interest because they are locally consumed and have been investigated for their nutritional or bioactive characteristics: stingless bee honey, gonggong, mangrove crab, mangrove apple, brown seaweed, sea cucumber, ikan biang, betel leaf, and ikan parang-parang. These resources represent diverse food groups, including bee-derived products, mollusks, crustaceans, mangrove-associated plants, seaweeds, echinoderms, and fish. The available evidence is not expected to be comparable across commodities, and some foods may be supported primarily by compositional studies rather than direct evidence of health-related biological activity.

Despite growing interest, the evidence concerning the functional potential of these foods remains fragmented. Existing studies differ substantially in the commodities investigated, bioactive

components characterized, experimental models used, and outcomes measured. Evidence generated outside the Riau Islands is often used to infer the potential of foods consumed in the region, although geographical origin, species, environmental conditions, and processing practices may influence nutritional and bioactive profiles. The evidence is also uneven across levels of biological validation, with many reported activities based on compositional analyses or in vitro experiments rather than animal or human studies. Existing reviews have largely examined single commodities, such as stingless bee honey[7–9], *Sargassum*[5,10], sea cucumber[6], betel leaf[11], mangrove apple[12], and mud crab[13], or marine functional ingredients in general[4], and typically pool evidence regardless of geographical origin. To our knowledge, no review has examined the coastal foods of the Riau Islands together, compared their evidence base across commodities, or distinguished region-specific evidence from evidence generated elsewhere. This fragmentation makes it difficult to determine which Riau Islands coastal foods have sufficient evidence to support functional-food development and which remain promising but under-investigated, leaving local researchers, food developers, and nutrition programs without a consolidated basis for setting priorities.

Therefore, this narrative review aimed to map and synthesize the available evidence on nine coastal and island-associated foods from the Riau Islands, with particular emphasis on their nutritional and bioactive constituents, reported biological activities, potential health relevance, and level of evidence, and to identify geographic and scientific evidence gaps and research priorities for translating these resources into evidence-based functional-food applications. Rather than presenting nine independent case studies, the evidence is organized around four cross-cutting dimensions, each addressing a specific limitation of commodity-by-commodity reviews. The first, the nutrient- versus bioactive-oriented pathway, separates claims that rest on established nutritional science from those that depend on assay-based bioactivity and therefore require different forms of validation. The second, the level of biological validation, prevents compositional or in vitro findings from being read as evidence of health benefit[2]. The third, geographical relevance, makes explicit whether the evidence was generated from locally harvested foods, given that composition varies with origin, species, and environment. The fourth, the translational stage, links the evidence for each food to the next research step required for food-based application. Together, these dimensions produce a region-specific evidence map that can guide research prioritization and local functional-food development, rather than a further descriptive summary of individual foods.

MATERIALS AND METHODS

Review design

This study employed a narrative literature review to synthesize scientific evidence concerning

the nutritional composition, bioactive compounds, biological activities, and potential health relevance of nine coastal and island-associated foods from the Riau Islands. A narrative approach was selected because the available literature encompasses heterogeneous study designs, food matrices, analytical methods, experimental models, and outcome measures, making quantitative synthesis inappropriate. As this study used only published literature and involved no human or animal subjects, ethical clearance was not required.

Literature search strategy

Literature searches were conducted in PubMed, ScienceDirect, and Taylor & Francis Online for publications from 2016 to 2026. For each commodity, the common, local, and scientific names were combined with terms related to nutritional composition, bioactive compounds, biological activity, food application, and safety (Table 1). Records were then limited to those with accessible full text, and review articles and other non-original publications were excluded. Because much of the regional evidence is published in Indonesian national journals, conference proceedings, and theses that are not indexed in these databases, Google Scholar was additionally searched using the same terms, and the reference lists of relevant publications were screened to trace further studies.

Table 1. Core search strings and number of records retrieved per database

Commodity	Core search string	PubMed	ScienceDirect	Taylor & Francis
Stingless bee honey (kelulut)	("stingless bee honey" OR "kelulut" OR "Meliponini" OR "Trigona" OR "Heterotrigona") AND ("phenolic" OR "flavonoid" OR "antioxidant" OR "antimicrobial" OR "physicochemical")	172	572	157
Gonggong	("Laevistrombus turturella" OR "Strombus turturella" OR "Laevistrombus canarium" OR "dog conch" OR "gonggong" OR "Strombidae") AND ("nutritional composition" OR protein OR "amino acid" OR bioactive OR antioxidant OR antimicrobial OR peptide OR "heavy metal")	9	18	4
Mangrove crab	("Scylla serrata" OR "Scylla" OR "mangrove crab") AND ("nutritional composition" OR "protein" OR "bioactive" OR "antioxidant" OR "Bintan" OR "Tanjungpinang")	296	2,571	146
Mangrove apple (pedada)	("Sonneratia caseolaris" OR "mangrove apple" OR "pedada") AND ("phenolic" OR "flavonoid" OR "antioxidant" OR "antimicrobial" OR "food product")	13	221	12
Brown seaweed (rengkam)	("Sargassum" OR "rengkam" OR "brown seaweed") AND ("fucoidan" OR "phenolic" OR "antioxidant" OR "antidiabetic" OR "alpha-glucosidase")	838	9,838	764
Sea cucumber (teripang)	("sea cucumber" OR "teripang" OR "Holothuria scabra" OR "Stichopus") AND ("collagen" OR "peptide" OR "antioxidant" OR "wound healing" OR "nutritional composition")	405	3,607	243
Ikan biang	("Ilisha elongata" OR "ikan biang") AND ("proximate composition" OR "protein" OR "fatty acid" OR "amino acid" OR "fish flour")	5	34	4
Betel leaf (daun sirih)	("Piper betle" OR "betel leaf" OR "daun sirih") AND ("phenolic" OR "antimicrobial" OR "antioxidant" OR "essential oil" OR "food preservation")	137	1,296	181
Ikan parang-parang	("Chirocentrus dorab" OR "ikan parang-parang") AND ("proximate composition" OR "fatty acid" OR "amino acid" OR "collagen" OR "nutritional")	3	21	8
Total		**1,878**	**18,178**	**1,519**

Values are the total numbers of records retrieved before filtering; subsequent filtering and screening are shown in Figure 1. Search strings were adapted to the syntax of each database.

Eligibility and study selection

Studies were eligible when they (1) investigated one or more of the nine selected food resources; (2) reported nutritional composition, bioactive compounds, functional properties, biological activities, food applications, safety, or health-related outcomes; (3) were published between 2016 and 2026; and (4) provided sufficient information to identify the food resource, study context, and principal findings. Three earlier primary studies (published 2010–2015) were exceptionally retained because

no more recent primary data were available for the corresponding commodity or outcome. Studies of the same species from outside the Riau Islands were retained when they informed the nutritional or bioactive characteristics of the corresponding resource, but their geographical origin was considered during interpretation. Studies were excluded when they were not original research articles, did not investigate any selected food resource, reported no relevant physicochemical, bioactive, health, quality, or functional-food outcomes, or fell outside the predefined scope. Review articles were not treated as primary evidence but were used selectively for background and to identify additional primary studies.

After removal of duplicates, database records were screened by title and then by abstract, and the remaining articles were assessed in full text against the eligibility criteria. Of the 3,424 unique database records, 640 full-text articles were assessed and seven studies were included. A further 23 studies were identified through Google Scholar and citation searching, giving a total of 30 included primary studies (Figure 1).

Data extraction and evidence classification

Information extracted from eligible studies included the food resource, species, geographical origin, study design, nutritional or bioactive components evaluated, analytical or experimental methods, principal findings, and reported biological or health-related outcomes. The strength of evidence was interpreted according to the highest level of biological validation available for each food: (1) compositional evidence, characterizing nutrients or bioactive compounds without directly evaluating biological effects; (2) in vitro evidence, evaluating biological or functional activities in laboratory assays; (3) animal evidence, evaluating biological or health-related outcomes in animal models; and (4) human evidence, comprising observational or intervention studies. Evidence was not considered equivalent across these levels, and findings from in vitro or animal studies were interpreted as indications of functional potential rather than established human health benefits[2].

Synthesis approach

Findings were synthesized narratively around four cross-cutting dimensions: the nutrient- versus bioactive-oriented pathway of functional potential, the level of biological validation, the geographical origin of the supporting evidence (Riau Islands, elsewhere in Indonesia, or outside Indonesia), and the translational steps required for food-based application. Cross-commodity comparisons were used to identify recurring compound classes, patterns of reported activity, and areas in which evidence remained limited or inconsistent. Where evidence was insufficient or geographically indirect, this limitation was reported explicitly rather than inferred as a confirmed functional effect. Because none of the included primary studies evaluated animal or human outcomes, evidence at these levels was drawn from published reviews and is identified as review-derived in

Tables 3 and 4.

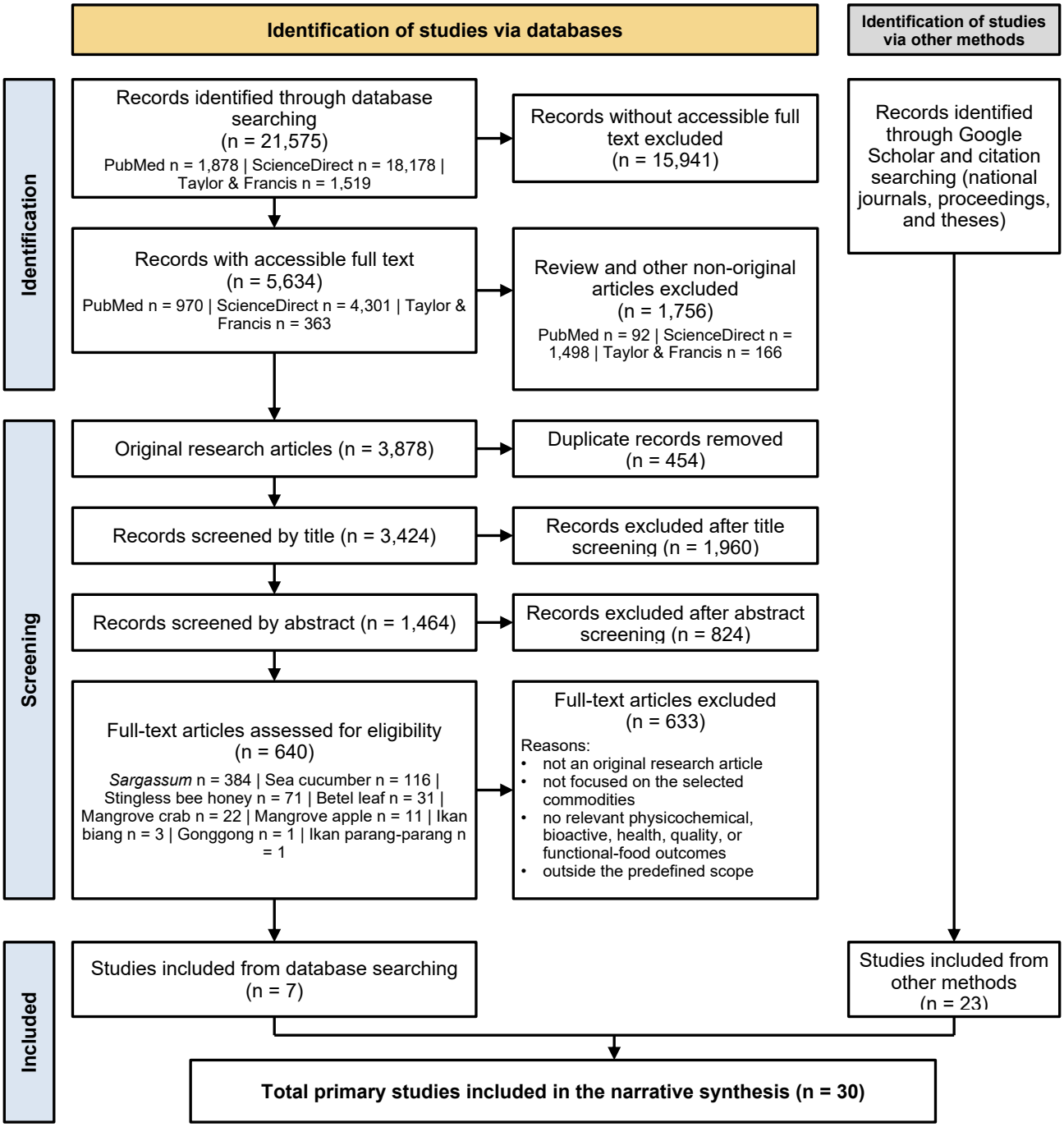


Figure 1. Flow diagram of literature identification and study selection

RESULTS

Characteristics of the included studies

The 30 included studies are summarized in Table 2. Sea cucumber (n = 6) and gonggong (n = 5) were the most frequently studied commodities, followed by ikan parang-parang (n = 4); stingless

bee honey, mangrove apple, *Sargassum*, and ikan biang were each represented by three studies, betel leaf by two, and mangrove crab by a single ecological study. Only five studies used samples from the Riau Islands (Bintan and Tanjungpinang), three used samples from mainland Riau Province, 17 used samples from other regions of Indonesia, and five were conducted outside Indonesia (Brazil, Thailand, and Malaysia). By study type, 12 studies evaluated in vitro bioactivity, eight reported compositional or safety analyses, nine developed or evaluated food products, and one was an ecological population study; none evaluated outcomes in animal models or human participants.

Table 2. Characteristics of the included primary studies (n = 30)

Commodity	Study	Sample origin	Material and analyses	Study type	Key findings
Stingless bee honey	Biluca et al., 2016[14]	Santa Catarina, Brazil	33 honeys from 10 species; physicochemical properties, minerals, phenolics, antioxidant activity	Composition; in vitro	Wide interspecies variation in moisture, acidity, minerals, total phenolics, and antioxidant activity
	Melia et al., 2024[15]	West Sumatra, Indonesia	Honeys from 4 species; physicochemical properties, phenolics, antioxidant and antimicrobial activity, microbiota	In vitro	Highest phenolics in *G. thoracica* and *T. melanoleuca*; all honeys inhibited *E. coli*, *Salmonella*, *S. aureus*, and *L. monocytogenes*
	Vega & Karaman, 2026[16]	West Sumatra, Indonesia	Honeys from 9 species; phenolics, flavonoids, DPPH, FRAP, HMF, GC-MS volatiles, FTIR	Composition; in vitro	Species-dependent bioactive, physicochemical, and volatile profiles
Gonggong	Viruly et al., 2020[17]†	Bintan, Riau Islands	Meat extracts of thin- and thick-shelled snails; DPPH, well-diffusion antimicrobial assay	In vitro	DPPH IC_{50} 1,433–2,052 ppm; stronger activity against Gram-positive than Gram-negative bacteria
	Viruly et al., 2023[18]	Bintan, Riau Islands	Meat extract; antimicrobial peptide identification and characterization	In vitro	12-amino-acid peptide (~1.4 kDa); MIC 0.50–1.03 mg/mL against *S. aureus* and *E. coli*
	Viruly, 2011[19]†	Bintan, Riau Islands	Fresh meat; proximate analysis; fermented seasoning	Composition; food product	19.77% protein; fermentation increased free amino acids; seasoning comparable to commercial oyster sauce
	Rasyid & Dody, 2018[20]†	Bangka, Indonesia	Dried meat; proximate composition, Pb, Cd, Hg	Composition; safety	44.66% protein (dry weight); Pb and Cd below FAO/WHO limits; Hg not detected

Commodity	Study	Sample origin	Material and analyses	Study type	Key findings
	Anam et al., 2019[21]†	Tanjungpinang, Riau Islands	Snails, seawater, and sediment; Pb and Cd by AAS	Safety	Pb 1.03–1.98 mg/kg and Cd 0.03–0.04 mg/kg in snail tissue
Mangrove crab	Tahmid et al., 2015[22]†	Bintan Bay, Riau Islands	*S. serrata* catch; size structure and population parameters	Ecological	Carapace width 64–172 mm; male stock over-exploited (E = 53.62%)
Mangrove apple	Audah et al., 2022[23]	Indonesia	Leaf ethanol extract; antioxidant and anti-MRSA assays	In vitro	Strong antioxidant activity and activity against methicillin-resistant *S. aureus*
	Kartikaningsih et al., 2025[24]	Indonesia	Leaf extracts with water-based and other solvents; DPPH, GC-MS, molecular docking	In vitro	Methanol and distilled-water extracts most active; TEMPO, choline, and betaine identified
	Marshanda et al., 2025[25]†	Indonesia	Fruit syrup (20%, 30%, 50% fruit); proximate, pH, hedonic test	Food product	20% formulation most accepted; protein 0.09–0.22%, carbohydrate 17.10–22.52%
Sargassum spp.	Edison et al., 2020[26]†	Indonesia	*S. plagiophyllum*; proximate, phytochemical screening, DPPH of three solvent extracts	Composition; in vitro	68.69% carbohydrate, 22.24% crude fiber (dry weight); weak DPPH activity (IC_{50} 532–1,106 ppm)
	Widyaswari et al., 2024[27]†	Makassar, Indonesia	*S. polycystum* and *S. ilicifolium*; phytochemical screening, DPPH	In vitro	DPPH IC_{50} approximately 51 ppm for both species
	Sinurat & Suryaningrum, 2019[28]†	Indonesia	*Sargassum* tea; blanching time; antioxidant activity, sensory evaluation	Food product	Blanching time affected antioxidant activity and sensory properties of the tea
Sea cucumber	Nobsathian et al., 2017[29]†	Thailand	Whole-body methanol extract and isolated compounds; phenolics, radical scavenging	In vitro	Extract EC_{50} 33.77 µg/mL; isolated compounds approximately 14.6–14.8 µg/mL
	Dehwie et al., 2021[30]†	Indonesia	Skin, chitin, and chitosan; phytochemical screening, DPPH	In vitro	Chitosan IC_{50} 235 ppm vs. chitin 620 ppm and skin 1,445 ppm
	Sroyraya et al., 2017[31]†	Thailand	Whole body and body wall; proximate, amino acids, fatty acids, vitamins, collagen	Composition	Protein 22.50% (whole body) and 55.18% (body wall); glycine, glutamic acid, and proline predominant

Commodity	Study	Sample origin	Material and analyses	Study type	Key findings
	Ardiansyah et al., 2020[32]†	Bungin, Belitung, Lampung, and Makassar, Indonesia	Commercial specimens; proximate, amino acids, minerals, Hg, Pb, Cd, As	Composition; safety	High protein, lipid 0.48–1.22%; glycine and calcium predominant; heavy metals not detected
	Rasyid et al., 2020[33]†	Bali, Indonesia (cultured)	Proximate, amino acids, minerals, vitamins, fatty acids	Composition	Protein 5.10% (wet weight); glycine 6,709 mg/kg; calcium 1,812 mg/100 g; vitamin E 0.48 mg/100 g
	Sahlan et al., 2020[34]†	Indonesia	*H. scabra* jelly; production and composition analysis	Food product	Jelly product produced and its composition characterized
Ikan biang	Azka et al., 2019[35]†	Riau Province (mainland)	Dried salted fish at 5%, 10%, and 15% salt; proximate	Composition	Protein 46.68–49.08%, fat 4.52–5.77%, ash 22.20–24.02%
	Suparmi et al., 2022[36]	Riau Province (mainland)	Fish flour in sago noodles; amino acids, fatty acids, minerals, sensory	Composition; food product	8% fortification optimal; flour rich in essential amino acids, EPA, DHA, Ca, P, Mg, Zn, and Fe
	Sumarto, 2022[37]†	Riau Province (mainland)	Functional biscuits with 4% fish flour; proximate, acceptance	Food product	Protein 17.31%, fat 19.54%; acceptance 93.75–100%
Betel leaf	Pin et al., 2010[38]†	Malaysia	Extracts of different solvent polarities; antioxidant and anti-inflammatory assays, HPLC	In vitro	Water extract gave highest yield and activity; hydroxychavicol and eugenol main constituents
	Zaini et al., 2026[39]†	Malaysia	Leaf extract; phenolics, DPPH, FRAP; whiteleg shrimp stored at 4 °C	In vitro; food application	2% extract reduced total bacteria, coliforms, and *Vibrio* over 16 days, comparable to sodium metabisulfite
Ikan parang-parang	Nopianti et al., 2026[40]†	South Sumatra, Indonesia	Fish of different body weights; proximate, amino acids, fatty acids; silky pempek	Composition; food product	~20.78% protein and 1.85% fat (800 g–1 kg); lysine, glutamate, and DHA predominant
	Az-Zahrah, 2022[41]†	Indonesia	Grilled pempek with fish:tapioca ratios of 0.6:1 to 1:1; physical and chemical analysis	Food product	1:1 ratio best chemical composition; 0.8:1 most preferred
	Wicaksono et al., 2023[42]†	Indonesia	Crackers with fish-bone meal; proximate, calcium, organoleptic test	Food product	Highest calcium in formula 3; formula 1 most preferred

Commodity	Study	Sample origin	Material and analyses	Study type	Key findings
	Safithri et al., 2019[43]†	Indonesia	Skin acid-soluble collagen; yield, physicochemical properties, amino acids	Composition	Yield 2.61%; glycine 26.69%, proline 12.24%, alanine 9.51%

†Identified through Google Scholar or citation searching; all other studies were identified through database searching. AAS, atomic absorption spectrophotometry; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; FRAP, ferric reducing antioxidant power; FTIR, Fourier-transform infrared spectroscopy; GC-MS, gas chromatography–mass spectrometry; HMF, hydroxymethylfurfural; MIC, minimum inhibitory concentration; MRSA, methicillin-resistant Staphylococcus aureus.

Overview of the nine coastal food resources

The evidence for the nine coastal food resources is summarized in Table 3, which presents the major constituents, reported activities, highest level of evidence, and geographic relevance of each commodity, and Table 4 maps this evidence against the four-level validation hierarchy used in this review. Both tables are referred to across the following subsections rather than being tied to a single commodity.

Table 3. Summary of reviewed evidence by commodity

Coastal food	Scientific name	Major constituents	Reported activity	Highest evidence level	Geographic relevance
Stingless bee honey	Meliponini spp.	Phenolics, flavonoids, sugars, minerals	Antioxidant, antimicrobial	Animal (limited)	Regional (West Sumatra)
Gonggong	*Laevistrombus turturella*	Protein, peptides, free amino acids	Antioxidant, antimicrobial	In vitro	Riau Islands (Bintan)
Mangrove crab	*Scylla* spp.	Protein, PUFA, minerals, chitin	Nutritional potential	In vitro (emerging)*	Ecological only (Bintan)
Mangrove apple (pedada)	*Sonneratia caseolaris*	Phenolics, flavonoids, tannins	Antioxidant, antimicrobial	In vitro	Regional
Brown seaweed (rengkam)	*Sargassum* spp.	Fucoidan, alginate, phenolics, fiber	Antioxidant, glucose-lowering	Animal (limited)	Regional
Sea cucumber	*Holothuria scabra*	Protein, collagen, peptides, saponins	Antioxidant, metabolic	Animal‡	Regional (Bali, other sites)
Ikan biang	*Ilisha elongata*	Protein, amino acids, minerals, fatty acids	Nutritional potential	Composition	Riau Province (mainland)
Betel leaf	*Piper betle*	Hydroxychavicol, eugenol, phenolics	Antimicrobial, antioxidant	Animal (safety only)	Regional
Ikan parang-parang	*Chirocentrus dorab*	Protein, fatty acids (DHA), collagen	Nutritional potential	Composition	Evidence gap

PUFA, polyunsaturated fatty acids; DHA, docosahexaenoic acid. *Based on non-local *Scylla* studies. ‡One small clinical trial of a sea cucumber-derived bioactive, not the whole food, has been reported[6]. Animal-level evidence is derived from published reviews.

Two pathways of functional potential

The evidence follows two broad, partly overlapping pathways toward functional-food potential.

Bioactive-oriented potential is characterized primarily by phenolic compounds, polysaccharides, peptides, saponins, and related secondary constituents whose relevance is demonstrated through antioxidant, antimicrobial, or other assay-based activities. Nutrient-oriented potential is characterized by protein, essential amino acids, minerals, and unsaturated fatty acids, and its relevance rests on established nutritional science rather than on assay-based bioactivity. Several commodities, notably gonggong and sea cucumber, contribute evidence to both pathways.

Bioactive-oriented resources

Stingless bee honey (madu kelulut). The composition of stingless bee honey is influenced by bee species, botanical origin, and environmental conditions. A characterization of 33 honey samples from ten stingless bee species reported substantial variation in moisture, acidity, pH, carbohydrate and mineral content, total phenolic content, and antioxidant activity[14]. In West Sumatra, honeys from four stingless bee species differed in physicochemical characteristics, total phenolic content, antioxidant and antimicrobial activity, carbohydrate profile, and microbiota; honeys from *Geniotrigona thoracica* and *Tetrigona melanoleuca* showed the highest phenolic contents, and all honeys inhibited *Escherichia coli*, *Salmonella*, *Staphylococcus aureus*, and *Listeria monocytogenes*[15]. A recent characterization of honeys from nine stingless bee species in West Sumatra combined physicochemical analysis with DPPH and FRAP antioxidant assays, microbiological screening, GC-MS volatile profiling, and FTIR fingerprinting[16]. A systematic review and meta-analysis likewise reported substantial heterogeneity in phenolic content, antioxidant activity, and physicochemical properties of stingless bee honey[7], and recent reviews note that evidence for nutraceutical effects in vivo remains limited[7,8]. Variation in bee species, floral source, post-harvest handling, and analytical methods, together with the absence of human clinical evidence, has also been identified as a key barrier to the commercial translation of stingless bee honey into functional food products[9].

Brown seaweed (Sargassum spp.; rengkam). The functional potential of *Sargassum* is associated with polysaccharides, phenolic compounds, flavonoids, pigments, sterols, terpenoids, and minerals; alginate and sulfated polysaccharides such as fucoidan are particularly relevant from a food-technology perspective[5]. Indonesian *Sargassum plagiophyllum* contained substantial carbohydrate and crude fiber fractions, and its hexane, ethyl acetate, and methanol extracts showed markedly different phytochemical profiles and antioxidant activities, all of which were classified as weak in the DPPH assay[26]. In contrast, *S. polycystum* and *S. ilicifolium* from Makassar showed considerably stronger DPPH scavenging activity[27], illustrating the broad variation associated with species, origin, and extraction method[5]. A review of 16 preclinical studies reported that extracts from eleven *Sargassum* species lowered blood glucose and improved insulin sensitivity and lipid profiles in rodent models, although no human data were available[10].

Sea cucumber (Holothuria scabra): bioactive constituents. The functional potential of sea cucumbers beyond their nutrient content is associated with triterpene glycosides, fucosylated chondroitin sulfate, other sulfated polysaccharides, peptides, cerebrosides, and collagen, which have been investigated for antioxidant, anticancer, antidiabetic, and lipid-lowering activities[6]. Much of this evidence has been generated using extracts, isolated fractions, or purified compounds rather than whole sea cucumber consumed as food. A methanol extract of whole-body *H. scabra* and three compounds isolated from it demonstrated radical-scavenging activity[29], while studies of its skin, chitin, and chitosan identified alkaloids, flavonoids, saponins, and triterpenoids, with chitosan showing greater antioxidant activity than the crude skin extract and chitin[30].

Betel leaf (Piper betle). Betel leaf contains diverse secondary metabolites, including phenolic compounds such as hydroxychavicol and eugenol, flavonoids, tannins, and terpenoid-related constituents[11,38]. Extracts prepared with solvents of different polarities showed different antioxidant capacities, with hydroxychavicol and eugenol identified as the main contributors[38]. Its antimicrobial potential is particularly relevant to food applications: extracts and essential oils inhibit a range of Gram-positive and Gram-negative bacteria and food-spoilage fungi[11], and a recent study showed that a 2% betel leaf extract reduced total bacterial, coliform, and *Vibrio* counts in whiteleg shrimp during 16 days of refrigerated storage[39].

Mangrove apple (pedada; Sonneratia caseolaris). The bioactive potential of *S. caseolaris* is associated with phenolic compounds, flavonoids, tannins, and other secondary metabolites, mostly documented in leaf and bark extracts[12]. Ethanol extracts of Indonesian *S. caseolaris* leaves showed strong antioxidant activity and activity against methicillin-resistant *S. aureus*[23], and aqueous and methanol leaf extracts have been evaluated as potential bioactive food ingredients[24]. Because this evidence is drawn from leaves or concentrated extracts, it should be interpreted as extract-level biological activity rather than evidence of health effects from consuming the fruit itself.

Gonggong (Laevistrombus turturella): peptide-derived bioactivity. Screening of gonggong collected from Bintan demonstrated antioxidant activity in the DPPH assay and antimicrobial activity that was stronger against Gram-positive than Gram-negative bacteria[17]. A 12-amino-acid antimicrobial peptide candidate (approximately 1.4 kDa) identified from *L. turturella* meat inhibited *S. aureus* and *E. coli*[18], expanding the functional-food perspective on this species beyond conventional antioxidant screening.

Nutrient-oriented resources

Ikan biang (Ilisha elongata). Dried salted *I. elongata* contained 46.68–49.08% protein, 4.52–5.77% fat, and 22.20–24.02% ash, varying with salt concentration[35]. Biang fish flour has additionally been characterized for its amino acids, fatty acids, and minerals, including several essential amino

acids, eicosapentaenoic and docosahexaenoic acids, and calcium, phosphorus, magnesium, zinc, and iron[36].

Ikan parang-parang (Chirocentrus dorab). Recent characterization of *C. dorab* showed that its nutritional profile varies with body weight, with approximately 20.78% protein and 1.85% fat in fish weighing 800 g–1 kg, together with substantial unsaturated fatty acids and essential amino acids; lysine was the predominant essential amino acid, glutamate the predominant non-essential amino acid, and docosahexaenoic acid the major unsaturated fatty acid[40].

Mangrove crab (Scylla spp.). Mangrove crab is primarily of interest as a source of high-quality animal protein. A recent review of edible *Scylla serrata* reported protein contents of 10.97–47.7% depending on location and sex, lipids rich in polyunsaturated fatty acids, and minerals, alongside chitin and chitosan from the shell[13]. However, this evidence is not specific to edible tissue from the Riau Islands.

Gonggong: protein content and processing potential. Fresh gonggong from Bintan contained 19.77% protein, and its fermentation with pineapple concentrate hydrolyzed proteins into free amino acids, producing a natural seasoning with sensory acceptance comparable to commercial oyster sauce[19]. Dried *L. turturella* from Bangka contained 44.66% protein on a dry-weight basis[20], indicating relevance not only as a source of marine protein but also as a raw material for value-added food products.

Sea cucumber: nutritional profile. *H. scabra* is characterized by high protein and low lipid content together with amino acids, minerals, fatty acids, vitamins, and collagen[31]. Commercially harvested *H. scabra* from four Indonesian coastal locations showed high protein and low fat contents, with glycine as the predominant amino acid and calcium as the most abundant mineral[32]. Cultured *H. scabra* from Bali similarly showed glycine and glutamic acid as the major amino acids, alongside calcium, sodium, magnesium, phosphorus, potassium, iron, vitamin E, and several fatty acids[33].

Level of biological validation

Across all nine commodities, evidence clusters at the lower end of the four-level validation hierarchy, with a pronounced drop-off after the in vitro level (Table 4). Every commodity has at least compositional support, such as proximate composition, amino acid or fatty acid profiles, mineral content, or phytochemical screening. This is a necessary but insufficient basis for a functional-food claim, because it establishes what a food contains, not what it does physiologically.

Table 4. Evidence hierarchy and main research gaps of coastal foods from the Riau Islands

Commodity	Composition	In vitro	Animal	Human	Main gap
Stingless bee honey	Available	Available	Limited	N/A	Clinical validation
Gonggong	Available	Available	N/A	N/A	Animal and human evidence
Mangrove crab	Available	Emerging*	N/A	N/A	Local bioactive characterization
Mangrove apple	Available	Available	N/A	N/A	Food-form (fruit) evidence
Sargassum spp.	Available	Available	Limited	N/A	Bioavailability, clinical trials
Sea cucumber	Available	Available	Available	Limited‡	Food-dose translation
Ikan biang	Available	N/A	N/A	N/A	Bioactivity studies
Betel leaf	Available	Available	Available (safety only)	N/A	Safety in food application
Ikan parang-parang	Available	N/A	N/A	N/A	Basic bioactive characterization

N/A, no evidence identified. *Based on non-local Scylla studies. ‡A single small clinical trial of a sea cucumber-derived bioactive, not the whole food[6]. Animal and human evidence are derived from published reviews.

For most bioactive-oriented commodities (stingless bee honey, *Sargassum*, sea cucumber, betel leaf, mangrove apple, and gonggong), the bulk of the available evidence is in vitro, chiefly DPPH, ABTS, or FRAP antioxidant assays and disc-diffusion, well-diffusion, or MIC-based antimicrobial assays. Such assays demonstrate the ability of extracted constituents to interact with reactive species or test microorganisms under experimental conditions but do not by themselves establish an effect following consumption[2].

Animal-level evidence is markedly sparser. In vivo nutraceutical evidence for stingless bee honey remains limited[8,9], *Sargassum* extracts have rodent evidence for glucose and lipid outcomes[10], betel leaf has animal toxicity and safety data[11], and sea cucumber-derived compounds have been tested in numerous animal models, often by non-oral routes of administration[6]. Gonggong, mangrove crab, mangrove apple, ikan biang, and ikan parang-parang currently have no animal-level evidence (Table 4).

Within the scope of this review, no commodity had direct human intervention or observational evidence linking consumption of the food itself to a health outcome. The only human data identified concerned sea cucumber-derived bioactives, for which a review covering 2012–2021 identified a single small clinical trial of a derived bioactive preparation rather than the whole food[6]. This should be interpreted as an absence of evidence within the literature captured by the present search strategy, not as evidence of no effect. This is nevertheless the most consistent gap across all nine foods and the primary reason none can currently be described as a clinically validated functional food.

Geographical relevance of the evidence

Geographical relevance is a second axis along which the nine commodities diverge,

independent of how much evidence exists overall. Gonggong provides the clearest case of region-specific evidence: its protein, antioxidant, antimicrobial, peptide, and contaminant data derive largely from Bintan and Tanjungpinang samples[17–19,21], making it the strongest Riau Islands-specific candidate despite remaining at the compositional and in vitro levels. Mangrove crab has region-specific ecological evidence, with population studies of *S. serrata* in the mangrove ecosystem of Bintan Bay[22], but this establishes fisheries relevance rather than functional-food properties, and no local bioactive characterization of edible tissue exists.

Ikan biang illustrates a subtler geographic gap: its nutritional and food-application literature is comparatively well developed but originates predominantly from Riau Province on the mainland rather than the Riau Islands[35–37]. The remaining commodities are supported almost entirely by evidence generated elsewhere: stingless bee honey from West Sumatra and Brazil[14–16], *Sargassum* from other Indonesian regions and international literature[5,26,27], sea cucumber from Bali and other Indonesian and Asian locations[29,32,33], and mangrove apple and betel leaf from general Indonesian and Southeast Asian literature[23,38,39]. Ikan parang-parang has the weakest geographic anchoring of all nine commodities (Table 3). Because environmental conditions, species, botanical sources, harvesting practices, and post-harvest processing influence nutrient and bioactive profiles, evidence generated elsewhere can establish biological plausibility but cannot automatically be treated as representative of foods produced or harvested in the Riau Islands.

DISCUSSION

To our knowledge, this review provides the first consolidated map of the evidence on the functional potential of coastal foods from the Riau Islands, together with the gaps that limit their translation. Its main contribution is not to establish health benefits but to show where the evidence stands for each commodity across functional pathway, validation level, and geographical relevance. The mapping shows that these foods contribute to functional-food potential through two complementary routes but that the supporting evidence is uneven in both depth and geographical relevance. Four issues are central to interpreting these findings and to translating them into practice.

From extract to food matrix

A recurring pattern across the bioactive-oriented commodities is that biological activity is demonstrated in an extract, isolated fraction, or non-edible part rather than in the food as consumed. The antioxidant and antimicrobial evidence for mangrove apple comes mainly from leaves[23,24]; the most detailed bioactivity data for sea cucumber come from isolated compounds, skin, chitin, and chitosan rather than the edible body wall[29,30]; and the antimicrobial evidence for betel leaf is strongest for concentrated extracts and essential oils[11]. Extraction solvent, plant or animal part, processing

conditions, and concentration can substantially alter apparent activity[26,38], so extract-level findings should be read as evidence of potential rather than evidence that eating the food produces an equivalent effect. Food-matrix effects, digestion, absorption, metabolism, dose, and habitual consumption patterns can all modify the physiological availability of a bioactive constituent[3]; for instance, α-glucosidase inhibition by a seaweed extract indicates potential carbohydrate-related activity but does not establish an antihyperglycemic effect after consumption, and DPPH or ABTS scavenging cannot be interpreted as an antioxidant effect in humans[2].

A smaller but growing set of studies sits at an intermediate, food-product level. Mangrove apple fruit syrup has been characterized nutritionally, with a 20% fruit formulation receiving the highest consumer acceptance[25], and mangrove apples are traditionally processed into chips, dodol, syrup, and confectionery[12]. *Sargassum* has been developed into seaweed tea, in which blanching time affected both antioxidant activity and sensory properties[28]. Sea cucumber has been processed into jelly products[34]. Biang fish flour has been used to enrich sago noodles, with 8% fortification giving the best sensory and nutritional profile[36], and in functional biscuits developed for stunting prevention[37]. Ikan parang-parang has been used in pempek[40,41] and in calcium-rich crackers made from its bone waste[42], and its skin has yielded acid-soluble collagen[43]. Gonggong has been fermented into a natural seasoning[19], and betel leaf extract has been applied directly to shrimp as a natural preservative[39]. These studies demonstrate technical feasibility and consumer acceptability, but formulation-level nutrient enrichment or preservation efficacy is a food-technology outcome and should not be equated with a demonstrated health benefit.

Safety and the coastal food-system perspective

Functional potential cannot be assessed independently of safety. Gonggong, a sediment-associated gastropod, is exposed to environmental contaminants: gonggong from Tanjungpinang in the Riau Islands contained measurable lead and cadmium[21], whereas dried *L. turturella* from Bangka had lead and cadmium concentrations below FAO/WHO limits and no detectable mercury[20]. Sea cucumber harvested from four Indonesian locations had no detectable mercury, lead, cadmium, or arsenic[32], but this cannot be assumed to hold for Riau Islands sources without local verification. For betel leaf, safety evaluation must distinguish the leaf itself from betel quid preparations containing areca nut or tobacco, which carry well-documented health risks[44].

More broadly, the nine resources are best understood as complementary parts of a coastal food system rather than as candidates for a single superfood. Marine animals contribute protein, amino acids, minerals, fatty acids, collagen, and peptides; seaweeds provide polysaccharides, minerals, and secondary metabolites; coastal fruits and leaves contribute phenolic and other phytochemicals; and bee products provide carbohydrate- and phenolic-rich matrices. Framed this

way, the value of this evidence base lies less in identifying one standout commodity than in supporting dietary diversification and locally adapted food-product development across several resources.

A staged research pathway toward evidence-based functional foods

The research needs identified for individual commodities converge on a single five-stage pathway, applicable to all nine foods but with different starting points for each:

1. **Species authentication and standardized compositional characterization**, establishing reproducible nutrient and bioactive profiles; most urgent for mangrove crab, ikan parang-parang, and species-level authentication of stingless bee honey.
2. **Processing studies**, determining how traditional and industrial processing affect nutrient retention, bioactive stability, sensory characteristics, and safety; relevant to honey, mangrove apple, *Sargassum*, ikan biang, and ikan parang-parang, which already have preliminary food-product work.
3. **Digestion, bioaccessibility, and bioavailability studies**, establishing whether candidate compounds survive digestion and reach a physiologically relevant site; currently missing for all nine commodities.
4. **Animal studies**, where mechanistic validation is justified; most feasible next for gonggong and sea cucumber given their comparatively stronger in vitro evidence.
5. **Appropriately designed human studies** on standardized products at realistic dietary doses, the end point that no commodity has yet reached.

Locally, this pathway should prioritize Riau Islands-specific replication throughout the first three stages, not only for the geographically weakest commodities (ikan parang-parang, mangrove apple, betel leaf, *Sargassum*, and stingless bee honey) but also for gonggong and ikan biang, where regional evidence exists but is narrow, and for mangrove crab and sea cucumber, where local safety verification should accompany further bioactive characterization.

Implications and limitations

Taken together, the evidence supports the Riau Islands as a promising setting for developing locally based functional foods, but their relevance to healthy aging and noncommunicable disease (NCD) prevention currently rests on established nutrient–health relationships rather than on outcome evidence for these specific foods. Several such relationships are plausible. The protein- and essential amino acid-rich animal foods, including gonggong, mangrove crab, sea cucumber, ikan biang, and ikan parang-parang, could help older adults meet the protein intake of at least 1.0 g/kg body weight per day recommended to preserve muscle mass and function[45]. The long-chain omega-3 fatty acids reported in ikan biang (eicosapentaenoic and docosahexaenoic acids) and ikan parang-parang (docosahexaenoic acid)[36,40] are relevant because supplementation with these fatty acids has been

associated with fewer cardiovascular events in meta-analyses of intervention trials[46], and the fiber-rich polysaccharides of *Sargassum*[26] align with evidence that higher dietary fiber intake is associated with lower risk of several NCDs[47]. Hypertension is a particularly relevant target because it is highly prevalent among Indonesian older adults even when their anthropometric profiles appear normal[48]. The same consideration calls for caution: traditional salting and drying, illustrated by the high ash content of dried salted ikan biang, which varied with salt concentration[35], can add substantial sodium, whereas reducing sodium intake is a central strategy for preventing hypertension[49]. These pathways indicate potential relevance, not demonstrated benefit, and a food should not be considered clinically functional solely because it contains a bioactive compound or shows activity in an isolated assay[1,2]. The main research opportunity is therefore not to identify additional antioxidant-rich foods but to connect local resources with standardized characterization, processing, bioavailability, safety assessment, and human validation.

This review has several limitations. First, as a narrative review, it did not apply formal risk-of-bias or certainty-of-evidence assessment or quantitative synthesis, and the classification of evidence levels involved reviewer judgment. Second, the search process may have introduced selection bias. The nine commodities were selected purposively on the basis of local relevance rather than through a systematic inventory of Riau Islands coastal foods. Records without accessible full text (n = 15,941) were excluded at the first stage, which may have omitted relevant subscription-only studies. Only seven studies were retained from the database searches, whereas 23 were identified through Google Scholar and citation searching; because these supplementary sources were searched iteratively and their yield was not recorded in the same structured way, this part of the search is less reproducible. Third, a considerable portion of the regional evidence is published in Indonesian national journals, conference proceedings, and theses with variable peer-review standards, some of which are not indexed in international databases and may have been missed. Finally, animal and human evidence was described from published reviews, so the evidence levels reported for these outcomes depend on the scope and completeness of those reviews. The findings should therefore be read as a structured map of the available evidence rather than an exhaustive or quantitative assessment.

CONCLUSION

This review mapped the evidence on nine coastal foods from the Riau Islands and showed that their potential differs in kind as well as in strength of evidence. In terms of nutritional value, gonggong, mangrove crab, sea cucumber, ikan biang, and ikan parang-parang are documented sources of protein, essential amino acids, and minerals, and some also provide long-chain omega-3 fatty acids; this contribution rests on established nutritional science. In terms of bioactive potential, stingless bee honey, gonggong, mangrove apple, brown seaweed, sea cucumber, and betel leaf have

shown antioxidant, antimicrobial, or related activities, mainly in vitro and often in extracts rather than in foods as consumed. In terms of clinical benefit, no food-level human evidence was identified within the scope of this review, and animal evidence was limited to a few commodities. These foods should therefore be regarded as nutritionally valuable and biologically promising candidates for functional-food development, not as clinically validated functional foods.

Future research should prioritize geographically specific characterization using standardized analytical methods, food safety and contaminant assessment, processing and bioavailability studies, product development, and appropriately designed human studies, beginning with the commodities whose evidence is most advanced. If supported by such evidence, integrating these foods with local food culture and sustainable coastal resource management could contribute to nutrition strategies for healthy aging and noncommunicable disease prevention in the Riau Islands.

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