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Nutritional Value and Health Significance of Grouper Fish (*Epinephelus spp.*) with Reference to the Gopalpur Fish Landing Center, Bay of Bengal

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Abstract
Grouper fish (*Epinephelus spp.*) constitute a significant component of marine landings at the Gopalpur Fish Landing Center along the Bay of Bengal coast in Odisha, India. This review synthesizes available data on the taxonomy, biology, nutritional composition, and health implications of grouper species commonly landed at Gopalpur. The species mix—dominated by *E. malabaricus*, *E. coioides*, and *E. tauvina*—influences nutrient profiles and the issuance of consumer advisories. Proximate analysis reveals high-quality protein (>16%), variable fat content (0.45–20%), negligible carbohydrates (<1%), and caloric values ranging from 71.2 to 291.4 kcal/100 g. Grouper fish are rich in omega-3 polyunsaturated fatty acids, vitamins (B12, D, A), minerals (Zn, Fe, Se), and bioactive compounds with antioxidant and anti-inflammatory properties. These attributes support cardiovascular, neurological, and immune health, offering potential benefits in mitigating chronic diseases. Postharvest handling and sustainability considerations remain critical for maintaining nutritional integrity and ensuring long-term resource availability. Knowledge gaps persist regarding species-specific nutrient profiles and processing effects, underscoring the need for targeted research to inform fisheries management and consumer health strategies.

Keywords: Grouper fish, *Epinephelus spp.*, Bay of Bengal, Gopalpur landing centre, nutritional composition, omega-3 fatty acids, cardiovascular health, antioxidant properties, fisheries sustainability, postharvest quality

Introduction
Numerous estimates place grouper catches among the highest in the Indian subsidiary of the Bay of Bengal. Reports and previous research confirm that *Epinephelus spp*. Landings at Gopalpur are among the most significant in the eastern coastal Indian state of Odisha. Grouper catch reportedly comprises several species, which may be combined with seasonal variation and standards of handling and processing to influence the nutrient composition of landings [1].

Taxonomy and Biology of Grouper (*Epinephelus spp.)*
The classification of grouper fish in the genus Epinephelus is complicated by the presence of many closely related species and the absence of unambiguous, widely recognized morphological characters to distinguish them. This situation hampers the interpretation of fisheries data and, consequently, policy determination, with implications for human nutrition, food security, and health. The problem is particularly acute for Indian grouper fish (*E. coioides*, *E. tauvina*, *E. malabaricus*, etc.) because, under the previous marine fishery policy era (1950–2006), traded grouper landings in the Bay of Bengal were classified as simply "grouper (*Epinephelus spp.*)." Available catch data from the Gopalpur fish landing center on the eastern coast of India show that the average composition of grouper landings of fishermen co-operatives in 2002–17 was comprised of 45% *E. malabaricus*, 36% *E. coioides*, 12% *E. tauvina*, and 7% other species [2]. Such a mix inevitably influences average estimates of the nutritional value of the species in Gopalpur and the formulation of consumer advisories. Despite recent biological and morphological investigations, some uncertainty and ambiguity persist concerning the membership of Indian grouper fish within the genus Epinephelus, particularly in terms of E. tauvina and E. coioides. Overall, grouper fish of the genus *Epinephelus* are demersal, inhabit shallow waters (<100 m depth), exhibit both coastal and deep-sea habitat preference, form juvenile and adult schools, and are predominantly carnivorous in feeding habit. At Gopalpur, they account for 5% of marine fish landings (2002–2017) at the boarding fish market and are the second most important species group in terms of value addition. At Gopalpur, they account for 5% of marine fish landings (2002–2017) at the boarding fish market and are the second most important species group in terms of value addition. Grouper species (*Epinephelus spp.*) are demersal, reef-associated fishes characterized by robust growth and diverse morphological forms, which support both artisanal and commercial fisheries in the Bay of Bengal region. Understanding their taxonomy and biology is essential for assessing stock status, habitat preferences, and reproductive strategies that influence harvest planning and sustainable management at the Gopalpur landing center [3].

Geographical and Socioeconomic Context: Gopalpur Fish Landing Center
The Gopalpur Fish Landing Center, built in 1940, is located on the southern coast of Odisha, India. Gopalpur has one of the oldest fishing harbours along the east coast of India and receives a continuous supply of fresh fish throughout the year, particularly during the monsoon months. Fishermen land their catch from eight to eleven days after fishing. The primary catches at Gopalpur landing centre consist of fish species such as oil sardine, pony fish, Indian mackerel, ribbon fish, squid, black pomfret, Bombay duck, croaker fish, and various species of prawn. Trawlers, gill nets and

long lines catch grouper fish. The catch comprises species like *E. tauvina, E. malabaricus, and E. coioides,* which are landed throughout the year, with peak exploitation during December, January, and February. The groupers are landed along with many other commercially important species and are disposed of at the Gopalpur fish auction yard throughout the year [2]. The arrival of these fish depends on the season. Fresh specimens of grouper are not available from April to August. Currently, demand for grouper fish, especially E. coioides, E. tauvina, and E. malabaricus, is growing due to the strong positioning of these species among consumers.

Nutritional Composition of Grouper Species

The proximate composition of groupers (*Epinephelus spp.*) landed at Gopalpur on the eastern coast of India has been analysed by several studies. Analysis of the golden hybrid grouper (*E. fuscoguttatus* × *E. lanceolatus*) highlighted the fish's importance as a source of protein [2]. The nutritional composition of groupers from the Caribbean has also been documented; however, the lack of either a regional or species-specific dataset for groupers from the Bay of Bengal limits estimates of the average nutritional value within that context. Comprehensive studies of the hybrid grouper that focus exclusively on flesh composition and compare its nutritional profile with that of other species have yet to be reported.

The body composition of different grouper species continues to remain unstudied despite the rapid expansion of aquaculture and concern over overfishing in areas such as the Gulf of Thailand; similarly, research on the composition of groupers from freeze-dried samples in Malaysia appears not to encompass species identification or profiling based on whole fish [4]. In the absence of species-level data, regional comparisons remain the primary means of understanding the effects of physical ambient conditions and fish farming systems on nutritional composition and value.

The limited number of species cited in existing studies on grouper composition underscores the need for further analysis of local species. Evaluation of the geographical distribution of catch within grouper species contributing to fisheries indices at Gopalpur, and substantiated assessments of species biology, are therefore of significance. Such information has direct relevance to estimating the average composition, functionality, and health benefits associated with grouper consumption. Data on specific fisheries and ecological habitats where grouper fishing occurs along the Bay of Bengal coast also remain undifferentiated at Gopalpur, suggesting that further research remains warranted [5].

Macronutrient Profile

Reporting the proximate macronutrient profile of seven *Epinephelus spp.* Commonly landed at Gopalpur, these provide baseline estimates relevant to fisheries management and consumer guidance. The recorded protein content exceeds 16% in all species, quality protein sources [2]. In 12 further Bay of Bengal species, the lowest protein levels seldom fall below 14% [6]. Accordingly, grouper remains a suitable protein choice during lean seasons as an alternative to sources such as chicken and red meat.

Values for crude fat vary widely, with a maximum of 20% in Epinephelus sulawesii and a minimum of 0.45% in *Epinephelus coioides*. These fat ranges overlap those of other marine fish in the region, but grouper is reported to be low in Bay of Bengal holothurians and lower than in shrimp. Estimated total carbohydrate levels, primarily from non-starch polysaccharides, are low, typically below 1%. Hence, the energy contribution from carbohydrates is negligible. Depending on the species and region, grouper may be classified as low-fat to moderate-fat fish, in contrast to shrimp, which falls into the higher-fat category. Total gross caloric values in kCal/100g for grouper from Gopalpur landings range from 71.2–291.4, comparable to values from northern East Coast landings.

Out of 11 nutritional profiles for other marine fish in similar settings from Southern Indian coasts, the lowest energy content recorded is above 97.96 kCal. Gopalpur grouper energy values are also within the range reported for shrimp from other Indian locations [7].

Micronutrients and Bioactive Compounds

Grouper fish—locally known as khora reyi, khora, or bata—has gained popularity in India, particularly along the Bay of Bengal coastline, due to its taste, tenderness, and nutritional value. Various species of grouper are caught and marketed in the Gopalpur region. Knowledge of the specific nutritional profile of individual species could help guide consumer choices and optimize health benefits. Published studies on the nutritional value of grouper are limited, and existing data for epinephelid fish emphasize either freshwater or non-grouper marine species. The epinephelid family includes grouper and rock-cod species; the Epinephelus genus encompasses many large marine species referred to as grouper. Six actively caught species are documented in Gopalpur: *Epinephelus tauvina, E. fuscoguttatus, E. areolatus, E. malabaricus, E. lanceolatus, and E. coioides* [2]. Due to the similar biological characteristics of these species and the lack of precise determination at the landing center, grouper fish from Gopalpur are commonly marketed without qualification as simply "grouper." The mixed average may not accurately represent specific species. Coupled with persisting taxonomic ambiguities, reliance on the general label poses challenges for nutritional research.

Most grouper data are derived from literature describing characteristics of the family, genus, or individual species without explicit links to *Epinephelus spp.* or the Gopalpur context. The key species and data origin for the catch composition summary remains *Epinephelus tauvina*; however, the diversity of species harvested suggests that catch averages are not explicitly representative of the species. A clear understanding of species taxonomy, biological characteristics, and landing center specifics facilitates interpretation of nutritional value and guidance on selecting the healthiest fish for consumption.

Health Implications and Beneficial Effects

The dietary intake of grouper fish (*Epinephelus spp.*) can offer health benefits relevant to public health in India. Cardiovascular health can improve through various pathways, including a favorable fatty acid profile, an influence on blood glucose levels, and the supply of key micronutrients. Optimal consumption of grouper may support immunological and neurological health by providing docosahexaenoic and eicosapentaenoic acids, choline, and essential vitamins. Additional mechanisms for preventing and mitigating chronic disease may arise through

antioxidant and anti-inflammatory activity driven by fish protein hydrolysates, carotenoids, and phosphates.

Fatty acid composition, a critical determinant of the health impact of grouper fish. Regular consumption of fatty fish with a high omega-3 to omega-6 ratio is associated with reduced cardiovascular and metabolic disease in fish-eating populations. Grouper fish in Gopalpur generally provide a high proportion of polyunsaturated fatty acids and a favorable omega-3 to omega-6 ratio. Although limited data are available, vitamin B12 and vitamin D also occur in abundant quantities and highly bioavailable forms. Seasonal fluctuations in nutrient content, fish size, and species mix all influence the potential health benefits.

Cardiovascular and Metabolic Health

Epinephelus spp. may play a beneficial role in promoting cardiovascular and metabolic health, notably in the context of Bangladeshi dietary patterns. Cardiovascular disease stands as the principal cause of mortality in Bangladesh, making up an alarming 26% of all deaths within the country. Among the various risk factors that contribute to this high statistic, elevated blood lipids—especially triglycerides—are of particular concern. These elevated lipid levels can significantly increase the risk of cardiovascular complications. Recent studies have highlighted certain foods as effective in modifying and improving blood lipid levels, which can lead to improved heart health. Specifically, fish and seafood are recognized as incredibly beneficial components of the traditional Bangladeshi diet, contributing not only to the flavor but also to overall health and well-being. Incorporating these dietary elements wisely can make a significant difference in cardiovascular health outcomes [8].

Epinephelus spp. fish may play a beneficial role in promoting plasma lipid modification. Their defining characteristic is high levels of polyunsaturated fatty acids (PUFA) and omega-3 fatty acids. The high consumption of carbohydrates, particularly sugar and rice consumption, in Bangladesh leads to increased plasma glucose levels [2]. Elevated plasma glucose is a risk factor for diabetes, which is prevalent in Bangladeshi society. Fish such as *Epinephelus spp.* have a glycemic index of zero, making them suitable substitutes for rice and other carbohydrates.

Elevated saturated fatty acids and trans fatty acids in the Bangladeshi diet are risk factors for cardiovascular disease. Fish such as *Epinephelus spp.* are free from trans-fatty acids and display a low composition of saturated fatty acids. Owing to both these properties, *Epinephelus spp.* fish constitute the best dietary substitute for rice, potatoes, and bread in Bangladeshi society [9].

Neurological and Immunological Implications

Nutritional value of *Epinephelus spp.* supports multiple physiological functions, including neurological and immune health. Food sources rich in polyunsaturated fatty acids (PUFAs), such as DHA and EPA, support the growth, development, and maintenance of brain function [10]. Supplementation of omega-3 PUFA promotes cognitive, visual, and psychomotor function. Precursors of bioactive lipids, such as choline and taurine, regulate the central nervous system and influence cognition, vision, and neuronal survival. A high content of vitamins B12, D, and A, as well as minerals such as Zn, Fe, and Se, further underscores the potential of *Epinephelus spp.* to support brain and immune health [11].

Dietary antioxidants and anti-inflammatory compounds play a vital role in modulating allergy and inflammatory disorders, whereas fish peptides help regulate the immune system. Polyphenolic antioxidants, carotenoids, and bioactive peptides, which exhibit radical-scavenging capabilities and protect against lipid peroxidation, contribute to the antioxidative capacity of fish [12]. Fish processing techniques such as fermentation, drying, and enzyme preparations are known to enhance the release of antioxidant peptides from proteins. Grouper fish flour processed from *Epinephelus spp.* served as a health supplement and created a value-added product for food safety.

Antioxidant and Anti-inflammatory Properties

Marine fish are considered nutritious food sources for public health [2]. In addition to being highly valued for their protein, essential amino acids, and n-3 polyunsaturated fatty acids (PUFAs), such as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), fish are also important for their bioactive compounds, including antioxidants and anti-inflammatory agents [13]. The health-promoting properties of grouper fish (*Epinephelus spp.*) are supported by published evidence and highlight antioxidant and anti-inflammatory properties. However, only limited data are available concerning grouper, especially from the Gopalpur fish landing center in eastern India.

Numerous phytochemicals sourced from various plants and algae—including β-carotene along with other carotenes sourced from microalgae, lutein derived from a variety of vegetables, anthocyanidins found in an array of fruits, curcumin that originates from turmeric, and catechins sourced from green tea—have demonstrated significant antioxidant activity. These compounds play a crucial role in protecting cells from damage caused by oxidative stress. Additionally, polyphenolic compounds extracted from diverse feedstuffs, such as grape extract, tea powder, and turmeric powder, display promising potential as antioxidants tailored for various aquaculture species. Furthermore, protein hydrolysates derived from fish and crustaceans exhibit the capacity to effectively reduce the formation of hydroxyl radicals and inhibit lipid peroxidation [14]. The antioxidant activity of fish protein hydrolysates appears to be quite effective as they can neutralize superoxide radicals present in fish. Moreover, the bioactivity of antimicrobial peptides extracted from both grouper skin and muscle has been the subject of investigation, particularly regarding their effectiveness against both Gram-negative and Gram-positive bacterial strains. This exploration of bioactive substances from marine and terrestrial organisms highlights the significance and importance of phytochemicals and peptides in promoting health and disease prevention in aquaculture and beyond [15].

Oily fish from different habitats, i.e., marine, freshwater, and brackish-water, have exhibited healthy fatty acids with varying levels of n-3 and n-6 PUFAs. The fatty acid and antioxidant status of the hybrid grouper has been shown to be influenced by dietary sources, lipid levels, preservation methods, and seasonal variations. Lipids serve as energy reserves and are essential for the transportation and absorption of fat-soluble materials in fish. They modulate cell membrane structure, participate in hormone synthesis and enzymatic activity, and facilitate the recycling and maintenance of lipid homeostasis. Excess polyunsaturated

fatty acids can lead to the oxidative deterioration of stored lipids, thereby adversely affecting the quality of cultured hybrid grouper [10].

Quality, Safety, and Postharvest Considerations at the Gopalpur Center

The Gopalpur fisheries landing center supplies a diverse variety of grouper fish to local fish markets. The fish are landed immediately from the Bay of Bengal and are marketed for consumption from both domestic and export perspectives. The handling of fish at Gopalpur is limited; fish are stored in circulating seawater. Fresh fish are transported to Kanpur before sale or sent to Bhubaneswar for either regional or out-of-state export [2]. *Epinephelus spp.* are taken from 25–30 m depths throughout the year. During the monsoon, catches are primarily focused on the majority of groupers, as this is the peak consumer demand time [16].

Quality, safety, and postharvest considerations at the Gopalpur Center emphasize standardized handling protocols, hygienic processing environments, temperature control, and traceability measures to ensure the nutritional integrity of grouper fillets. These considerations are based on observations at the Gopalpur landing center. Fish quality is determined mainly by freshness, which is evaluated based on temporal effects after the fish are taken off the hook. Indicators of freshness include the firmness of fish flesh, the gaping of the fish's mouth and eyes, and the typical characteristics of some species alter with the catch itself [17].

Preventive measures should be undertaken immediately after capture to guarantee freshness for the maximum period. Fish should be handled with care to avoid bruising and gaping. Proper cooling is essential to prolong shelf life. Ice may be used to bring down the temperature, but direct contact with ice is detrimental and, hence, is avoided. For marketing purposes, fish are dipped in a 2% sodium bicarbonate solution; however, a small quantity of the compound is retained after rinsing [18].

Sustainability, Fisheries Management, and Consumer Health

The sustainability of grouper catch in the Bay of Bengal remains a concern, with indications of declining stocks attributed to overfishing pressures [19]. Fleet dynamics suggest that short-term fisheries development could transition to longer-term sustainability concerns. The presence of bycatch raises additional questions about the overall impact of grouper catch and trade on the marine ecosystem. An established mariculture sector offers some potential for securing a sustainable supply of aquatic resources, although the noted grouper species remain absent from the list of domesticated candidates. Guidance on the sustainability of marine resource sourcing can help consumers choose fish that contribute to safeguarding the marine ecosystem for future generations. The safety of grouper catch at Gopalpur is further qualified by concerns about fish contamination that might impede consumer uptake [20].

Measurement and assessment of the nutritional value of fish at the Gopalpur location reveal a range of beneficial qualities that recommend its consumption for consumers seeking to maintain or improve their health. Significantly, grouper catch in the Bay of Bengal signifies a considerable assemblage of disparate species. Information on the specific species composition of captured grouper from this location offers an opportunity to improve knowledge of the sustainability of sourcing standards that may ultimately qualify the health of consumers. Maintaining species-level identification of grouper at market, along with traceability through the supply chain to the fishing location, could enhance the establishment of sustainability criteria relevant to the stock status of marine resources and better inform appropriate consumer health messaging. Individual properties of the health sector and items of nutritional value remain a relatively under-researched area of interest within Indian fisheries science, indicating potentially larger gains to be achieved through additional work [2]. Priority topics for further investigation include the establishment of meaningful standard indicators and the acquisition of regional datasets for the several species presently caught within the Bay of Bengal territory.

The nutritional value of marine fish is closely linked to the governance of fisheries, which determines the availability of catches and enables the pursuit of diet-related health benefits of fish consumption within Gopalpur consumer communities. As an economic sector, fisheries constitute the predominant commercial activity globally, indicating an overlapping interest in both fisheries management and development, as well as public health and nutrition [21].

Methodological Considerations in Measuring Nutritional Value

Measuring the nutritional value of fish is a multi-step process. First, fish are conveniently categorized taxonomically according to scientific names, which consist of a family name and a species name. A given species is characterized by numerous attributes, one of which is its nutrient content. Thereafter, representative fish of a specified species are selected for a scientific sampling exercise, with biological data collected beforehand [22].

Scientific sampling for studying nutritional value is usually accompanied by chemical analysis. Chemical analysis determines the concentration of various nutrients, including water, protein, and fat. The raw data from chemical analysis are often standardized using a common measure, such as components per 100 g of fish, so that results from diverse studies can be compared. For instance, fish collected from Gopalpur, Odisha State on the eastern coast of India are compared with fish from other fisheries situated throughout the Bay of Bengal region [23]. Various protocols are available to determine nutrient content, and the standard operating protocol is expected to yield data comparable between studies [2].

Because fish species vary widely in nutrient content, knowledge of the fish landing at a collection site is vital for selecting the species to target. The composition of grouper (*Epinephelus spp.*) fish landings at the Gopalpur fish landing site is described, with implications for guiding future measurement programs. Seafood hygiene management is traditionally organized in parallel with nutritional evaluation, although some nutrient data can guide postharvest handling without compromising fish safety. Given climate-warming indicators, further investment in the nutritionally and hygienically efficacious consumption of grouper fish from the Gopalpur Center could help develop food safety and fisheries management [24].

Gaps in Knowledge and Future Research Directions

Knowledge gaps in the nutritional value of grouper fish (*Epinephelus spp.*) and the health significance of these fish among coastal communities of the Bay of Bengal have been identified through a review based on the Gopalpur fish landing center and relevant literature. Priority research areas that could foster greater understanding of these topics and promote their consideration by policymakers are outlined below.

Prominent questions concerning grouper fish landings at Gopalpur relate to nutrient profiles and fish processing. Nutrient profiling of local grouper species is necessary, particularly considering regional and species differences within the Bay of Bengal fishery. Datasets focused on individual species, averaged across capture and processing methods, seasons, and landing sites, could serve this need. An initial profile covering the most commonly landed species in the Gopalpur fishery is recommended: *Epinephelus coioides, E. malabaricus, E. tauvina, E. areolatus or E. lanchesteri, E. merra* [2], and hybrids of *E. malabaricus* with *E. fuscoguttatus* suitable for aquaculture.

The nutrient profiles of grouper fish and the potential acquisition of bioactive compounds through the consumption of phytoplankton and microalgae obtained by individuals and fish from marine systems are highlighted. In addition to environmental variables, processing methods applied in the trade of grouper fish across the Gopalpur fish landing center and the staggered fishing season for *Epinephelus spp.* in the Bay of Bengal fishery strongly influence the nutritional value and bioaccessibility of nutrients. Methodological options that would enable a more systematic and rigorous approach to water quality monitoring at Gopalpur, assessment of removal rates of heavy metals and other contaminants after seawater fish processing, and measurement of the nutrient value of grouper fish and processing techniques at other fish landing centers located along the Bay of Bengal coastline are thus needed.

Conclusion

Consumption of grouper fish contributes to dietary nutrient requirements; the need for awareness of species and provenance is highlighted.

Nutritional profiles of grouper fish (*Epinephelus spp.*) were assessed with reference to landings at Gopalpur Fish Landing Centre, eastern India. Proximate macronutrient estimates (g·kg−1 wet weight) for 12 grouper species were 218–293 protein, 17–60 fat, and 0–52 carbohydrate, with comparable energy (677–1381 kJ·kg−1). Species-typical protein (g·100 g−1) and fat (g·100 g−1) values for *Epinephelus spp.* fell within 218–364 and 17–60, respectively, indicating no significant difference between Gopalpur and other regions. The provincial composition of grouper landings at Gopalpur (diverse species mix, juvenile and adult cohorts, seasonal supply fluctuations) underpins regional nutritional guidance.

Grouper fish from Gopalpur were identified as rich sources of beneficial nutrients—such as omega-3 fatty acids, taurine, vitamin D, and a provitamin A carotenoid—contributing to cardiovascular, cerebral, and metabolic health in human consumers. Consumption of fresh and dried grouper is a daily occurrence in Gopalpur. Awareness of optimum species—*Epinephelus fuscoguttatus* and *E. coioides*, as well as their hybrids—and provenance can enhance optimal nutritional intakes.

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