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Nutrient composition of dried marine small fish in Bangladesh and their potential to address hidden hunger☆

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ABSTRACT

This study investigates the nutrient composition of fish powder intended for direct consumption, sourced from seven small fish species indigenous to the Bay of Bengal, Bangladesh. Locally known as chapila, chewa, faissa, ichre, loittya, mola, and olua, these fish were collected, dried to a moisture content consistent with local practices, pulverized, and subjected to analysis for proximate composition, mineral content, vitamin levels, heavy metal presence, and fatty acid profile. While the dried fish samples exhibited high nutritional quality, significant variations were observed among species for each nutrient analyzed. Consequently, no single species emerged as superior when considering all nutritional factors collectively. However, consuming 10 g of dried small fish powder sourced from the analyzed species could potentially fulfill 100% of the recommended nutrient intake (RNI) for protein, calcium, selenium, and vitamin B12 among children aged 6–23 months. Moreover, its serves as a significant source of these nutrients for pregnant or lactating women. Importantly, this intake level does not pose any risk associated with mercury or cadmium content. These findings hold promise as a valuable addition to the national food composition table, offering insights into the utilization of dried small fish from marine sources as a potent tool in the fight against malnutrition.

1. Introduction

In low- and lower middle-income countries, such as Bangladesh, multiple forms of malnutrition co-exist indicating the emergence of double and triple burden of malnutrition. This complexity can hinder the effectiveness of nutrition-specific interventions. Malnutrition encompasses undernutrition, overweight and obesity, with undernutrition manifesting as stunting (low height for age), wasting (low weight for height) and micronutrient deficiency (hidden hunger). Hidden hunger (iron, zinc, iodine, vitamin A, vitamin B12, folic acid) can occur even without a deficit energy intake. To combat hidden hunger, food-based solutions, such as incorporating foods rich in essential micronutrients, are recognized as effective measures to reduce reliance on methods like fortification and supplementation (Akhtar et al., 2013). Despite being a rich source of various micronutrients, the potential contribution of fish and fish products to alleviating hidden hunger is often overlooked (Béné et al., 2015). Recently, the global prevalence of deficiency in at least one of three micronutrients has been estimated to be 56% (Stevens et al., 2022). In Bangladesh, the latest available data from 2011, indicate that the prevalence of iron, zinc and vitamin A deficiency in children aged 6–59 months is 11, 32 and 15%, respectively. Moreover, 52% of children in this age group are reported to have a deficiency in at least one of these

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three micronutrients (Stevens et al., 2022).

In Bangladesh, as a riverine country, total fish production, from both marine and inland sources, has shown a consistent upward trend over the past two decades (DoF, 2017; Shamsuzzaman et al., 2020). The fisheries sector now contributes to more than a quarter of the agricultural gross domestic production (DoF, 2019). Approximately 15% of total fisheries production is derived from marine fisheries, covering an area of about 118,813 km^2, including the 200 nautical miles of the exclusive economic zone (EEZ) from the coastline of the Bay of Bengal (DoF, 2017; DoF, 2019). As estimated by different researchers, the total number of marine fish species in Bangladesh water body ranges from 475 to 740 (Islam, 2003; Habib & Islam, 2020). According to the Department of Fisheries (DoF), Ministry of Fisheries and Livestock, Government of Bangladesh, 0.588 million fishers are engaged in fish capture activities in the coastal region, thereby supporting their livelihoods (DoF, 2022).

Fish consumption in Bangladesh has progressively risen, with fish contributing to two-third of the total animal protein consumption (Belton et al., 2011). Household data provided by the Bangladesh Bureau of Statistics (BBS) reveal that, in terms of daily intake, fish (62.6 g per capita per day) ranks as the third-most consumed food, following starches (471.3 g per capita per day) and vegetables (167.3 g per capita per day). Fish consumption covers approximately 60% of total annual animal protein intake (BBS, 2017). Despite its high dietary importance, there is a notable lack of analytical data regarding the nutrient composition of small indigenous fish species. For instance, the food composition table of Bangladesh only provides nutrient composition for 15 marine fish species (Shaheen et al., 2013). Values of 8 minerals and 9 vitamins are included, yet crucial nutrients such as iodine and essential fatty acids are missing (Shaheen et al., 2013).

Fish is often considered as a homogenous food category, yet its nutrient composition can vary significantly across different species. For instance, iron content (per 100 g raw edible part) of some small indigenous fish in Bangladesh has been observed to range from 0.46 to 19.0 mg, while the zinc content varies from 0.60 to 4.7 mg (Bogard et al., 2015). An analysis of a potential promotion program for mola carplet (*Amblypharyngodon mola*) intake demonstrated its cost-effectiveness in alleviating the burden of micronutrient malnutrition in Bangladesh (Fiedler et al., 2016).

Small fish, whether consumed whole or as fish powder, represent an undervalued resource, with drying being a widely adapted method for their preservation (Bavinck et al., 2023). Currently, the Bangladeshi food composition table only includes values for three types of dried small fish, with values on important micronutrients lacking. Before advocating for small fish as safe and nutritious solutions to address hidden hunger, comprehensive analytical data is imperative.

The objective of this study is to provide novel analytical data on nutrient composition and heavy metals present in seven dried fish species. Additionally, it aims to assess the nutrient composition and the concentration of heavy metals of these fish as potential food sources for vulnerable groups.

2. Material and methods

2.1. Sample collection

A total of seven fish species considered low-valued fish and mostly destined to feed ingredients in the fish and cattle industry were purchased directly from the fish landing centers. Among these fish species, *loittya* (Bombay duck, *Harpadon nehereus*) is captured for commercial purposes whereas *chapila* (sardine, *Sardinella longiceps*), *chewa* (bearded worm goby, *Pseudapocryptes elongatus*), *faissa* (thryssa, *Thryssa dussumieri*), *ichre* (Indian anchovy, *Spratelloides gracilis*), *mola* (white sardine, *Escualosa thoracata*) and *olua* (Anchovy, *Coilia dussumieri*) are considered trash fish. All the fish species are consumed in both cooked, raw and dried form. However, *loittya* and *chewa* are more popular in dried form. Except for *loittya*, the other six fish have poor commercial value and are mainly consumed by local coastal people of Bangladesh who are socio-economically and nutritionally vulnerable. The species were verified using protocols describing taxonomic characteristics.

The sampling sites were selected depending on the availability of the species in maximum fresh condition and drying facility by the USAID-funded ECOFISH II project beneficiaries. The samples were collected by the project staff (researchers) to ensure the target species. For each species, at least 5 kg of raw fish was dried to get at least 1 kg of dried fish samples. *Chewa* (*Pseudapocryptes elongatus*) was collected from Nijhum Dwip, Hatiya, Noakhali, while all the other species were collected from Sonarpara Fish Landing Center, Ukhiya, Cox's Bazar whereas (Fig. 1). The average length, weight, habitat (pelagic and/or demersal), local availability, and price of fish samples is presented in Table 1. The purchased fish were transported immediately in insulated ice boxes (KYL52, Keyang, China) by maintaining a 1:1 ratio of ice to fish to the project beneficiary's house adjacent to the landing center. All procedures performed in this study were approved by the ethical research committee of Noakhali Science and Technology University. After collecting the fresh catch, the fish were immediately washed with fresh water and kept in refrigerator overnight before further processing.

2.2. Drying and processing

We followed an improved traditional method to dry the collected fish. Fish samples were thoroughly washed with potable water to remove dirt, sand, and other foreign materials (if any). Viscera were removed from all species except *mola* using a clean worktable with a sharp sterilised knife. The cleaned fishes were dried by spreading on a bamboo made platform by exposing to direct sunlight for 3 days from 07:00 am to 05:00 pm (with an area of 12×6 square feet or 6.69 m^2 and 4 feet or 1.22 m above the ground). The average day temperature varied from 25 to 30 °C. While drying, the platform was covered by a mosquito net to avoid insects' infestations (e.g., flies) and animal attacks (e.g., birds). Fish were turned over at every two-hours intervals for homogenous drying. Finally, the dried fish samples were packed with paper and then polythene for transporting to the Nutrition Lab of the Department of Fisheries and Marine Science at Noakhali Science and Technology University. After receiving the fish samples in the laboratory, the samples were kept at 65 °C in an electrical oven (VZLG-9620, EJER TECH, China) for 18 hours to keep samples dry. We carried out this additional step to make it simpler to ground for subsequent processing. In the dry fish industry, fish is typically packaged after being sun-dried. At least one kilogram of whole dried fish from each species was ground using an electric grinder (Chef Pro-MG 128, Preethi, India) for ease of shipment in the laboratory and to obtain the most representative samples possible. To prepare fish powder, the ground components were then sieved into a fine powder (500-micron mesh). The ground powder was packaged with high density polyethylene and stored at 4 ºC. The flow chart of sample collection, processing, and powder preparation is presented in Fig. S1.

2.3. Chemical analysis

The fish powder was put into airtight packets, sent to the laboratories at the Institute of Marine Research (IMR), Norway, and stored at minus 80 °C pending analyses. The detailed description of the chemical analysis (except from analyses of vitamin B_{12}), instruments, measurement range and uncertainty, and overview of certified reference material used, is described in Reksten et al. (2020a). Chemical analyses were performed at the IMR laboratories using methods accredited to ISO 17025:2005, except for iron which is validated but not accredited.

2.3.1. Proximate analysis

The energy expressed in kilojoules (kJ) was measured in one gram of freeze-dried sample using an Automatic Isoperibol Calorimeter (Parr Calorimeter 6400, Moline, IL, USA). Dry matter was determined by

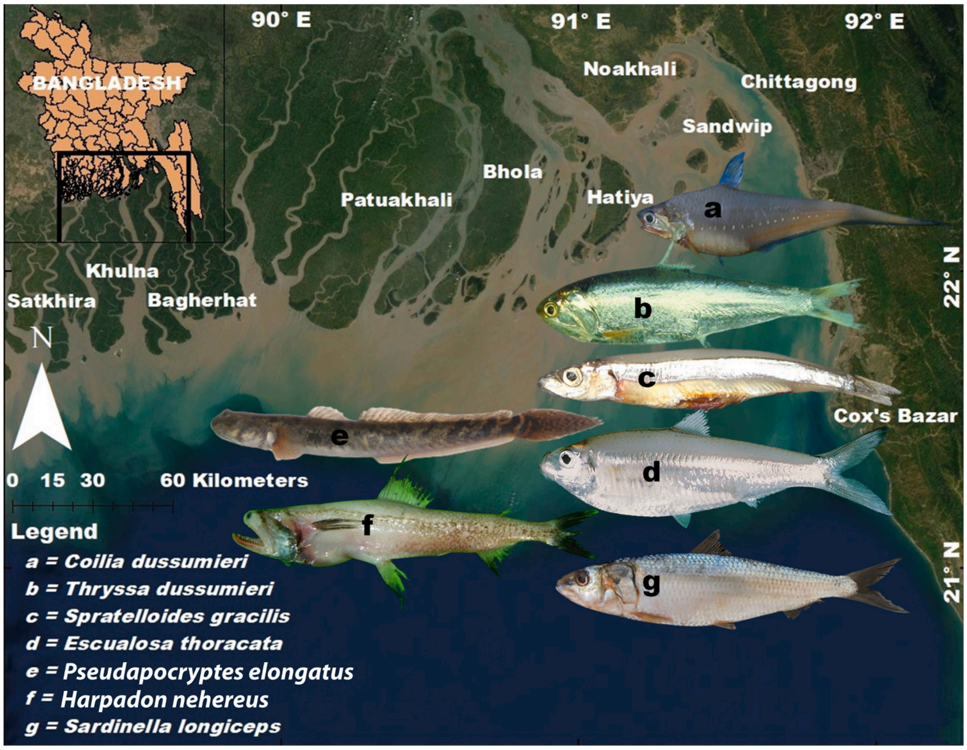

Fig. 1. Map of Bangladesh and small fish species included in the study.

Table 1
Overview of species sampled.

Scientific names	English names	Local names	Habitats	Length[a] (cm)	Weight[a] (g)	Weight of 1000 g raw fish after drying[b] (g)	Local availability[c]	Approximate price per kg in BDT (USD)[d]
Sardinella longiceps	Sardine	*Chapila*	Pelagic	15.0 ± 1.2	29.7 ± 6.5	318 ± 10	High	100–150 (1.0–1.5)
Pseudapocryptes elongatus	Bearded worm goby	*Chewa*	Demersal	23.0 ± 12.2	21.2 ± 4.8	477 ± 19	High	80–120 (0.8–1.2)
Thryssa dussumieri	Thryssa	*Faissa*	Pelagic	12.2 ± 1.1	17.1 ± 4.7	322 ± 14	High	100–120 (1.0–1.2)
Spratelloides gracilis	Indian anchovy	*Ichre*	Pelagic	3.15 ± 0.22	1.90 ± 0.44	472 ± 20	Low	200–220 (2.0–2.2)
Harpadon nehereus	Bombay duck	*Loittya*	Demersal	21.6 ± 4.8	77.4 ± 28.1	417 ± 10	High	120–150 (1.2–1.5)
Escualosa thoracata	White sardine	*Mola*	Pelagic	6.90 ± 1.10	4.15 ± 1.73	367 ± 27	Moderate	250–350 (2.4–3.4)
Coilia dussumieri	Anchovy	*Olua*	Pelagic	11.7 ± 0.9	9.00 ± 2.36	476 ± 10	High	100–120 (1.07–1.2)

Values are presented as mean ± SD, otherwise indicated
[a] Length and weight were calculated from 20 *olua*, 20 *faissa*, 20 *ichre*, 20 *mola*, 39 *chewa*, 30 *loittya*, and 20 *chapila* samples
[b] Mean ± SD are calculated from three readings
[c] Chewa is not available in Cox's bazar but available in Nijhum Dwip marine protected area (MPA); other species are available in Cox's bazar
[d] Approximate price was collected during the period of December to February 2022, and the conversion of Bangladeshi Taka (BDT) to USD was based on the exchange rate (1 USD= 100 BDT) on 6th October 2022

placing a 1 g sample in an electric drying oven (Termaks TS 8056, Houm, Oslo, Norway) at 105 °C overnight. Crude fat was detected by weighing the solvent after extracting using 30 ml isopropanol (VWR International A.S., Oslo, Norway) in ethyl acetate (technical grade, VWR International A.S., Oslo, Norway). The method is based on a Norwegian Standard 9402 (Norsk Standard Norwegian Standard, 9402., 1994). Crude protein was calculated from total nitrogen which was determined by burning the sample in pure oxygen gas (quality 5.0, Nippon Gases Norway, Bergen, Norway) in a combustion tube (Leco Corporation Svenska AB, Saint Joseph, MI, USA). Nitrogen was detected with a thermal conductivity detector (Leco FP 628 Nitrogen Determinator, Leco Corporation Svenska AB, Sain Joseph, MI, USA) and the content of nitrogen was calculated from an estimated average of 16% nitrogen per 100 g protein. The following formula was used: g nitrogen/100 g x 6.25 = g protein/100 g, in accordance with the method accredited by the Association of Official Agricultural Chemists (AOAC) (AOAC, 1995). Analysis of ash content was performed according to the Nordic Committee on Food Analysis (NMKL) Method 23.3 using a Thermolyne F30430 oven (ThermoFisher Scientific Inc, Oslo, Norway).

2.3.2. Fatty acid composition

For analysis of fatty acids, lipids from the samples were extracted according to Folch et al. (1957). After filtering, the remaining samples were saponified with 0.5 M NaOH p.a. (VWR International A.S., Oslo, Norway) and methylated using 12% boron trifluoride (VWR International A.S., Oslo, Norway) in 20% methanol (Optima™ LC/MS Grade, Fischer Scientific Inc, Oslo, Norway) at 100°C. After cooling the solution, the methyl ester was extracted with hexane (VWR International A. S., Oslo, Norway). The fatty acid composition of total lipids was analyzed using Bruker Scion 436 GC (Bruker, Oslo, Norway) with Bruker flame ionization detector and programmable temperature vaporizer injector (Bruker, Oslo, Norway) as previously described by Lie & Lambertsen (1991), and Torstensen et al. (2004).

2.3.3. Vitamins

For analysis of vitamin A_1 (sum of all trans-retinol and 13-, 11-, 9 cis retinol) and A_2 (3,4 didehydro-all-trans-retinol), sample were mixed with ethanol (VWR International A.S., Oslo, Norway), pyrogallon (Merck KGaA, Darmstadt, Germany), ascorbic acid (Merck Life Science Limited/Sigma-Aldrich Ireland Ltd.), saturated ethylenediaminetetraacetic acid (EDTA) (Leco Corporation Svenska AB, Sain Joseph, MI, USA) and KoH. The solution was saponified in a block-heater and distilled water and n-hexane (VWR International A.S., Oslo, Norway) were added after cooling and thereafter centrifuged. The hexane phase was evaporated to dryness, added n-hexane (VWR International A.S., Oslo, Norway) and analyzed using a high-performance liquid chromatography (HPLC, Agilent Technologies 1260, Agilent Technologies Inc, Santa Clara, CA, USA). All samples were integrated using Chromeleon$^{(R)}$ software where the content of vitamin A_1 was calculated by external calibration (standard curve) and the content of vitamin A_2 was calculated based on the external calibration curve for all-trans-retinol multiplied by a correction factor. The method is based on a method previously described by the Comitè Europèen de Normalisation (CEN, 2000a). Vitamin B_{12} was analyzed using UHPLC (Thermo Fisher Ultimate 3000 with a quaternary pump, automatic sample injector, diode array detector, degassing system and Chromeleon integration software, ThermoFisher Scientific, Waltham, MA, USA). The vitamin B_{12} peak is identified by comparing it with the retention time and UV spectrum of the standard. The limit of detection and limit of quantification are 0.001 mg/kg and 0.004 mg/kg, respectively (1 g sample). The majority of matrices analyzed were within the trueness requirements of 80–120%. For analysis of vitamin D_3 (cholecalciferol), samples were mixed with ethanol, internal standard (ergocalciferol, 0.5 µl/ml, art. No. 95220, (Merck Life Science Limited/Sigma-Aldrich Ireland Ltd.), pyrogallon (Merck KGaA, Darmstadt, Germany), ascorbic acid (Merck Life Science Limited/Sigma-Aldrich Ireland Ltd.) and KOH, and saponified in a block heater. Distilled water and n-hexane were added after cooling and the solution was centrifuged. The hexane phase was washed with distilled water and added iso-propanol before evaporation to dryness. N-hexane (VWR International A.S., Oslo, Norway) was added, and vitamin D was determined by a method based on standards developed by CEN (2009), using HPLC (reverse phase) and UV detector at 265 nm (HPLC LaChrom Merck HITACHI system, Tokyo, Japan). For analysis of vitamin E (α-, β-, γ -, and δ-tocopherol and α-, β-, γ -, and δ-tocotrienol), samples were mixed with ethanol, pyrogallon (Merck KGaA, Darmstadt, Germany), ascorbic acid (Merck Life Science Limited/Sigma-Aldrich Ireland Ltd.), saturated EDTA (Leco Corporation Svenska AB, Sain Joseph, MI, USA) and KOH, and saponified in a block heater. Distilled water and n-hexane/ethyl acetate were added after cooling and the solution was centrifuged. The hexane phase was evaporation to dryness. N-hexane (VWR International A.S., Oslo, Norway) was added, and vitamin E was analyzed using HPLC and fluorescence detector (HPLC UltiMate3000 system, Thermo Fisher Scientific, Waltham, MA, USA). The method is based on standards developed by CEN (CEN, 2000b).

2.3.4. Minerals and trace elements

The concentration of all elements except for iodine, were determined by inductively coupled plasma-mass spectrometry (ICP-MS, Thermo iCapQ with collision cell and FAST autosampler, ThermoFisher Scientific, Waltham, MA, USA) equipped with an auto-sampler after wet digestion in a microwave oven (UltraWawe and UltraClave with corresponding digestion tubes and sample racks, Milestone Srl, Sorisole, Italy) as described by Julshamn et al. (2007). For the determination of iodine, the sample preparation is a basic extraction with tetramethylammonium hydroxide (TMAH 25%, FJUIFILM Wako Chemicals Europe GMBH, Neuss, Germany) before ICP-MS analysis (Thermo iCapQ with collision cell and FAST auto sampler, ThermoFisher Scientific, Waltham, MA, USA). Internal standards are used for correcting drift in the selected mass range. Gold (Spectroscan, Teknolab Sorbent, Ski, Norway) is used to stabilize the mercury ions. For iodine tellurium (NIST, National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg, USA) was used as the internal standard, Julshamn et al. (2001).

2.4. Evaluation of heavy metal intake

The concentrations of chemical contaminants were compared with EU legislation on maximum permissible levels and provisional tolerable intake established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). The maximum permissible levels for cadmium (Cd) in muscle tissue is 0.05 mg/kg wet weight, for methylmercury (Hg) 0.5 mg Hg/kg wet weight and for lead 0.3 mg/kg wet weight (European Union, Commission Regulation (EC) No 1881/2006). The established provisional tolerable weekly intake (PTWI) level for mercury is 1.6 µg/kg body weight (JECFA Joint FAO/WHO Expert Committee on Food Additives., 2010), and the provisional tolerable monthly intake (PTMI) level of cadmium is 25 µg/kg body weight (JECFA Joint FAO/WHO Expert Committee on Food Additives., 2006). For lead (Pb), PTWI (0.025 mg/kg body weight) was withdrawn by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) in 2010 due to no longer being considered health-protective. To calculate PTWI for mercury and PTMI for cadmium, we used the 3rd percentile for 6-months-old girls from WHO Child Growth Standards for weight for age (WHO, 2023).

2.5. Potential contribution to address malnutrition

To assess the potential contribution of dried fish as a micronutrient source, we focused on eight nutrients based on national and global public health concerns and the nutritional importance of marine fish. These nutrients are protein, iron, zinc, calcium, selenium, iodine, vitamin B_{12}, and DHA.

For each of the eight nutrients, we compared the nutrient content of the fish species to the daily recommended nutrient intake (RNI) for pregnant and lactating women (PLW), infants 6–11 months old, and children 12–23 months old. We used a daily serving size of 10 g of fish powder (Byrd et al., 2021). The RNI for iron for pregnant women was estimated based on the FAO/WHO (2004) value for women aged 19–50 years old (10% bioavailability), as no specific value for pregnant women is given. The RNI for protein for children 12–23 months old and for pregnant and lactating women (PLW) were directly received from the Indian Council of Medical Research (ICMR, 2011); however, the ICMR does not directly provide the RNI for protein for infants from 6 months until 12 months old. Because of this, we considered the median body weight of boys and girls at 9 months of age, which is the average and median value between 6 and 12 months, and then calculated the average standard body weight (De Onis et al., 2006). The standard body weight was then multiplied by 1.69 to obtain the recommended daily protein intake (ICMR, 2011). For zinc, moderate bioavailability was assumed (FAO/WHO, 2004). We calculated the daily zinc requirement by averaging the requirement across the three trimesters of pregnancy and the first 12 months of lactation, using a value of 7.5 mg for pregnancy and 8.5 mg for lactation. For calcium, selenium, iodine, and vitamin B_{12}, the FAO/WHO (2004) recommendation was followed. Finally, FAO recommends a daily intake of DHA of 200 mg/d for pregnant and lactating women, while the adequate daily intake for children 6–23 months old is estimated at 10–12 mg per kg body weight per day (FAO, 2010).

Following Bogard et al. (2015), however, we used a daily intake of 110 mg of DHA for children 6–23 months old. Note that this is the midpoint of the recommended range of DHA intakes based on the respective weights of children at 7 months and 23 months of age at the 50th percentile (De Onis et al., 2006). Detailed calculation regarding how one serving of the fish powder could contribute to meeting the requirements of protein, iron, zinc, calcium, selenium, iodine, and vitamin B_{12} for children and women is provided in Table S1.

2.6. Statistical analysis

The descriptive statistics of the data are reported as the mean values together with the standard deviation, which were computed using Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA). Every sample was examined three times for each nutrient. Consequently, we possess three values for every fish species pertaining to each nutrient, unless otherwise specified. Significant differences among the fish species were evaluated using one-way analysis of variance (ANOVA) and Tukey's HSD post-hoc test. The statistical analyses were conducted using IBM SPSS Statistics Version 26 (IBM Corporation, New Orchard Road, Armonk, NY 10504–1722, United States). Data is consistently reported based on a wet weight (WW) basis of 100 g (nutrients) or per kg (heavy metals); however, to assess the recommended nutrient intake (RNI), a portion size of 10 g of dried fish was considered. Wet weight is in this context dried fish powder with a dryness similiar to what a local small-scale producer would be able to achive (approximately 10%, see Table 2 for exact numbers).

3. Results

3.1. Sample characteristics

Length, weight, types of habitats, and market price of the fish are presented in Table 1. The average length of the sampled raw fish ranged between 3.2 cm (*ichre*) and 24.7 cm (*loittya*). The weight of raw fish ranged between 1.9 g (*ichre*) and 77.4 g (*loittya*). Of the samples, *olua*, *faissa*, *ichre*, *mola*, and *chapila* are pelagic, *chewa* and *loittya* are demersal. The price range of the fresh fish species varied from 0.8 to 3.4 USD.

3.2. Proximate composition and fatty acid concentration

Table 2 presents the energy, dry matter, protein, fat, and ash concentrations of the sampled dried fish. Except for dry matter, the other proximate compositions are significantly different from each other ($p<0.05$). Due to low moisture content, all species are rich sources of protein (62.0–73.7 g/100 g) and ash (12.2–19.9 g/100 g). However, there are significant variations between the different species, especially when it comes to total fat content with a range from 4.63 to 15.9 g/100 g (Table 2). A statistically significant ($p<0.05$) variation in fatty acid composition is also found (Table 3). The concentrations of EPA range from 282 to 1068 mg/100 g, and the concentrations of DHA from 586 to 840 mg/100 g. Interestingly, the studied fish species had statistically different fatty acid compositions; for instance, the total fatty acid concentration is higher in *loittya*, *chewa* is rich in mono-unsaturated fatty acids (MUFA), *olua* and *mola* are richest in total poly-unsaturated fatty acids (PUFA), omega-3, omega-6, and DHA, but the EPA is higher in *mola* ($p<0.05$, Tukey's HSD). Full profile of the fatty acid composition for potential use in food composition tables or databases can be found in Table S2-S4.

3.3. Vitamins, minerals, and trace elements

Concentrations of vitamins, minerals, and trace elements with high public health importance are presented in Table 4. Additional data on vitamin E, minerals and trace elements is provided in Table S5 and S6, respectively. The vitamin and mineral concentrations statistically vary ($p<0.05$, Tukey's HSD) between species for almost all nutrients, except for vitamin B_{12}. It is interesting to note that *mola, faissa, loittya,* and *olua* are important sources of vitamin A_2, and for *olua,* the concentration of vitamin A_2 is higher than vitamin A_1. *Mola* is the only fish analyzed whole compared to the other species where viscera were removed. In terms of vitamins A_1, A_2, and *mola* and *olua*, they are comparatively high in nutrients. None of the studied fish species were superior to each other based on different mineral compositions.

Table 2
Energy, dry matter, protein, fat, and ash concentration of dried fish (mean ± standard deviation, N=3*). *Mola* is analyzed as whole fish, while all other species are whole fish with viscera removed. Values are given as mean ± standard deviation on a wet weight basis**.

Local name	Energy (J/100 g)	Dry matter (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	Ash (g/100 g)
Chapila	209 ± 1^{b}	92.3 ± 0.6	64.0 ± 0.0^{ab}	15.3 ± 0.2^{de}	14.7 ± 0.1^{ab}
Chewa	211 ± 1^{b}	92.0 ± 0.0	62.0 ± 0.0^{ab}	15.9 ± 0.1^{e}	12.2 ± 0.1^{a}
Faissa	189 ± 2^{ab}	88.0 ± 0.0	59.7 ± 0.6^{a}	13.4 ± 0.0^{cd}	18.9 ± 0.2^{cd}
Ichre	189 ± 9^{ab}	90.7 ± 1.5	71.0 ± 1.0^{c}	7.77 ± 2.23^{b}	14.1 ± 0.5^{ab}
Loittya	190 ± 22^{ab}	88.3 ± 4.6	59.7 ± 5.8^{a}	12.4 ± 0.6^{c}	17.6 ± 3.4^{bcd}
Mola	182 ± 2^{a}	90.3 ± 0.6	73.7 ± 0.6^{c}	4.63 ± 0.06^{a}	16.1 ± 0.1^{bc}
Olua	171 ± 1^{a}	90.0 ± 0.0	67.3 ± 1.2^{bc}	4.80 ± 0.10^{a}	19.9 ± 0.4^{d}

Here, different superscripts indicate statistically significant differences among all the species ($p<0.05$, Tukey's HSD).

* For each species, at least 5 kg of raw fish was dried to get at least 1 kg of dried fish samples. From this primary sample, three composite samples were prepared and analyzed.

** Wet weight is in this context fish powder with a level of dryness similar to what a local small-scale producer would be able to achieve with their equipment.

3.4. Heavy metals

The concentration of As, Cd, Hg and Pb varies significantly from species to species (Table 5). The PTWI for Hg and PTMI for Cd for children 6 months of age with a weight of 5.4 kg (3rd percentile) are 8.6 μg and 135 μg, respectively. Assuming a daily intake of 10 g dried fish, the weekly intake of Hg ranges from 0.49 μg (*chewa*) to 4.5 μg (*olua*). For cadmium, assuming daily intake of 10 g of dried fish, the monthly intake ranges from 10.5 μg (*mola*) to 114.6 μg (*ichre*). For a 6-month-old child with low weight (3rd percentile), daily consumption of 10 grams of dried fish with the highest concentrations of Cd and Hg would contribute with 85% and 52% of the PTMI and PTWI, respectively.

3.5. Potential contribution to address malnutrition

Our calculation shows that one serving (10 g fish powder) of all the fish powders could fully meet the daily RNI of selenium, and all but *loittya* could fully meet the daily RNI of vitamin B_{12} for 6–11 m infants (Fig. 2). In addition, all the fish powders, except *chewa*, could meet at least 50% of the daily DHA requirement for 6–11 m infants (Fig. 2). According to European Union legislation, food is considered as a significant source of vitamins and minerals if one serving (in this case 10 g for fish powder) of food could potentially meet ≥ 15% of the nutrient reference values (Regulation No. 1169/2011 on food information to consumers). Considering this, all the fish powders could be significant sources of iron, calcium, selenium, vitamin B_{12}, and DHA for 6–11-month infants and 12–23-month children (Table S1). Furthermore, all

Table 3
Analytical value of the fatty acid composition of the sampled dried fish (N=3*). *Mola* is analyzed as whole fish, while all other species are whole fish with viscera removed. Values are given as mean ± standard deviation (% of total fatty acids in parentheses) on a wet weight basis**.

Species name	Total SFA g/100 g (%)	Total MUFA g/100 g (%)	Total PUFA g/100 g (%)	Total n-3 g/100 g (%)	Total n-6 g/100 g (%)	EPA mg/100 g (%)	DHA mg/100 g (%)
Chapila	6.36 ± 0.92 (46.6)[b]	3.40 ± 0.03 (24.9)[d]	2.85 ± 0.02 (20.9)[bc]	2.25 ± 0.02 (16.5)[bc]	0.440 ± 0.002 (3.23)[ab]	1068 ± 7 (7.83)[f]	741 ± 3 (5.43)[ab]
Chewa	5.33 ± 0.95 (46.8)[b]	3.73 ± 0.08 (32.7)[e]	1.28 ± 0.02 (11.3)[a]	0.93 ± 0.02 (8.1)[a]	0.216 ± 0.003 (1.90)[a]	406 ± 5 (3.57)[b]	586 ± 164 (1.80)[a]
Faissa	5.64 ± 0.74 (47.2)[b]	2.56 ± 0.06 (21.4)[c]	2.93 ± 0.02 (24.5)[c]	2.25 ± 0.02 (18.7)[c]	0.628 ± 0.004 (5.27)[cd]	648 ± 8 (5.43)[c]	1204 ± 12 (10.0)[bc]
Ichre	2.81 ± 0.77 (49.1)[bc]	1.01 ± 0.25 (17.8)[b]	1.37 ± 0.07 (25.1)[ac]	1.09 ± 0.07 (20.0)[cd]	0.237 ± 0.016 (4.37)[bc]	372 ± 78 (6.57)[d]	586 ± 164 (11.1)[bc]
Loittya	6.10 ± 0.83 (52.7)[c]	2.91 ± 0.41 (25.1)[d]	1.88 ± 0.02 (16.3)[ab]	1.41 ± 0.13 (12.2)[ab]	0.419 ± 0.033 (3.63)[b]	371 ± 40 (3.20)[a]	802 ± 66 (6.97)[ab]
Mola	1.81 ± 0.38 (40.5)[a]	0.649 ± 0.013 (14.5)[a]	1.69 ± 0.03 (37.8)[d]	1.38 ± 0.02 (30.9)[e]	0.266 ± 0.03 (5.90)[d]	373 ± 5 (8.33)[g]	840 ± 11 (18.8)[d]
Olua	1.68 ± 0.12 (40.8)[a]	0.733 ± 0.04 (17.8)[b]	1.36 ± 0.01 (32.9)[d]	1.07 ± 0.00 (26.0)[de]	0.266 ± 0.001 (6.50)[d]	282 ± 2 (6.87)[e]	647 ± 1 (15.7)[cd]

Here, different superscripts indicate statistically significant differences among the percent composition of total fatty acid in all the species ($p<0.05$, Tukey's HSD).

* For each species, at least 5 kg of raw fish was dried to get at least 1 kg of dried fish samples. From this primary sample, three composite samples were prepared and analyzed.

** Wet weight is fish powder with a level of dryness similar to what a local small-scale producer would be able to achieve with their equipment.

Table 4
Analytical value of the vitamins and mineral composition of the sampled dried fish (mean ± standard deviation, N=3*). *Mola* is analyzed as whole fish, while all other species are whole fish with viscera removed. Values are given as mean ± standard deviation on wet wet-weight basis**.

Species name	Vit A1 (µg/100 g)	Vit A2 (µg/100 g)	Vit D (µg/100 g)	Vit B_{12} (µg/100 g)	Ca (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	Se (µg/100 g)	I (µg/100 g)
Chapila	1.77 ± 0.31[a]	< 0.5c[a]	2.00 ± 0.00[a]	9.23 ± 0.21	3500 ± 0[c]	27.3 ± 1.2[c]	6.33 ± 0.06[b]	273 ± 6[d]	240 ± 0[ab]
Chewa	4.00 ± 0.87[ab]	< 0.5c[a]	1.00b[a]	7.30 ± 0.17	2370 ± 60[ab]	44.7 ± 1.5[d]	6.37 ± 0.06[b]	123 ± 6[a]	277 ± 6[ab]
Faissa	17.3 ± 1.5[c]	8.67 ±1.15[c]	3.33 ± 0.58[a]	11.0 ± 0.0	5870 ± 150[e]	21.3 ± 1.2[bc]	7.00 ± 0.20[bc]	173 ± 6[ab]	107 ± 6[a]
Ichre	3.33 ± 0.40[ab]	< 0.5c[a]	5.67 ± 6.35[a]	8.20 ± 5.03	2830 ± 400[b]	11.7 ± 0.6[a]	7.40 ± 0.44[c]	173 ± 40[ab]	413 ± 220[b]
Loittya	11.6 ± 7.6[bc]	0.63b[a]	4.00b[a]	6.13 ± 1.93	1930 ± 100[a]	16.3 ± 5.5[ab]	3.57 ± 0.15[a]	190 ± 26[bc]	90 ± 34[a]
Mola	15.3 ± 0.6[c]	4.83 ± 0.15[b]	13.0 ± 0.0[b]	8.43 ± 0.40	4170 ± 200[d]	24.7 ± 1.5[c]	11.7 ± 0.6[e]	240 ± 10 [cd]	123 ± 6[a]
Olua	12.7 ± 1.2[c]	18.7 ± 1.5[d]	6.00 ± 0.00[ab]	8.73 ± 0.40	5400 ± 170[e]	63.0 ± 2.7[e]	8.57 ± 0.15[d]	210 ± 0[bc]	160 ± 20[a]

**Wet weight is fish powder with a level of dryness similar to what a local small-scale producer would be able to achieve with their equipment.

[b]one value below the limit of quantification (LoQ)

[c]All values below LoQ

Here, different superscripts indicate statistically significant differences among all the species ($p<0.05$, Tukey's HSD).

* For each species, at least 5 kg of raw fish was dried to get at least 1 kg of dried fish samples. From this primary sample, three composite samples were prepared and analyzed.

the fish powders could be considered significant sources of calcium, selenium, and vitamin B_{12} for pregnant and lactating women. However, none of the fish powder was able to potentially meet more than one-third (33%) of the daily zinc requirement for 6–11 m infants. For 12–23 m children, except *chewa*, all other fish powders were able to meet 100% of the daily selenium requirement and at least 50% of the daily DHA requirement. All the fish powders were potentially able to meet at least 50% of the vitamin B_{12} requirement of the 12–23 m children. Furthermore, all the fish powders, except *chewa* and *loittya*, were potentially able to meet at least 50% of the daily selenium requirement and one-fourth of the daily vitamin B_{12} requirement for pregnant mothers. Finally, all fish powders except *chewa* were potentially able to meet at least one-third of the daily selenium requirement for lactating mothers, whereas all fish powders except *loittya* were potentially able to meet at least one-fourth of vitamin B_{12} and one-fifth of the calcium requirement for the lactating mothers.

4. Discussion

All the fish powders prepared from selected marine small fish exhibit high nutrient density. However, their nutritional profiles vary significantly by species, with no single species emerging as superior when considering all analyzed nutrients. For instance, *olua* contains 5.4 times more iron than that of *ichre*, *mola* has 3.3 times more zinc content than *loittya*, and *loittya* contain 13.3 times higher vitamin E content than *chewa*. These findings align with Bogard et al. (2015) and Nordhagen et al. (2020), who also observed substantial variation in micronutrient concentration among fish species in Bangladesh. Therefore, our findings underscore that fish are not nutritionally homogenous, and certain species may be more effective in supplying specific nutrients. Fish powders derived from the sampled marine small fish in Bangladesh hold significant potential for meeting the daily RNI for calcium, selenium, vitamin B_{12}, and DHA for children and pregnant and lactating women. However, for nutrients like zinc and iron, specific small fish, rather than small fish in general, may be recommended. For individuals with iron deficiency, *olua* powder emerges as a promising option as one serving of 10 g has the potential to meet 68%, 100%, 21%, and 42% iron requirements for the 6–11 m, 12–23 m, pregnant and lactating mothers, respectively. Similarly, *mola* powder emerges as the preferred choice for individuals with zinc deficiency.

Table 5
Concentration of chemical contaminants of dried fish (mean ± standard deviation, N=3*). *Mola* is analyzed as whole fish, while all other species are whole fish with viscera removed. Values are given as mean ± standard deviation on wet weight basis**.

Local name	As (mg/kg)	Cd (mg/kg)	Hg (mg/kg)	Pb (mg/kg)
Chapila	6.47 ± 0.12[d]	0.227 ± 0.006[c]	0.014 ± 0.001[a]	0.400 ± 0.010[c]
Chewa	1.63 ± 0.06[a]	0.070 ± 0.003[ab]	0.007 ± 0.000[a]	0.587 ± 0.015[d]
Faissa	4.43 ± 0.06[c]	0.107 ± 0.006[ab]	0.097 ± 0.003[e]	0.227 ± 0.038[b]
Ichre	4.73 ± 0.49[c]	0.382 ± 0.076[d]	0.032 ± 0.004[b]	0.163 ± 0.012[a]
Loittya	1.83 ± 0.21[a]	0.080 ± 0.009[ab]	0.051 ± 0.004[c]	0.163 ± 0.038[a]
Mola	2.83 ± 0.12[b]	0.035 ± 0.003[a]	0.059 ± 0.003[d]	0.217 ± 0.006[ab]
Olua	2.70 ± 0.00[b]	0.133 ± 0.006[b]	0.064 ± 0.001[d]	0.353 ± 0.006[c]

Here, different superscripts indicate statistically significant differences among all the species ($p<0.05$, Tukey's HSD).

* For each species, at least 5 kg of raw fish was dried to get at least 1 kg of dried fish samples. From this primary sample, three composite samples were prepared and analyzed.

** Wet weight is in this context fish powder with a level of dryness similar to what a local small-scale producer would be able to achieve with their equipment.

In the food composition table of Bangladesh, nutritional values are provided for three marine dried fish species: *faissa* or anchovy (*Setipinna phasa*), *vetkee* or giant sea perch (*Lates calcarifer*), and *rupchanda* or pomfret (*Pampus argenteus*). However, only one of these species (*faissa*) overlaps with the present study and can thus be compared (Shaheen et al., 2013). Notably, our study reveals higher concentrations of fat (13.4 vs 4.9 g/100 g), ash (18.9 vs 11.9 g/100 g) and calcium (5870 vs 1680 mg/100 g). Conversely, our study indicates lower protein levels (59.7 vs 70.9 g/100 g), while vitamin A and iron content are comparable. The food composition table lack values for fatty acids, vitamin B12, selenium, iodine, and vitamin D data are missing for *faissa*. The data source cited in the food composition table includes USDA National Nutrient Database for Standard Reference (Haytowitz et al., 2011) and the Tables of nutrient composition of Bangladeshi foods (Darnton-Hill et al., 1988). Consequently, it is difficult to evaluate whether the data are based on analyses of local fish, or data borrowed from the US. Additionally, differences in the nutrient composition may stem from variation in the part of the fish analyzed. For instance, in the food composition table of Bangladesh, the term "edible portion" is not explicitly defined. This could encompass the fillet, the whole fish, or the whole fish with certain parts discarded prior to analysis. The differences in nutrient composition could also be due to differences in the time and place of catch, level of maturity, and diet of the fish. However, large variation in nutrient content has also been reported within the same species. For instance, Wessels et al. (2023) observed considerable variation in iron (5.8–180 mg/100 g), iodine (540–1600 μg/100 g) and vitamin A (48–230 μg/100 g) concentration in 41 samples of sun-dried silver cyprinid (*Rastrineobola argentea*) from eight different markets in Kenya. Similarly, Nerhus et al. (2018) reported varying iodine concentration in five different species collected from three major seas off the coast of Norway. Such discrepancies can be attributed to diverse factors, including differences in nutrient analysis methods, variations in fish samples (e.g., size, age, seasons), and geographical origins (Ahern et al., 2021; Abdullahi, 2001; Effiong & Fakunle, 2011; Rasul et al., 2021). Despite these variables, it is evident that the nutritional value of the whole fish surpasses that of fish fillet (Nordhagen et al., 2020; Reksten et al., 2020b).

Our analysis reveals that small pelagic fish such as *olua*, *mola*, and *faissa* exhibit higher nutritional value compared to commercial and demersal fish like *loittya*. This finding aligns with the results of studies conducted by Nordhagen et al. (2020) and Reksten et al. (2020b), which assessed the nutrient levels of some common marine fish in Bangladesh

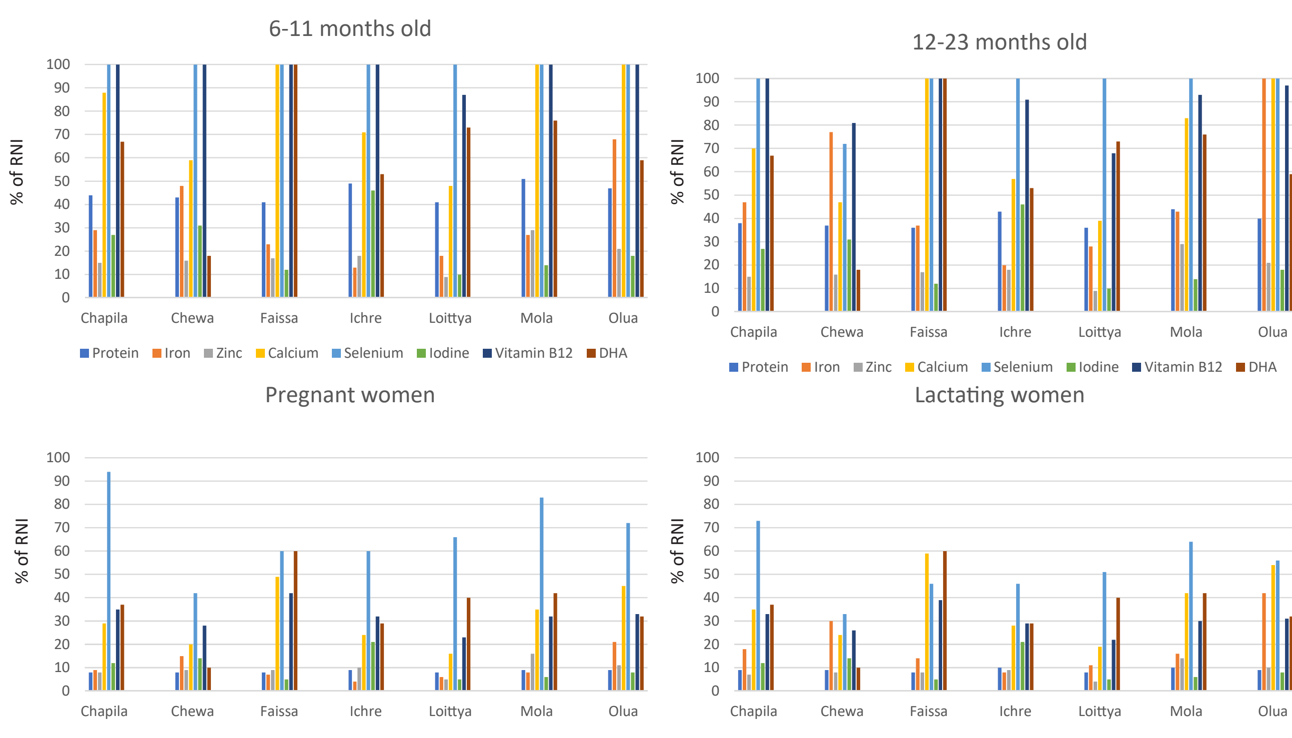

Fig. 2. Percentage of recommended nutrient intake (RNI) of nutrients in 10 g of dried fish powder for the two age groups of children, pregnant and lactating women. Each color represents different nutrients. The x-axis displays the seven different fish species.

and Sri Lanka, respectively. Their investigations demonstrated that small fish surpass large fish in nutritional content across various categories, including protein, fat, fatty acids, vitamin A, vitamin B_{12}, vitamin D, calcium, iodine, iron, selenium, and zinc. Moreover, they observed that pelagic fish tends to be more nutritious than demersal fish in terms of protein, fat, iron, iodine and selenium. Despite their high nutritional value, some small fish are bycatch leading to lower market prices and making them available for consumption by the local and poor population groups. Studies conducted in Malawi, Zambia and Southern Africa have shown that pelagic small fish are the most widely consumed fish, particularly among the poor (Longley et al., 2014; Marinda et al., 2018). Additionally, research in Bangladesh has demonstrated that small fish offer superior nutrition compared to farmed fish (Bogard et al., 2015). Consequently, the consumption of pelagic small fish represents a promising avenue for combatting malnutrition, especially among the poor in low- and lower-middle income countries (Ahern et al., 2020).

Small fish, consumed whole or in powdered form, represent a stable and affordable nutrient dense source, potentially suitable for fortifying cereal-based staple foods (Bavinck et al., 2023). However, attention must also be given to food safety parameters. In our study, the fish samples studied were found to be below the EU maximum limit of 0.5 mg Hg/kg (European Union, Commission Regulation (EC) No 1881/2006). However, all species except mola exceeded the EU maximum limit of 0.05 mg/kg for cadmium and three of the species were above the EU maximum limit of 0.3 mg/kg for lead. Considering portion size and the child's weight, Cd would contribute 85% of the PTMI for a 6-month-old child with low weight (3rd percentile). Given that the PTMI is heavily dependent on weight, the risk posed by consuming 10 g of dried fish would decrease in children with normal weight and as the child gains weight. These results are in accordance with a recent study by Reksten et al. (2021), which found that raw marine small fish from Bangladesh and Sri Lanka had significantly higher levels of cadmium, arsenic, and lead than large fish, although larger fish had higher mercury levels. However, Reksten et al. (2021) concluded that the fish analyzed do not pose health risks to adults and children when consumed in recommended amounts. The most recent risk-benefit evaluation conducted by FAO/WHO concluded that there is strong evidence for the benefits of fish consumption during all life stages but that national and regional risk-benefit assessments taking into consideration parameters such as local consumption patterns, contamination levels and nutritional status of the population of interest are needed (FAO/WHO, 2023). Cd and Pb were not addressed in this report, nor was the consumption of small fish or processed fish.

Small fish have a high potential in combating malnutrition. Previous studies conducted in Bangladesh have demonstrated that mola has the potential to enhance iron and vitamin A status among children (Kongsbak et al., 2008; Andersen et al., 2016). However, the presences of bones in small fish poses a challenge for children to consume small fish cooked traditionally in Bangladesh. Considering this, the utilization of fish powder emerges as a potential solution (Chattopadhyay, Gupta., 2004; O'Meara et al., 2020). Incorporating fish and fish-based products such as smashed fish, powdered fish, and chutney into the Children's deits is recommended as a potential solution to address micronutrient deficiencies (Thilsted and Wahab, 2014).

5. Conclusions

The analyzed marine small fish have high nutritional value and have the potential to significantly meet the dietary requirement of calcium, selenium, vitamin B_{12}, and DHA for 6–23 months children, as well as pregnant and lactating women. It is noteworthy that small fish exhibit considerable variability in their nutrient profiles, with pelagic small fish demonstrating higher levels of Zn, and Ca than the commercial fish *loittya*. The analyzed concentrations of Hg and Cd pose no risk for consumption even for a 6-month-old child with low weight.

Ethical approval

All procedures performed in this study were approved by the ethical research committee of Noakhali Science and Technology University.

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CRediT authorship contribution statement

Abdullah-Al Mamun: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **M. A. Rifat:** Writing – review & editing, Writing – original draft, Visualization, Software, Formal analysis, Data curation. **Md. Abdul Wahab:** Writing – review & editing, Supervision, Conceptualization. **Muhammad Arifur Rahman:** Writing – review & editing, Investigation, Data curation. **Md. Nahiduzzaman:** Project administration, Resources, Supervision, Writing – review & editing. **Shakuntala Haraksingh Thilsted:** Conceptualization, Resources, Supervision, Writing – review & editing. **Marian Kjellevold:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Data curation, Formal analysis.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Marian Kjellevold reports was provided by the United States Agency for International Development (USAID).

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2024.106241.

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