

Nutritional analysis of the male freshwater crab *Maydelliathelphusa harpax* from the Jia Bharali River basin of Assam, India

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Abstract

This study evaluated the nutritional composition of the muscle tissue of male freshwater crab *Maydelliathelphusa harpax* collected from the Jia Bharali River basin of Assam, India. The muscle contained $77.32 \pm 0.18\%$ moisture, $15.65 \pm 0.01\%$ crude protein, $1.11 \pm 0.02\%$ crude fat, $2.71 \pm 0.02\%$ ash, and $3.21 \pm 0.12\%$ carbohydrate on a wet-weight basis. Mineral analysis revealed calcium, magnesium, and potassium as the dominant elements on a wet-weight basis. Phenylalanine was the most abundant measured essential amino acid, proline was the predominant conditionally essential amino acid, and alanine was the only quantified non-essential amino acid. Vitamin E and vitamin C showed the highest concentrations among the measured fat-soluble and water-soluble vitamins, respectively. Lead, cadmium, chromium, arsenic and mercury were below the analytical detection limits in the analysed muscle samples. The study provides species-specific and region-specific baseline nutritional data for an underutilized freshwater crab and supports further evaluation of its nutritional potential, minerals bioavailability and food-safety status.

1. Introduction

The escalating global population has intensified the demand for nutritionally adequate, safe, and sustainable protein sources, particularly in developing regions where malnutrition and limited access to adequate food remain persistent challenges. In this context, increasing attention has been directed toward the exploration and utilization of non-conventional food resources to enhance dietary protein availability. Aquatic ecosystems constitute a critical component of this strategy, as fish and other edible aquatic organisms are widely recognized for their superior nutritional value and high-quality protein content. Among these, crustaceans, including shrimp, crabs, lobsters, crayfish, barnacles, and krill, represent a nutritionally rich and commercially valuable group with significant contributions to both domestic and international seafood markets [1].

Within crustaceans, crabs hold a prominent position in terms of both production and economic importance, ranking third globally after shrimps and lobsters [2,3]. Their widespread consumer preference is largely attributed to their desirable meat quality, distinct flavor, and culinary versatility, which make them a valued delicacy commanding premium prices in international markets [4–6].

From a nutritional perspective, crab meat constitutes a dense and biologically valuable food matrix characterized by highly digestible proteins and a well-balanced essential amino acid profile, essential for growth, metabolic regulation, and immune competence [7–10]. Muscle tissue alone accounts for approximately 80% of the total body protein content, underscoring its nutritional significance [11]. In addition to its protein fraction, crab meat contains a diverse array of bioactive compounds, including free amino acids and peptides, which contribute to its functional and nutritional properties [1]. Proximate composition analyses further indicate that crab meat is characterized by high moisture content (78–82.9%), substantial protein levels ($\sim 16\%$), and moderate ash content (1.5–1.7%) [12,13].

Crab meat also represents an excellent source of essential minerals. It contains appreciable quantities of macro- and microelements, including calcium, zinc, potassium, phosphorus, magnesium, manganese, copper, selenium, and chromium [14–22].

Despite these well-established nutritional benefits, the consumption of crustaceans has historically been constrained by concerns related to cholesterol content, allergenicity, and potential contamination with toxic elements, particularly in the hepatopancreas [23–25]. However, accumulating scientific evidence supports the inclusion of crustaceans in a balanced diet, highlighting that their health benefits outweigh potential risks when consumed in moderation [11,17,25–30].

It is well established that the nutritional composition of crab species is not uniform and can vary significantly depending on species, geographical origin, seasonal fluctuations, and processing methods. Such variability underscores the necessity for species-specific and region-specific investigations to accurately characterize their nutritional potential [13,15,17,18,27,31–39].

Although several studies have investigated the nutritional composition of both freshwater and marine crab species at the national level [40–44], demonstrating that crabs are rich sources of essential nutrients, comprehensive data from the northeast region of India remain scarce. This region, characterized by rich aquatic biodiversity and diverse indigenous fauna, harbors several freshwater crab species that remain underexplored in terms of their nutritional potential.

Although previous studies have established the nutritional value of several freshwater crab and decapod species, their findings cannot be directly extrapolated to *Maydelliathelphusa harpax*, because the proximate and mineral composition of crabs may vary according to species, tissue type, sex, maturity, reproductive condition, season, geographic origin, and habitat [45–47]. The present study therefore advances existing research by providing a species-specific and region-specific nutritional assessment of *M. harpax* from the Jia Bharali River Basin of Assam, India. By characterizing the nutritional profile of this underexplored freshwater crab, the study generates baseline data for a species and region for which comparable nutritional information remains limited. These data may support future evaluation of the species as an underutilized aquatic food resource and contribute to the sustainable utilization of freshwater biodiversity.

Accordingly, the present study evaluates the nutritional composition of the freshwater crab *Maydelliathelphusa harpax* collected from the Jia Bharali River basin of Assam, India. This study specifically examines its nutritional composition to establish baseline data and to highlight the potential of this underutilized freshwater crab species as a nutritionally significant resource, thereby contributing to regional food security and sustainable utilization of aquatic biodiversity.

2. Materials and Methods

2.1. Sampling sites and studied taxa

In the present study, 30 specimens of adult male *Maydelliathelphusa harpax* (Fig. 1) were collected through random sampling from multiple sites across the Jia Bharali River basin in Assam, India during December 2024 to December 2025. The sample size was considered adequate for an exploratory species-specific and region-specific baseline assessment because the study aimed to characterize the nutritional composition of adult male crabs from the Jia Bharali River basin rather than estimate population-wide variation or compare predefined biological groups.

The basin extends between longitudes 91°58'–93°23'E and latitudes 26°36'–27°59'N in northeastern India. The Jia Bharali River, a major tributary of the Brahmaputra River, originates in the lower Himalayan region of Arunachal Pradesh, where it is known to as the Kameng River. It flows southward through mountainous terrain before entering the plains of Bhalukpong, where it assumes the name Jia Bharali (with “Jia” meaning “alive” in the local language) [48]. The river subsequently traverses the Assam plains, passing through the Tezpur region, before ultimately merging with the Brahmaputra River.

2.2. Sample preparation

Live specimens were collected manually by hand picking and immediately euthanized by placement in ice-filled containers to minimize stress and preserve biochemical integrity prior to processing. The samples were then transported to the laboratory under chilled conditions for subsequent nutritional analysis.

In the laboratory, the carapace of each specimen was carefully removed, and non-edible tissues, including the gonads and hepatopancreas, were discarded. Muscle tissues from the body, chelae (claws), walking legs, and swimming legs of the 30 crabs were manually excised and pooled to obtain a representative sample. The tissue was then transferred to sterile Petri dishes and subjected to lyophilization. The lyophilized samples were stored at 4°C refrigerator until further analysis of proximate composition (moisture, crude protein, crude fat, total ash, and carbohydrate) and mineral analysis.

2.3. Proximate composition analysis

Analysis for each parameter was carried out in six replicates. The calculated values are expressed as Mean ± standard deviation.

2.3.1. Moisture:

Moisture content was determined using the hot air oven method following standard AOAC procedures [49]. A known weight of crab sample was evenly distributed in a clean glass Petri dish and dried in a hot air oven (Thermo Scientific, Model: Heratherm) at 105°C until a constant weight was achieved. After drying, the Petri dish containing the sample was cooled in a desiccator and reweighed to obtain the final weight. Moisture content was calculated from the loss in sample weight during drying and expressed as a percentage (%).

$$\text{Moisture (\%)} = \frac{(\text{Initial weight} - \text{Final weight})}{\text{Initial weight}} \times 100$$

2.3.2. Crude protein:

Crude protein was determined by estimating total nitrogen using the micro-Kjeldahl method (Pelican Equipment, Model: KELPLUS) and applying Jones factor or a nitrogen-to-protein conversion factor of 6.25. The method involved acid digestion of organic nitrogen to form ammonium sulphate, followed by alkaline distillation to liberate ammonia, which is subsequently quantified by titration [50,51].

An accurately weighed portion of the crab sample was transferred to a digestion tube, and its mass was recorded as W . The sample was digested with concentrated sulphuric acid in the presence of a catalyst consisting of copper sulphate and potassium sulphate until a clear solution was obtained. The digest was then subjected to distillation under alkaline conditions using 40% sodium hydroxide in a micro-Kjeldahl system (Pelican Equipment, KELPLUS), and the liberated ammonia was collected in boric acid solution mixed indicator. The distillate was titrated against standardized 0.1 N sulphuric acid, and a reagent blank was run simultaneously.

The nitrogen content was calculated using the following equation:

$$\text{Nitrogen (\%)} = \frac{(T-B) \times N \times 14.01 \times 100}{1000} \times W$$

where, T = volume (mL) of acid used for the sample, B = volume (mL) used for the blank, N = normality of the acid, and W = weight (g) of the sample

Crude protein was calculated as:

$$\text{Crude Protein (\%)} = \text{Nitrogen (\%)} \times 6.25$$

The nitrogen-to-protein conversion factor of 6.25 was used based on the assumption that proteins contain approximately 16% nitrogen [52].

2.3.3. Crude fat:

Crude fat content was determined by Soxhlet extraction using a solvent extraction system (Pelican Equipment, Model: SOCSPLUS) following standard AOAC procedures [49]. An accurately weighed portion of the crab sample was placed in an extraction thimble, and its mass was recorded as W_s . The thimble was then transferred into the Soxhlet apparatus. Petroleum ether was used as the extraction solvent, and continuous extraction was carried out for several hours under controlled heating conditions.

After completion of extraction, the solvent was evaporated, and the lipid-containing flask was dried in a hot-air oven to remove residual solvent. The flask was then cooled in a desiccator and weighed to obtain a constant weight.

The crude fat content was calculated using the following formula:

$$\text{Crude fat (\%)} = \frac{(W_2 - W_1)}{W_s} \times 100$$

where, W_1 = weight of empty oil flask (g), W_2 = weight of oil flask containing extracted fat (g), and W_s = weight of sample for extraction (g)

2.3.4. Total Ash:

Total ash content was determined by incineration in a muffle furnace at 600°C following standard AOAC procedures [49]. A measured portion of the dried crab sample was transferred to a pre-weighed silica crucible. The sample was first charred over a low flame and then incinerated in the furnace for 6–8 h until a stable greyish-white ash residue was obtained. The crucible was cooled in a desiccator and weighed.

The total ash content was calculated using the following formula:

$$\text{Ash content (\%)} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$$

where, W_1 = weight of the empty crucible (g), W_2 = weight of the crucible with sample (g), and W_3 = weight of the crucible with ash (g)

2.3.5. Carbohydrate content:

Carbohydrate was estimated by difference following De et al. [53]. The calculation was based on the proximate composition values expressed on the same weight basis. Carbohydrate content was calculated by subtracting the sum of moisture, crude protein, crude fat, and total ash contents from 100.

$$\text{Carbohydrate (\%)} = 100 - [\text{Moisture (\%)} + \text{Protein (\%)} + \text{Fat (\%)} + \text{Ash (\%)}]$$

2.4. Mineral analysis

Mineral analysis was carried out following wet acid digestion as described by Gokoglu et al. [54] and Mohanty et al. [55]. An accurately weighed portion of sample was taken in a conical flask and digested using a mixture of concentrated nitric acid and hydrochloric acid (HNO_3 : HCl , 1:3 v/v). The digestion mixture was heated in a water bath at 85°C for 4 h, followed by overnight (~ 12 h) incubation at room temperature, and subsequently heated for 2–3 h until a clear solution was obtained. The digested sample was filtered through Whatman No. 42 filter paper and diluted to a final volume of 100 mL with 2% HNO_3 .

Mineral concentrations were determined using atomic absorption spectrophotometry [49,56] with a flame atomic absorption spectrophotometer (Analytik Jena, Model: ZEEnit 700P). Calibration curves were prepared using standard solutions along with reagent blanks, and element concentrations were quantified based on their respective calibration curves.

2.5. Amino acid analysis

The amino acid profile of the crab sample was quantified using a Biochrom 30 amino acid analyzer. An accurately weighed portion of the sample was transferred to a hydrolysis vessel, and 20 mL of 6 M

hydrochloric acid (HCl) was added. The sample was hydrolyzed at 100°C for 6 h and then allowed to cool to room temperature. The hydrolysate was filtered through a membrane syringe filter to remove particulate matter. An aliquot of 750 µL of the filtered hydrolysate was transferred to an autosampler vial fitted with a chromatography insert and mixed with 750 µL of Biochrom loading buffer, resulting in a 1:1 dilution. The prepared solution was homogenized and loaded into the analyzer for chromatographic analysis.

Amino acid separation was performed using ion-exchange chromatography with a pre-treatment column and an analytical separation column. Six lithium-based buffer systems supplied by the manufacturer were used as the mobile phases. The system was operated using a dual-pump configuration at a constant flow rate of 25 mL h⁻¹, with an injection volume of 20 µL. The total chromatographic run time was approximately 4 h per sample, allowing the separation and quantification of the amino acid constituents.

2.6. Vitamin analysis

Dried crab powder of *Maydelliathelphusa harpax* was used for vitamin analysis. An accurately weighed portion of the sample was taken for the extraction of water-soluble and fat-soluble vitamins.

For the extraction of water-soluble vitamins B1, B6, B12, and C, the sample was mixed with 20 mL of 40% of ethanol and heated at 95–100°C for 30 minutes. The mixture was cooled to room temperature, sonicated for 15 minutes, and centrifuged at 6,000 rpm for 10 minutes. The supernatant was collected and filtered through a 0.22 µm membrane filter before HPLC analysis. For vitamin B12, the extract was additionally treated with 1% pepsin and incubated at 37°C for 2 hours before centrifugation and filtration.

For the extraction of fat-soluble vitamins A, D, E, and K, the sample was subjected to alkaline saponification using ethanol, potassium hydroxide, and ascorbic acid. EDTA was additionally used in the vitamin A extraction. Following saponification, the vitamins were extracted with n-hexane. The hexane layer was collected after centrifugation, and the extraction was repeated twice. The combined extracts were concentrated below 40°C, reconstituted in the appropriate solvent, and filtered through a 0.22 µm membrane filter before analysis.

The vitamin extracts were analyzed by gradient high-performance liquid chromatography using an Agilent G4288C 1220 Infinity II Gradient LC System VL equipped with OpenLab CDS2 software. Separation was performed on Agilent TC-C18(2) column, 4.6 × 250 nm, with a particle size of 5 µm. A 10 µL sample volume was injected at ambient temperature. Vitamin-specific mobile phases, flow rates, and detection wavelengths were used for the individual vitamins.

2.7. Data analysis

All analyses were performed in six replicates, and the results are expressed as mean ± standard deviation (SD). These analytical replicates represent repeated measurements of the prepared sample and should not be interpreted as six independent biological samples.

3. Results

3.1. Biometric characteristics

Maydelliathelphusa harpax (Alcock, 1909) is a decapod crab belonging to family Gecarcinucidae. For the present study, male samples of the crab were collected from multiple sites across the Jia Bharali River basin in Assam. Males collected were in the size range of 30–62 mm CW, with a weight range of 6–84 g (mean size 53.00 ± 5.87 mm and mean weight 59.74 ± 14.94 g).

3.2. Proximate composition

The proximate composition of the muscle tissue of male *Maydelliathelphusa harpax* is presented in Table 1. The moisture content of the fresh sample was found to be $77.32 \pm 0.18\%$. On a wet weight basis, the muscle exhibited a crude protein content of $15.65 \pm 0.01\%$, indicating that protein is the dominant nutritional component. The crude fat content was relatively low, measured at $1.11 \pm 0.02\%$, while the total ash content was $2.71 \pm 0.02\%$, reflecting the mineral fraction of the tissue. The carbohydrate content, calculated by difference, was $3.21 \pm 0.12\%$ on a wet weight basis.

Table 1 Proximate composition (%) of muscle tissue of male <i>Maydelliathelphusa harpax</i>	
Parameters	Content
Moisture	77.32 ± 0.18
Crude protein	15.65 ± 0.01
Crude fat	1.11 ± 0.02
Total Ash	2.71 ± 0.02
Carbohydrate	3.21 ± 0.12

Values are expressed as mean $\pm$ SD (n = 6). All values are presented on a wet weight basis.

3.3. Mineral composition

The mineral composition of the muscle tissue of male *Maydelliathelphusa harpax* is presented in Table 2. Calcium (Ca) was the dominant mineral, recorded at 525.23 ± 2.94 mg/100 g, followed by magnesium (Mg) and potassium (K). Among the trace elements, zinc (Zn) was present in relatively higher concentration (22.25 ± 0.12 mg/100 g), followed by iron (Fe), copper (Cu), and manganese (Mn). The toxic heavy metals lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and mercury (Hg) were below the detection limit (BDL) in the samples.

Table 2
Mineral composition
(mg/100 g wet weight) of the
muscle tissue of male
Maydelliathelphusa harpax

Minerals	Content
Ca	525.23 ± 2.94
Mg	240.60 ± 2.11
K	158.26 ± 3.40
Zn	22.25 ± 0.12
Fe	5.60 ± 0.23
Cu	2.02 ± 0.03
Mn	0.10 ± 0.02
Pb	BDL
Cd	BDL
Cr	BDL
As	BDL
Hg	BDL

Values are expressed as mean ± SD (n = 6). BDL= Below Detection Limit. All values are presented on a wet weight basis.

3.4. Amino acid composition

The amino acid composition of the muscle tissue of male *Maydelliathelphusa harpax* is presented in Table 3. Among the essential amino acids, phenylalanine was recorded in the highest concentration at 0.071 ± 0.03 g/100 g wet weight, followed by valine, leucine, isoleucine, methionine, lysine, tryptophan, and histidine, while threonine was below the detection limit. Among the conditionally essential amino acids, proline was the predominant at 0.176 ± 0.02 g/100 g wet weight, followed by tyrosine and cysteine, whereas arginine and glycine were below the detection limit. Among the non-essential amino acids, only alanine was quantified at 0.014 ± 0.01 g/100 g wet weight, whereas aspartic acid, asparagine, glutamic acid, glutamine, and serine was below the detection limit.

The sums of the quantified essential, conditionally essential, and non-essential amino acids were 0.335, 0.244, and 0.014g/100 g wet weight respectively.

Table 3
Amino acid composition (g/100g wet weight) of the muscle
tissue of male *Maydelliathelphusa harpax*

Essential amino acids (EAA)	Content
Histidine	0.004 ± 0.00
Isoleucine	0.053 ± 0.02
Leucine	0.055 ± 0.02
Lysine	0.020 ± 0.01
Methionine	0.052 ± 0.01
Phenylalanine	0.071 ± 0.03
Threonine	BDL
Valine	0.067 ± 0.02
Tryptophan	0.013 ± 0.01
Σ quantified EAA	0.335
Conditionally essential amino acids (CEAA)	
Arginine	BDL
Cysteine	0.007 ± 0.00
Glycine	BDL
Proline	0.176 ± 0.02
Tyrosine	0.061 ± 0.01
Σ quantified CEAA	0.244
Non-essential amino acids (NEAA)	
Alanine	0.014 ± 0.01
Aspartic acid	BDL
Asparagine	BDL
Glutamic acid	BDL
Glutamine	BDL
Serine	BDL
Σ quantified NEAA	0.014

3.5. Vitamin composition

The vitamin composition of the muscle tissue of male *Maydelliathelphusa harpax* is presented in Table 4. Among the fat-soluble vitamins, vitamin E showed the highest concentration at 17.21 ± 0.07 µg/g wet weight, followed by vitamin A, vitamin D, and vitamin K. However, among the water-soluble vitamins, vitamin C was recorded at the highest concentration, with 17.25 ± 0.02 µg/g wet weight, followed by vitamin B6, vitamin B12, and vitamin B1.

Table 4
Vitamin composition (µg/g wet weight)
of the muscle tissue of male
Maydelliathelphusa harpax

<i>Fat soluble vitamin</i>	<i>Content</i>
Vitamin A	4.77 ± 0.04
Vitamin D	3.29 ± 0.02
Vitamin E	17.21 ± 0.07
Vitamin K	2.78 ± 0.03
<i>Water soluble vitamin</i>	
Vitamin B1	1.02 ± 0.06
Vitamin B6	5.82 ± 0.03
Vitamin B12	5.08 ± 0.05
Vitamin C	17.25 ± 0.02

4. Discussion

This study provides the first comprehensive report on the nutritional composition of *Maydelliathelphusa harpax*, a freshwater crab species for which nutritional information is scarce. The nutritional composition of crabs is governed by a complex interplay of ecological and physiological factors, including habitat salinity, dietary habits, osmoregulatory mechanisms, and interspecies variation [57,58].

4.1. Proximate composition

The proximate composition of the muscle tissue of *M. harpax* is presented in Table 1.

4.1.1. Moisture

The moisture content of *M. harpax* ($77.32 \pm 0.18\%$) falls within the reported range for freshwater crabs i.e., 77.97–79.09% [11,59–61]. The moisture content in crustacean muscle is not fixed but varies with species, sex, moulting stage, season, diet, and pre-analytical handling [47,62]. In decapods, tissue water content also changes across the moult cycle, as newly moulted animals take up water before

mineralisation of the new cuticle [63]. Because the moulting stage of the sampled males were not recorded, the marginally lower value observed here cannot be attributed to a specific factor and may simply reflect normal inter-specific and seasonal variation. Indeed, the difference of less than one percentage point between *M. harpax* and the lower bound of the reported range falls within the natural variation observed among the cited freshwater crab species [11,59–61].

4.1.2. Crude protein

The crude protein content of *M. harpax* ($15.65 \pm 0.01\%$) was lower than the values reported for freshwater crabs i.e., 16.46–18.9% [11,59–61]. A possible biological explanation is tissue-specific nutrient allocation. Comparative decapod studies have shown that muscle and gonadal tissues are relatively protein-rich, whereas the hepatopancreas contains a greater proportion of lipid reserves [47]. Therefore, the lower protein concentration in the present muscle sample may reflect species-specific tissue competition and nutrient partitioning rather than an absence of nutritional value.

4.1.3. Crude fat

The crude fat content of *M. harpax* ($1.11 \pm 0.02\%$) was within the low range reported for freshwater crabs i.e., 0.68–1.02% [11,59–61]. The low lipid level is consistent with the tissue-specific distribution of energy reserves in decapods. In redclaw crayfish, *Cherax quadricarinatus*, the hepatopancreas was identified as the principal lipid-storage tissue, whereas glycogen was stored mainly in abdominal muscle [64]. Similarly, lipid reserves in the hepatopancreas of American lobster changed across moult categories, demonstrating that lipid availability is linked to physiological state and reserve mobilisation [65]. The present result therefore supports the classification of *M. harpax* muscle as a lean tissue.

4.1.4. Total Ash

The ash content of *M. harpax* ($2.71 \pm 0.02\%$) falls within the upper range of values reported for freshwater crabs i.e., 0.99–1.79% [11,59–61]. The relatively high ash content of *M. harpax* is consistent with its elevated concentrations of calcium (525.23 mg/100 g) and magnesium (240.60 mg/100 g), since ash represents the total inorganic residue of the tissue and is therefore a direct reflection of its mineral content. Freshwater crustaceans actively accumulate calcium from water and diet to support cuticle formation and moulting [63,66], and dietary mineral supply has been shown to influence tissue mineral deposition in crabs [67]. In addition, ash content in crustaceans varies with species, body size, moulting stage, and environmental ion availability [62,63].

4.1.5. Carbohydrate

The carbohydrate content ($3.21 \pm 0.12\%$) was within the upper range of values reported for freshwater crabs i.e., $1.46 \pm 0.23\%$ [61]. However, because carbohydrate was calculated by difference rather than measured directly, it should be treated as an approximate estimate that may include the combined error of the moisture, protein, fat, and ash determinations.

4.2. Mineral composition

The mineral profile of the muscle tissue of male *M. harpax* is presented in Table 2.

Mineral concentrations in crabs can vary with species, body size, age, moulting stage, diet, tissue type, and environmental conditions [62]. In the present study, only male *M. harpax* were examined; therefore, sex-related variation was not assessed, and the results should not be generalized to female crabs. Hence, the inter-specific comparisons should be interpreted cautiously and should not be taken as evidence that any particular factor caused the observed differences.

4.2.1. Macro elements

Calcium was the most abundant macro-mineral in *M. harpax* muscle, with a concentration of 525.23 ± 2.94 mg/100 g, followed by magnesium (240.60 ± 2.11 mg/100 g), and potassium (158.26 ± 3.40 mg/100 g). The relatively high calcium content may be related to the role of calcium in crustacean growth, cuticle formation, and moulting. Freshwater crustaceans actively absorb calcium through gills and intestine to maintain calcium balance, particularly when calcium availability in the surrounding water is low [63,66]. Calcium is also mobilised from the old cuticle before moulting and used again during the formation of the new cuticle after moulting [63,68]. Dietary calcium has also been shown to influence tissue mineral deposition and exoskeleton development in crabs [67]. Thus, the high calcium concentration in *M. harpax* may be associated with the mineral requirements of growth and moulting. But the level of calcium in *M. harpax* is among the highest documented for edible crab muscle [11,59,60,76]. This highlights its potential as a calcium-rich dietary resource. However, because moulting stage, diet, and water chemistry were not examined in the present study, this explanation remains tentative.

Magnesium was the second most abundant mineral. It is involved in ionic regulation, ATP-dependent enzymatic reactions, and several processes related to growth and moulting. Magnesium uptake through gills and intestine is important for maintaining ionic balance in freshwater crustaceans [66]. Its interaction with calcium may also influence tissue mineral deposition and exoskeleton development [67]. The magnesium concentration observed in *M. harpax*, may therefore reflect the physiological demands of living in freshwater as well as the mineral requirements associated with growth.

Potassium was present at a moderate concentration in the muscle. It is the principal intracellular cation and contributes to the maintenance of membrane potential, cellular volume, and neuromuscular function. Potassium balance is closely associated with osmoregulation and ion transport across the gills, particularly in freshwater crustaceans [66].

4.2.2. Trace or micro elements

Zinc was the most abundant trace element (22.25 ± 0.12 mg/100 g), followed by iron (5.60 ± 0.23 mg/100 g), copper (2.02 ± 0.03 mg/100 g), and manganese (0.10 ± 0.02 mg/100 g). Zinc is involved in enzyme activity, protein synthesis, antioxidant defence, and immune function. Its concentration in crustacean tissues can be influenced by biological factors such as age and sex, as well as by exposure

to water and sediment [62]. The iron concentration observed in the present study may reflect its role in oxygen transport and oxidative metabolism, although sediment composition can also influence iron accumulation in benthic freshwater decapods [69].

Copper is required for formation of hemocyanin, the copper-containing respiratory protein responsible for oxygen transport in many crustaceans [70,71]. The copper concentration in *M. harpax* was therefore consistent with a normal physiological requirement. Manganese was the least abundant trace element. Although required in smaller amounts, manganese contributes to antioxidant enzyme activity, including the activity of manganese-dependent superoxide dismutase in crustaceans[70]. Overall, the trace-element concentrations measured in *M. harpax* were considerably lower than those of the macrominerals but still indicate the presence of nutritionally important elements.

4.2.3. Heavy metals

Lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and mercury (Hg) were below the analytical detection limits in the analysed muscle samples of *Maydelliathelphusa harpax*. These findings indicate that the concentrations of the investigated elements were not quantifiable under the conditions of the present analytical method. However, below-detection-limit results should not be interpreted as evidence of the complete absence of these elements from the tissue.

The presence of potentially toxic elements in aquatic organisms is an important food safety concern, as metal contamination can vary depending on the species, tissue type, feeding habits, environmental conditions, and exposure to contaminated water or sediments. Toxic heavy metals are of major concern in aquatic food products because they can bioaccumulate in tissues and pose chronic health risks, including nephrotoxicity, neurotoxicity, and carcinogenicity [72,73]. Previous studies on freshwater crustaceans from various regions have reported detectable levels of cadmium and lead in the hepatopancreas and muscle tissues of both crabs and crayfish, often exceeding permissible limits [74,75].

In the present study, Pb, Cd, Cr, As, and Hg were not detected above the analytical detection limits in the examined muscle samples. This is a favourable preliminary finding from the food-safety perspective. However, the results should be interpreted with caution because the analysis was limited to the muscle of the male *M. harpax* collected from Jia Bharali River basin. Therefore, these findings cannot confirm that the entire river basin is free from metal contamination or establish the overall safety of the species for human consumption. Further studies involving larger sample sizes, both sexes, different seasons, additional tissues, and site-specific environmental assessments would help provide a clearer understanding of metal accumulation and the food-safety status of *M. harpax*.

4.3. Amino acid composition

The amino acid profile of the muscle tissue of male *Maydelliathelphusa harpax* is presented in Table 3. The pattern of amino acid of *M. harpax* differed from that reported for the freshwater Chinese mitten crab, *Eriocheir sinensis*. In *E. sinensis*, glutamic acid was the most abundant amino acid (2.74 g/100g

meat), followed by aspartic acid, arginine, lysine, and leucine at 1.79, 1.78, 1.46, and 1.39 g/100g meat, respectively [11]. A similar pattern was reported for another freshwater crab, *Sudanonautes aubryi*, in which glutamic acid was the major non-essential amino acid, whereas histidine was prominent in the meat and valine was prominent in the shell [76].

The total quantified amino acid values in *M. harpax* were 0.335, 0.244, and 0.014 g/100g wet weight for essential, conditionally essential and non-essential amino acids, respectively. These values are considerably lower than those reported for *E. sinensis*, for which the amino acid content of body meat was approximately 18.11 g/100g meat [11]. The low values in the present study may be related to hydrolysis and recovery procedure, since acid hydrolysis can result in loss of tryptophan and sulphur-containing amino acids, while glutamine and asparagine may be converted to glutamic and aspartic acids [77]. Therefore, the below-detection values for threonine, arginine, glutamic acid, aspartic acid, glycine, and serine should be interpreted in relation to the analytical procedure and should not automatically be considered evidence that these amino acids are absent from *M. harpax*.

Overall, the amino acid results show that *M. harpax* muscle contains several amino acids, while its amino acid pattern differs from those reported for the freshwater crabs *E. sinensis* and *S. aubryi*. These differences may be related to species-specific protein composition, tissue characteristics, and analytical conditions. The present findings therefore provide useful baseline information for *M. harpax* muscle and can support further evaluation of its protein quality after the calculated nutritional indices are incorporated.

4.4. Vitamin composition

The vitamin composition of the muscle tissue of *M. harpax* is presented in Table 4. The higher concentrations of vitamins E and C indicate that these two vitamins made the greatest contribution to the measured vitamin profile of *M. harpax* muscle. The remaining vitamins were detected at lower concentrations, but their presence indicates that the muscle contains both fat-soluble and water-soluble vitamins. This complements the protein and mineral composition observed in the same tissue.

Quantitative information on the vitamin composition of freshwater crab muscle is limited. The differences among the individual vitamins may be related to their different distribution and stability in crab tissue. Comparable freshwater crab studies have mainly discussed vitamins as a part of the overall nutritional quality of *E. sinensis*, while a complete quantitative profile of the same vitamins analysed in the present study has not been reported consistently [59]. Further investigation of vitamin composition in the edible tissues of *E. sinensis* has also been recommended [20]. Moreover, differences in extraction procedures and reporting units may contribute to variation in vitamin concentrations among studies [78,79].

Overall, the muscle of male *M. harpax* contained a range of fat-soluble and water-soluble vitamins, with vitamins E and C showing the highest concentrations within their respective groups. These results

provide baseline information on the vitamin composition of *M. harpax* from the Jia Bharali River basin and add to the available nutritional information on this underutilized freshwater crab.

5. Conclusion

The present study highlights the nutritional importance of the male freshwater crab *Maydelliathelphusa harpax* from the Jia Bharali River basin of Assam, India. The findings indicate that its muscle contains appreciable protein, important minerals, nutritionally relevant amino acids, and essential vitamins. The relatively high levels of calcium and magnesium further suggest that this species may contribute useful minerals to the diet when consumed as part of a balanced food system.

The detection of nutritionally important elements and bioactive nutrients indicates that *M. harpax* deserves greater attention as a potentially valuable, yet underutilized, freshwater food resource. At the same time, the concentrations of Pb, Cd, Cr, As, and Hg remained below the analytical detection limits in the muscle samples examined. Although this is encouraging from a preliminary food-safety perspective, it should not be taken as proof that metals are completely absent or that the species is universally safe for consumption.

As the study is limited to male crabs collected from a particular river basin, further research should include both sexes, different seasons, larger sample sizes, additional tissues, and environmental monitoring. Such investigations would help establish a more comprehensive understanding of the nutritional quality, metal accumulation, and food-safety status of the species.

Moreover, the results suggest that *M. harpax* holds significant potential as an alternative nutritional resource among underutilized freshwater crustaceans, with possible contributions to dietary diversification and food security in northeastern India. By adding to the limited nutritional information available on freshwater crabs from this biodiversity-rich region, the present study helps address an important gap in their nutritional inventory and provides a foundation for their responsible and sustainable utilization.

Declarations

Ethics Statement

Not applicable

Consent for publication

Not applicable

Competing Interest

The authors declare that they have no conflicts of interest.

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Author Contribution

A.S. wrote the original draft of the manuscript and performed the methodology, investigation, formal analysis, data curation, and visualization. K.K., P.D., S.D., S.R., and H.B. reviewed and edited the manuscript. T.K. contributed to project administration. P.S., K.C., S.B., M.P., P.S., and R.S. carried out the investigation. D.B. conceptualized and supervised the study, contributed to project administration, and reviewed the manuscript. All authors read and approved the final manuscript.

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Data Availability

All obtained data are presented in this study; raw data can be available upon reasonable request to the authors.

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Figures



Figure 1

Dorsal (D) and ventral (V) views of male *Maydelliathelphusa harpax* showing morphometric measurements: carapace width (CW) and carapace length (CL)