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Nutritional properties of commercially important cephalopods from the south-west coast of India

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Abstract

Cephalopods are widely regarded as healthy and nutritionally rich seafood resources. This study focuses on analysing the nutritional composition of six commercially important edible cephalopod species *viz.*, *Cistopus indicus*, *Amphioctopus marginatus*, *Amphioctopus aegina*, *Sepia pharaonis*, *Sepia elliptica* and *Sepia aculeata*, from the Malabar coast of the Indian peninsula. The selected cephalopods were determined to be a rich source of protein ranging from 12.41 to 19.02 g 100 g^{-1}. The amino acid profile demonstrated a balanced ratio of essential to non-essential amino acids (0.93-1.63) with a higher concentration of essential amino acids, attributing enhanced biological value of proteins in these cephalopods. *S. pharaonis* recorded the highest arginine-to-lysine ratio (~1.77), indicating excellent cholesterolemic index. Notably, octopus species had the lowest total cholesterol content (~100 mg 100 g^{-1}) compared to cuttlefish species which recorded higher cholesterol levels (~160 mg 100 g^{-1}). *A. marginatus* recorded more significant quantities of polyunsaturated fatty acids (PUFA) (36.85% total fatty acids) among all the species studied. Octopus species exhibited significantly greater $\sum n$-3/$\sum n$-6 ratio than cuttlefish species. The ideal atherogenicity/thrombogenicity indices (<1.0) in the edible tissues of the studied cephalopods qualify these species as potentially healthy food. *A. aegina* was found to exhibit greater vitamin E (α-tocopherol) contents (17.84 IU), whereas ascorbic acid was pronounced more in *A. marginatus* (47.06 µg 100 g^{-1}). The higher vitamin D3 content in *A. aegina* (96.23 µg 100 g^{-1}) among the species studied, highlights its potential role in preventing osteoporosis in adults. Among microelements such as iron and zinc were found in significant quantities in the cephalopod species studied. The findings from the current study provide valuable insights into the nutritional benefits of these species, positioning them as promising candidates for the seafood industry as possible healthy dietary options.

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Introduction

Cephalopods are considered as one of the healthiest and nutritionally rich seafood sources and a culinary delicacy in many cultures. The global cephalopod catches amount to approximately 4.8 million t annually (FAO, 2014) and in the year 2010, cephalopods accounted for about 4% of the world's fish trade (FAO, 2016). Among cephalopods, cuttlefish and octopus species are gaining wider pharmaceutical recognition due to their potential as sources of biologically active compounds with therapeutic significance (Derby, 2014). In recent decades, cephalopod mariculture has acquired significance due to its potential for nutritional supplementation, short culture cycles, favourable production-to-biomass ratios and enhanced cost-effectiveness (Vidal *et al.,* 2014). The cephalopod molluscs are recognised for their high protein content, with cephalopods contributing to 2% of the world's total protein consumption (Mouritsen and Styrbæk, 2018). Cephalopods are characterised by their low fat content, high levels of essential amino acids, antioxidants and polyunsaturated fatty acids (PUFAs) and rich in minerals, that may not be readily available from other sources (Monroig *et al.,* 2017). These organisms are also rich sources of other micro/macro nutrients. Cephalopod aquaculture has gathered growing interest due to its high nutritional value and market potential. Asia, encompassing China, South Korea, Thailand, India and Vietnam, along with European countries, particularly the Netherlands and Spain, and the USA, dominate the global cephalopod market (Ospina-Alvarez *et al.*, 2022). Notably, South-East Asian and Mediterranean countries, are the major consumers of cephalopods (FAO, 2012). In India, speices of the orders Octopoda and Sepiida *viz., Cistopus indicus, Amphioctopus marginatus, Amphioctopus aegina, Sepia pharaonis, Sepia elliptica* and *Sepia aculeata* (Fig. 1) contribute significantly to the fishery sector, playing an important role in the country's socio-economic development (FAO, 2016; 2018). In view of the above, the current study investigated the nutritional composition of the above mentioned species with an objective to enhance its recognition among consumers and to ascertain its importance for shaping future policies for sustainable utilisation of these species.

Materials and methods

Sample collection and pre-treatment

The cephalopod species belonging to the order octopoda, namely *C. indicus*, *A. marginatus* and *A. aegina* (~3 kg each), and that belonging to the order Sepiida, namely *S. pharaonis, S. elliptica* and *S. aculeata* (~2.5 kg each) were collected from the Malabar coast of India (8°48'N; 78°9'E and 9°14'N; 79º14'E) during December 2019 to March 2020 (Fig. 1). The collectd specimens were cleaned thoroughly with distilled water to get rid of mucus, dirt, and any other adhering particles. The edible portion of the cleaned cephalopod species was considered, whilst other parts, such as the ink gland, opercula, digestive gland and egg masses were carefully removed. The edible portion was sliced into small portions and subjected to separate homogenisation before being kept at -80ºC until further use. The samples were lyophilised using a lyophiliser (Martin Christ beta 2-8 LD plus, Germany) yielding the freeze-dried powder of *C. indicus* (420±15 g), *A. Marginatus* (480±10 g), *A. aegina* (330±25 g), *S. pharaonis* (510±20 g), *S. elliptica* (284±25 g) and *S. aculeata* (325±15 g), which were used for further biochemical and nutritional studies.

Biochemical analysis

The proximate composition analysis was conducted following standard procedures. The protein levels in the edible portion of cephalopod species were evaluated by Lowry's method (Lowry *et al.*, 1951), whereas amino acid analysis was performed as per the previously described Pico-Tag protocol with appropriate alterations (Heinrikson and Meredith, 1984). The lipid extractions from the edible meat of cephalopods were performed by Folch extraction (Folch *et al.,* 1957) method using 200 ml chloroform: methanol (v/v, 2:1). The fatty acid composition of extracted lipid were evaluated as reported previously (Metcalfe *et al.,* 1966; Chakraborty and Paulraj, 2009). Total carbohydrate contents were ascertained by the previously mentioned dinitrosalicylic acid (DNS) method (Maneesh and Chakraborty, 2018). The complete cholesterol content in cephalopod species was determined through spectrophotometric analysis (Wanasundara and Shahidi, 1999). About 10-30 mg of samples were meticulously combined with 0.33 ml of potassium hydroxide (33%) and 3.0 ml of ethyl hydroxide (95%). This mixture was then heated in a water bath to a temperature between 70-80°C for a duration of 15 min. After cooling, 10 ml of hexane and 3 ml of distilled water were introduced into the mixture, allowing it to separate into two distinct layers. Subsequently, 1 ml aliquots were collected from the upper hexane layer and evaporated under a discharge of nitrogen. To this, 2 ml of *O*-phthalaldehyde reagent (50 mg dl^{-1} in glacial acetic acid) and 1 ml of H_2SO_4 was carefully added and thoroughly mixed. Following a 10-min incubation period, the optical absorbance of the solutions was measured at a wavelength of 550 nm. To establish a reference curve, a cholesterol standard was employed. The cholesterol

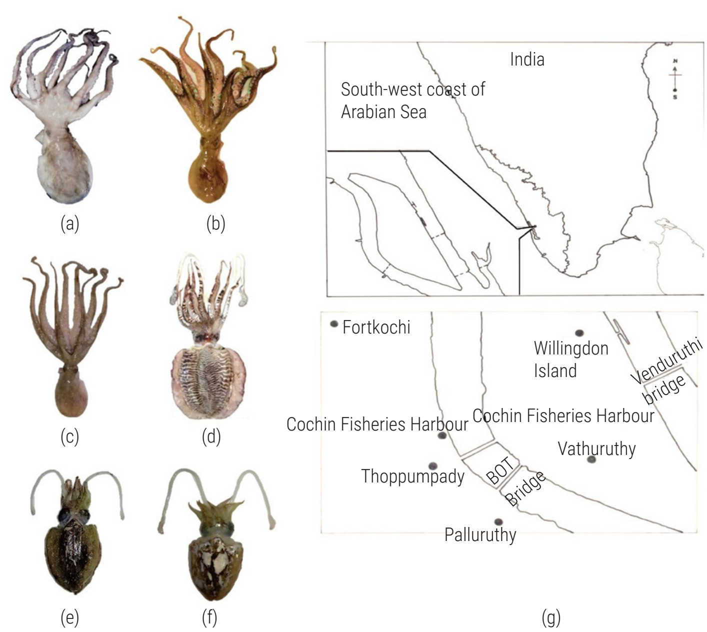

Fig. 1. Representative photographs of (a) *C. indicus* (b) *A. marginatus* (c) *A. aegina* (d) *S.pharaonis* (e) *S. elliptica* and (f) *S. aculeata*. (g) Sample collection sites of the species from the south-west coast of India (8°48' N; 78°9' E and 9°14' N; 79º14' E)

content in the sample was quantified as mg per 100 g of wet sample. Mineral analysis was conducted through inductively coupled plasma mass spectrometry (ICP-MS) using a Thermo Fisher iCAPTM Q instrument, with mineral levels expressed in mg per kg of dry tissue. The vitamins, A, D3, E, and K were evaluated using a method reported earlier (Salo-Vaananen *et al.,* 2000). The moisture content of the samples was determined in accordance with AOAC (1990) standards, while the analysis of crude ash was done as per well-established methods (Krishnan *et al.,* 2019).

Nutritional indices

Using several health indices based on fatty acid and amino acid composition, the nutritional value of tissue portions of six cephalopod species was evaluated. These health indices, including total polyunsaturated fatty acids/total saturated fatty acid (ΣPUFA/ΣSFA), docosahexaenoic acid (DHA)/eicosapentaenoic acid (EPA) and Σn-6/Σn-3 polyunsaturated fatty acids (PUFAs), were examined in comparison to the guidelines provided by the United Kingdom Department of Health (HMSO, 2001). The atherogenicity (AI) and thrombogenicity (TI) indices were computed according to the methodologies described by Ulbricht and Southgate (1991) and Barrento *et al*. (2010). As suggested by Santos-Silva *et al*. (2002), the hypocholesterolemic/hypercholesterolemic (h/H) ratio was calculated. As recommended by the Food and Agriculture Organisation of the United Nations (FAO)/World Health Organisation (WHO) (FAO/WHO/UNU, 2007), the amino acid score for the essential amino acids was also determined.

Statistical analyses

To evaluate potential variations among the means, one-way analyses of variance (ANOVA) were conducted using the Statistical Program for Social Sciences 13.0 (SPSS, USA, ver. 13.0). Significance levels were denoted as $p<0.05$. The reported values represent the mean of triplicate measurements along with their corresponding standard deviations.

Results and discussion

Global cephalopod fishery has risen in the past decades due to increased awareness of their greater nutritional profile. The edible meat of cephalopods has seen remarkable growth in international market value, positioning them as promising candidates for human consumption (Chakraborty *et al.,* 2016). The current work demonstrated the proximate composition of the edible portion of six economically important cephalopod species (octopuse and cuttlefish), thus, ensuring that these species can be consumed as potential health food without any risk of lifestyle diseases.

Carbohydrates (including starches, sugars and fibres) are the major source of energy for animals. Noticeably, octopuses are reported to accumulate significant quantities of carbohydrates due to their comparable shorter life span favouring rapid growth. These serve as energy reserves for various metabolic activities (Salaskar and Nayak, 2011; Shafakatullah *et al.,* 2013). The total carbohydrate content was registered to be higher in *A. aegina* (14.25 g 100 g^{-1} wet weight). The primary constituents of carbohydrates in molluscs predominantly consist of glycogen and glycosaminoglycans, which have been used at different phases like gametogenesis and spawning (Salas *et al.,* 2018). The octopus samples were harvested during the post-monsoon season, which effectively aligns with the statement mentioned earlier. The moisture content of the studied species ranged from 80 to 89% of the wet tissue (Table 1).

In marine molluscs, cholesterol is a prominent sterol biosynthesised from the mevalonate pathway, plays a pivotal role in the normal functioning of cellular metabolism and works as a precursor to the biogenesis of steroid hormones and other vital vitamins. The present study demonstrated that the total cholesterol content recorded in the octopus species (98-110 mg 100 g^{-1}) was lower than those registered in cuttlefish samples (145-170 mg 100 g^{-1}) (Table 1). *Amphioctopus* spp. recorded the lowest cholesterol content (<100 mg 100 g^{-1}) among all the investigated species. Noticeably, the cholesterol content for octopus species has been reported to be low compared to finfish and other bivalve molluscs (Moniruzzaman *et al.,* 2021). Remarkably, the edible tissue of the studied cephalopod species displayed notably lower total cholesterol content compared to that found in meat products in a common diet (Dinh *et al.,* 2011). From a human health perspective, these results indicate that octopuses and cuttlefish are the favoured food items.

The selected molluscs used in this study were identified as valuable protein sources (12.41-19.02 g 100 g^{-1}), which is crucial for the growth and bodily functions, including recovery and repair of tissues for human well-being (Table 1). Previous literature reported comparable protein content for *O. vulgaris* (15.8%) and *S. officinalis* (15.5%) (Zlatanos *et al.,* 2006). The present study focused on amino acid profiles to determine the quality of protein. The amino acid profile (Table 2) of the selected cephalopod species exhibited a greater concentration of essential amino acids (1.19-1.48 g 100 g^{-1}) suggesting that the proteins in the cephalopods possessed a greater nutritional value. Notably, the presence of considerably greater quantities of essential amino acid (TEAA) in all the

Table 1. Biochemical composition (g 100 g^{-1} wet tissue) of Cephalopod species

Biochemical parameters	*C. indicus*	*A. marginatus*	*A. aegina*	*S. pharaonis*	*S. elliptica*	*S. aculeata*
Moisture	89.62^{a}±0.22	85.58^{b}±0.19	87.65^{c}±0.26	81.65^{d}±0.09	89.64^{e}±0.09	86.25^{f}±0.09
Dry matter	10.40^{a}±0.09	14.42^{b}±0.18	12.35^{c}±0.12	18.35^{d}±0.10	10.36^{a}±0.14	13.75^{e}±0.15
Protein	12.41^{a}±0.11	14.24^{b}±0.24	17.55^{c}±0.19	13.83^{d} ±0.28	16.25^{e}±0.31	19.02^{f}±0.21
Lipid	1.44^{a}±0.15	1.90^{b}±0.11	1.18^{c}±0.17	2.02^{d} ±0.14	1.57^{e}±0.10	0.90^{f}±0.12
Carbohydrate	10.44^{a}±0.10	12.96^{b}±0.19	14.25^{c}±0.30	9.25^{d} ±0.26	8.56^{e}±0.15	9.86^{f}±0.22
¥Cholesterol	108.02^{a}±0.1	98.26^{b}±0.07	99.14^{c}±0.11	158.25^{d}±0.16	147.58^{e}±0.15	168.11^{f}±0.18
Crude ash	0.81^{a}±0.22	0.72^{b}±0.22	0.75^{b}±0.22	0.81^{a}±0.22	0.94^{c}±0.22	1.02^{d}±0.22

Data are expressed as mean ± standard deviation (n=3). Means followed by the different superscripts (a-f) within same row indicate significant difference ($p<0.05$).
¥ Total cholesterol content is expressed in mg 100 g^{-1} wet tissue.

studied cephalopod species also supports the above statement. Arginine was found to be the predominant essential amino acid, with approximately 0.35 g 100 g^{-1}, followed by lysine (~0.25 g 100 g^{-1}) (Table 2). The arginine/lysine ratio has been considered as an important parameter determining the cholesterolemic properties and cardiovascular health (Vallabha *et al.,* 2016). Among the studied cephalopod species, *S. pharaonis* recorded the highest arginine-to-lysine ratio (~1.77) followed by *S. aculeata* (~1.75) indicating a good cholesterolemic index. The isobaric leucine and isoleucine amino acids are the predominant amino acids, which make about two-thirds of the muscle protein (Holecek, 2018). Notably, all the studies of cephalopod species exhibited a prescribed leucine to isoleucine ratio (1.2-3.0) by FAO/WHO (FAO, 1990) in which the *C. indicus* displayed the highest ratio of 3.0. The present study revealed that a total of 20 amino acids are present in the edible tissue portions of investigated species with a considerably greater share of lysine followed by arginine and phenylalanine. This indeed implies that these are promising food sources owing to their high-quality protein content. Nurjanah *et al.* (2012) estimated that the cuttlefish, *Sepia recurvirostra* contains arginine (0.97%) and lysine (0.7%) in considerably greater share among essential amino acids in the head and mantle, respectively. Glutamate is one of the predominant non-essential amino acids in all the cephalopod species and cuttlefish species recorded greater concentration of glutamate than octopus, with *S. elliptica* (0.41 g 100 g^{-1}) registering the highest. Sulfur-containing amino acids which significantly contribute to the maintenance of cellular integrity. Sulfur-containing amino acids such as methionine and cysteine were found to be in higher concentrations in octopus species (>0.15 g 100 g^{-1}) compared to cuttlefish species in which *A. marginatus* recorded the highest (0.18 g 100 g^{-1}). This amino acid composition data established that the true protein from cephalopod mollusc could serve as a valuable supplement for amino acid deficiency in daily diets. Table 2 presents the amino acid scores for essential and non-essential amino acids in cephalopod species, with *S. elliptica* demonstrating significantly higher scores compared to the other cephalopod species.

Table 2. Amino acid composition (g 100 g^{-1} wet weight) of the edible part of cephalopod species

Amino acids	*C. indicus*	*A. marginatus*	*A. aegina*	*S. pharaonis*	*S. elliptica*	*S. aculeata*
Essential amino acids						
Thr	$0.12^a \pm 0.02$	$0.05^b \pm 0.02$	$0.10^a \pm 0.05$	$0.12^a \pm 0.04$	$0.16^a \pm 0.04$	$0.14^a \pm 0.04$
Val	$0.04^a \pm 0.02$	$0.03^a \pm 0.02$	$0.02^a \pm 0.03$	$0.09^b \pm 0.05$	$0.14^c \pm 0.03$	$0.09^b \pm 0.03$
His	$0.06^a \pm 0.02$	$0.02^a \pm 0.03$	$0.05^a \pm 0.02$	$0.03^a \pm 0.03$	$0.05^a \pm 0.02$	$0.04^a \pm 0.01$
Lys	$0.36^a \pm 0.04$	$0.29^b \pm 0.05$	$0.31^b \pm 0.06$	$0.18^c \pm 0.01$	$0.22^c \pm 0.04$	$0.16^c \pm 0.03$
Met	$0.16^a \pm 0.03$	$0.14^a \pm 0.04$	$0.12^a \pm 0.04$	$0.08^b \pm 0.06$	$0.10^b \pm 0.05$	$0.09^b \pm 0.03$
Leu	$0.12^a \pm 0.03$	$0.08^a \pm 0.03$	$0.09^a \pm 0.05$	$0.15^b \pm 0.04$	$0.22^c \pm 0.07$	$0.19^c \pm 0.03$
Ileu	$0.04^a \pm 0.02$	$0.05^a \pm 0.03$	$0.05^a \pm 0.03$	$0.12^b \pm 0.07$	$0.16^c \pm 0.03$	$0.12^b \pm 0.03$
Phe	$0.16^a \pm 0.03$	$0.12^b \pm 0.03$	$0.10^b \pm 0.04$	$0.15^a \pm 0.04$	$0.11^b \pm 0.05$	$0.08^c \pm 0.03$
Arg	$0.36^a \pm 0.02$	$0.41^b \pm 0.05$	$0.38^a \pm 0.07$	$0.32^c \pm 0.07$	$0.32^c \pm 0.03$	$0.28^d \pm 0.05$
TEAA	$1.42^a \pm 0.02$	$1.19^b \pm 0.03$	$1.22^c \pm 0.01$	$1.24^c \pm 0.04$	$1.48^d \pm 0.03$	$1.19^c \pm 0.02$
Non-essential amino acids						
Glu	$0.22^a \pm 0.04$	$0.20^b \pm 0.05$	$0.18^a \pm 0.04$	$0.36^c \pm 0.04$	$0.41^d \pm 0.03$	$0.35^c \pm 0.04$
Asp	$0.09^a \pm 0.03$	$0.07^b \pm 0.02$	$0.08^a \pm 0.02$	$0.12^a \pm 0.03$	$0.32^c \pm 0.04$	$0.16^d \pm 0.03$
Ser	$0.06^a \pm 0.03$	$0.06^a \pm 0.03$	$0.04^a \pm 0.04$	$0.05^a \pm 0.02$	$0.08^a \pm 0.02$	$0.14^b \pm 0.03$
Gly	$0.14^a \pm 0.04$	$0.14^a \pm 0.03$	$0.18^b \pm 0.02$	$0.02^c \pm 0.02$	$0.14^a \pm 0.04$	$0.14^a \pm 0.03$
Ala	$0.08^a \pm 0.03$	$0.04^b \pm 0.01$	$0.05^a \pm 0.02$	$0.12^c \pm 0.03$	$0.21^d \pm 0.02$	$0.24^e \pm 0.04$
Pro	$0.14^a \pm 0.04$	$0.16^b \pm 0.07$	$0.12^b \pm 0.03$	$0.09^d \pm 0.04$	$0.12^d \pm 0.03$	$0.14^a \pm 0.03$
Tyr	$0.14^a \pm 0.02$	$0.12^b \pm 0.05$	$0.09^c \pm 0.02$	$0.05^c \pm 0.03$	$0.05^c \pm 0.03$	$0.08^c \pm 0.04$
Cys	ND	$0.04^a \pm 0.02$	$0.03^a \pm 0.01$	ND	$0.03^a \pm 0.01$	$0.02^a \pm 0.02$
TNEAA	$0.87^a \pm 0.01$	$0.83^b \pm 0.02$	$0.77^c \pm 0.05$	$0.81^b \pm 0.02$	$1.36^d \pm 0.03$	$1.27^e \pm 0.01$
Ratio of amino acids						
TAA	$2.29^a \pm 0.02$	$2.02^b \pm 0.03$	$1.99^c \pm 0.03$	$2.05^d \pm 0.03$	$2.84^e \pm 0.03$	$2.46^f \pm 0.02$
TEAA/TAA	$0.62^a \pm 0.03$	$0.59^a \pm 0.01$	$0.61^a \pm 0.03$	$0.60^a \pm 0.02$	$0.52^b \pm 0.01$	$0.48^c \pm 0.04$
TNEAA/TAA	$0.36^a \pm 0.01$	$0.40^a \pm 0.03$	$0.37^a \pm 0.03$	$0.37^a \pm 0.01$	$0.45^b \pm 0.02$	$0.48^b \pm 0.02$
TEAA/TNEAA	$1.63^a \pm 0.02$	$1.43^b \pm 0.01$	$1.58^c \pm 0.02$	$1.53^d \pm 0.02$	$1.08^e \pm 0.03$	$0.93^f \pm 0.02$
TArAA	$0.36^a \pm 0.03$	$0.26^b \pm 0.02$	$0.24^b \pm 0.02$	$0.23^b \pm 0.02$	$0.21^c \pm 0.02$	$0.20^c \pm 0.04$
TSCAA	$0.16^a \pm 0.02$	$0.18^a \pm 0.04$	$0.15^a \pm 0.03$	$0.08^b \pm 0.02$	$0.13^a \pm 0.01$	$0.11^b \pm 0.02$
Arg/Lys	$1.00^a \pm 0.01$	$1.41^b \pm 0.02$	$1.22^c \pm 0.02$	$1.77^d \pm 0.03$	$1.45^e \pm 0.01$	$1.75^f \pm 0.02$
Leu/Ileu	$3.00^a \pm 0.01$	$1.60^b \pm 0.02$	$1.80^c \pm 0.04$	$1.25^d \pm 0.02$	$1.37^e \pm 0.02$	$1.58^b \pm 0.03$

TEAA-Total essential amino acids; TNEAA-Total non-essential amino acids; TAA-Total amino acids; TArAA-Total aromatic amino acids; TSCAA-Total sulfur containing amino acids (tryptophan was not determined).
Data are expressed as mean ± standard deviation (n=3)
ND: Non-detectable
Means followed by different superscripts (a-f) within same row indicate significant difference ($p < 0.05$).

The lipid contents of octopus (1.18-1.90 g 100 g^{-1}) and cuttlefish (0.90-2.02 g 100 g^{-1}) species (Table 1) were found to be significantly lower in comparison to Nudibranch gastropod mollusks (1.42-2.14 g 100 g^{-1}) (Zhukova, 2014). Among octopuses, *A. aegina* (1.18 g 100 g^{-1}) recorded the least lipid content, whereas *S. aculeata* (0.90 g 100 g^{-1}) displayed the minimum content among cuttlefish samples. One of the nutritionally important constituents is the total triglyceride content. Triglycerides, the main constituents of animal fat and one of the nutritionally important constituents, are necessary for diverse biological and metabolic functions. In order to determine the nutritional value of lipid content, the specific fatty acid composition of the triglyceride fraction was evaluated (Table 3). The results demonstrated that the selected species are rich in saturated fatty acids (SFA) ranging from 33 to 43% in which predominant is the palmitic acid (16:0). The PUFAs in the edible tissue part of cephalopod species primarily consist of *n*-3 fatty acids (~27% TFA) than *n*-6 fatty acids (~ 5 % TFA). *A. marginatus* recorded greater quantities of polyunsaturated fatty acids (PUFA) (36.85 %) among the other studied species. Monosaturated fatty acids (MUFA) constituted the lowest percent (<32%) of total fatty acids. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are two biologically important dietary components as they affect various cardiovascular functions, such as chronic arterial disorders, myocardial infarction, and anticoagulation (Swanson *et al.,* 2012). The ∑*n*-3/∑*n*-6 fatty acid ratio is of great significance as it determines the quality of the lipid. An increase in the ratio, proportional to the lipid quality is crucial for aiding in the prevention of coronary heart disease and diminishing the risk of occurrence of cancer (Chakraborty *et al.,* 2014). Among the studied species, octopus samples exhibited significantly greater, nearly two times the ∑*n*-3/∑*n*-6 ratio value showed by cuttlefish. The *n*-3/*n*-6 PUFA proportions of *C. indicus* and *A. marginatus* were found to be considerably higher (7.20-7.41) compared to other cephalopod species. *A. marginatus* exhibited a higher ∑PUFA/∑SFA ratio (>1.0) than the recommended threshold (above 0.45) necessary for achieving balanced fatty acid nutrition (HMSO, 2001). The greater value of *n*-3/*n*-6 fatty acids could evidently contribute to reduced atherogenicity (AI) and thrombogenicity (TI) indices, which implied that the consumption of these plays a cardio-protective and anti-thrombogenic role and must be included in the diet (Ulbricht and Southgate, 1991). AI and TI values in the studied species ranged from 0.53-0.74 and 0.26-0.45, respectively.

The ratio of hypocholesterolemic and hypercholesterolemic fatty acids (h/H index) is a crucial index of fatty acid profile in validating the lipids based on lipid metabolism. A higher h/H ratio is regarded as favourable from the nutritional point of view. The h/H ratio was found to be in the range of 1.59 to 2.10 in all the studied species, in which cephalopod species *C. indicus* and *S. pharaonis* recorded the highest, and therefore, indicating that this ratio contributes to their favourable nutritional and health attributes.

Major water-soluble vitamin C (ascorbic acid) and fat-soluble vitamin E (α-tocopherol) together play an imperative role in the anti-oxidant defense system, and are exclusively acquired through dietary sources. *A. aegina* exhibited greater vitamin E contents (17.84 IU), whereas ascorbic acid was found to be significantly greater in *A. marginatus* (47.06 μg 100 g^{-1}) (Table 4). A greater vitamin D3 content in the edible part of *A. aegina* (96.23 μg 100 g^{-1}) (Table 4) among the other species supported its significance in impeding osteoporosis in adults. Cuttlefish exhibited higher contents of vitamin A (150-180 IU) than those displayed by the octopus species, thereby implicating the greater immune-boosting functions of the former, besides imparting normal vision, proper growth and development. Being rich in vitamins, these species are considered healthy food, which offers greater health benefits.

Cephalopods are recognised as healthy seafood and are a prominent source of macro minerals and trace elements (Aubourg *et al.,* 2021). The studied cephalopod species were found to be abundant sources of macro (Na, K, P and Mg) and micro elements (Fe, Zn and Cu) (Table 4). Phosphorous emerged as the most prevalent macro element trailed by sodium and potassium, whereas calcium was found in appreciable quantities in all the studied species. A greater level of P was recorded in the cuttlefish *S. pharaonis* (~605 mg kg^{-1}). The well-balanced sodium-potassium ratio (≤1.0) of the cephalopod species underscores their significance as healthy dietary options, suggesting their potential utility for individuals with cardiovascular conditions. The Na/K ratio in the cephalopods was within the range of 0.87-1.30 and the highest was recorded in *S. aculeata*. Adequate intake of calcium and phosphate is of significant importance in sustaining normal physiological functions and osteo-health. Deficiency of these two nutrients leads to conditions such as cardiovascular disease and chronic kidney problems (Borrelli *et al.,* 2020).

The examined cephalopod species exhibited Ca+P content in greater quantities (490-610 mg kg^{-1}). Micromineral iron (Fe) is needed for overall growth and development, whereas copper (Cu) and zinc (Zn) play integral roles in various protein functions Considering microelements, cephalopod species were notably abundant in both iron (Fe) and zinc (Zn). *S. elliptica* recorded a greater content of Fe (51.25 ppb) followed by that in the edible part of *A. aegina* (Table 4). Hence, cephalopods, which are rich in macro and micronutrients, could form part of a healthy diet to support optimal human health.

The current work demonstrates a detailed evaluation of the nutritional characteristics of commonly available edible cephalopods belonging to the order Octopoda and Sepiida from the Malabar coast of India. These results recognised that these species could be valuable marine resources of essential nutritional elements for human dietary and metabolic needs. The species constituted prominent levels of C20-22 PUFA (DHA and EPA) and a balanced proportion of *n*-3/*n*-6 fatty acid, which supported their suitability as a well-rounded dietary choice. The ideal atherogenicity/thrombogenicity indices (≤1.0) in the edible tissues qualify these species as a potential health food. Noticeably, the octopus species recorded lesser cholesterol content than those displayed by the studied cuttlefish species. The amino acid profile demonstrated a greater concentration of essential amino acids suggesting a greater biological value of proteins in the cephalopods. Furthermore, they serve as a notable source of vitamins and essential macro and micro minerals crucial for the metabolic functions of the human body. The findings of this study provide valuable insights into the significance of these species for the seafood industry highlighting their potential as contributors to the production of nutritious and healthful food options.

Table 3. Fatty acid composition (% total fatty acids) of the edible part of cephalopod species

Fatty acids	*C. indicus*	*A. marginatus*	*A. aegina*	*S. pharaonis*	*S. elliptica*	*S. aculeata*
Saturated fatty acids						
12:0	0.20[a] ± 0.02	0.18[a] ± 0.05	0.16[b] ± 0.03	0.74[c] ± 0.02	0.48[d] ± 0.02	0.85[e] ± 0.03
14:0	2.09[a] ± 0.03	1.96[b] ± 0.02	2.15[c] ± 0.01	1.95[b] ± 0.03	1.19[d] ± 0.03	2.18[e] ± 0.05
15:0	1.72[a] ± 0.03	1.58[b] ± 0.04	1.64[c] ± 0.03	2.55[d] ± 0.02	1.62[c] ± 0.02	0.39[e] ± 0.02
16:0	24.18[a] ± 0.01	21.16[b] ± 0.01	22.07[c] ±0.02	23.18[d] ± 0.04	21.30[e] ± 0.01	24.50[f] ± 0.01
17:0	0.22[a] ± 0.02	0.15[b] ± 0.02	0.28[c] ± 0.04	1.24[d] ± 0.05	1.15[e] ± 0.02	2.29[f] ± 0.03
18:0	8.78[a] ± 0.03	8.34[b] ± 0.02	9.63[c] ± 0.03	10.15[d] ± 0.01	6.83[e] ± 0.04	7.61[f] ± 0.04
20:0	0.17[a] ± 0.04	0.15[b] ± 0.03	0.19[c] ± 0.03	0.32[d] ± 0.02	0.52[e] ± 0.02	1.26[f] ± 0.02
22:0	0.11[a] ± 0.01	0.09[a] ± 0.05	0.08[a] ± 0.01	0.08[a] ± 0.04	0.41[b] ± 0.01	0.27[c] ± 0.01
24:0	0.06[a] ± 0.02	0.08[a] ± 0.01	0.09[a] ± 0.02	1.21[b] ± 0.01	1.06[c] ± 0.01	1.49[d] ± 0.01
∑ SFA*	37.53[a] ± 0.03	33.69[b]± 0.01	36.29[c]± 0.02	41.42[d] ± 0.01	34.56[e] ± 0.03	40.84[f] ± 0.02
Monounsaturated fatty acids (MUFA)						
14:1n-7	3.22[a] ± 0.02	2.96[b] ± 0.01	3.14[c] ± 0.03	2.25[d] ± 0.02	2.61[e] ± 0.04	2.48[f] ± 0.01
15:1n-7	2.69[a] ± 0.03	2.51[b] ± 0.05	2.53[c] ± 0.02	1.29[d] ± 0.04	1.26[d] ± 0.01	0.18[e] ± 0.03
16:1n-7	5.08[a] ± 0.04	4.57[b] ± 0.02	4.37[c] ± 0.04	5.62[d] ± 0.03	4.18[e] ± 0.03	3.82[f] ± 0.04
18:1n-7	0.18[a] ± 0.02	0.18[a] ± 0.04	0.15[a] ± 0.03	0.12[b] ± 0.03	0.15[a] ± 0.04	0.05[c] ± 0.06
18:1n-9	14.86[a] ± 0.02	14.78[b]± 0.03	13.11[c]± 0.01	19.61[d] ± 0.01	21.86[e] ± 0.02	21.23[f]±0.01
20:1n-9	0.29[a] ± 0.03	0.39[b] ± 0.03	0.32[c] ± 0.03	0.11[d] ± 0.04	0.09[e] ± 0.01	0.32[c] ± 0.02
22:1n-9	0.44[a] ± 0.03	0.36[b] ± 0.01	0.38[b] ± 0.04	0.23[c] ± 0.03	1.44[d] ± 0.01	1.25[e] ± 0.03
24:1n-9	0.21[a] ± 0.02	0.24[a] ± 0.04	0.19[b] ± 0.02	0.18[b] ± 0.03	0.17[b] ± 0.03	0.33[c] ± 0.04
∑ MUFA**	26.87[a] ± 0.03	25.99[b]± 0.02	24.19[c]± 0.04	29.41[d]± 0.01	31.76[e]± 0.03	29.66[f]±0.03
Polyunsaturated fatty acids (PUFA)						
16:2n-4	0.12[a] ± 0.02	0.04[b] ± 0.03	0.04[b] ± 0.01	0.15[c] ± 0.03	0.08[d] ± 0.05	0.18[c] ± 0.04
16:3n-4	0.06[a] ± 0.03	0.03[a] ± 0.01	0.03[a] ± 0.02	0.05[a] ± 0.02	0.06[a] ± 0.07	0.07[a] ± 0.01
18:2n-6	1.39[a] ± 0.01	1.48[b] ± 0.03	1.36[a] ± 0.03	1.63[c] ± 0.01	2.24[d] ± 0.03	1.15[e] ± 0.04
18:3n-6	0.32[a] ± 0.05	0.28[b] ± 0.04	0.24[b] ± 0.04	0.52[c] ± 0.01	0.53[c] ± 0.01	0.43[d] ± 0.04
18:3n-3	0.96[a] ± 0.02	1.08[b] ± 0.04	1.15[c] ± 0.02	0.93[a] ± 0.04	0.89d ± 0.02	2.10[e] ± 0.03
20:2n-6	1.58[a] ± 0.04	2.15[b] ± 0.02	2.25[c] ± 0.03	1.92[d] ± 0.03	2.15[b] ± 0.06	2.15[b] ± 0.02
20:3n-6	0.33[a] ± 0.01	0.39[b] ± 0.03	0.32[a] ± 0.03	0.59[c] ± 0.03	1.72[d] ± 0.07	1.18[e] ± 0.02
20:4n-6	0.25[a] ± 0.03	0.18[b] ± 0.01	0.20[a] ± 0.01	1.14[c] ± 0.04	0.98[d] ± 0.02	1.29[e] ± 0.01
20:5n-3 EPA	12.98[a] ± 0.02	12.14[b] ± 0.02	12.26[c]± 0.05	7.89[d] ± 0.02	8.11[e] ± 0.03	7.44[f] ± 0.03
22:5n-3	0.38[a] ± 0.04	0.56[b] ± 0.03	0.62[c] ± 0.03	0.32[d] ± 0.05	0.76[e] ± 0.04	0.53[b] ± 0.06
22:6n-3 DHA	14.37[a] ± 0.02	18.52[b] ± 0.05	16.58[c] ±0.02	11.85[d] ± 0.01	12.60[e] ± 0.03	8.92[f] ± 0.02
∑PUFA***	32.74 ± 0.01	36.85 ± 0.04	35.05 ± 0.03	26.99 ± 0.02	30.12 ± 0.02	25.44 ± 0.04
∑n-3	28.69[a] ± 0.03	32.30[b] ± 0.02	30.61[c] ±0.06	20.99[d] ± 0.09	22.36[e] ± 0.07	18.99[f] ± 0.02
∑n-6	3.87[a] ± 0.02	4.48[b] ± 0.04	4.37[c] ± 0.08	5.80[d] ± 0.07	7.62[e] ± 0.02	6.20[f] ± 0.03
∑n-3/∑n-6	7.41[a] ± 0.03	7.20[b] ± 0.03	7.00[c] ± 0.07	3.61[d] ± 0.08	2.93[e] ± 0.05	3.06[f] ± 0.03
18:1n-7/n-9	0.01[a] ± 0.03	0.01[a] ± 0.03	0.01[a] ± 0.03	0.005[b] ± 0.03	0.0063[b]±0.03	0.0021[c]±0.03
DHA+EPA	27.35[a] ± 0.02	30.66[b] ± 0.04	28.84[c] ±0.08	19.74[d] ± 0.06	20.71[e] ± 0.02	16.36[f] ± 0.01
∑PUFA∑SFA	0.87[a] ± 0.01	1.09[b] ± 0.04	0.96[c] ± 0.05	0.65[d] ± 0.06	0.87[a] ± 0.07	0.006[e] ± 0.09
AI	0.69[a] ± 0.03	0.59[b] ± 0.06	0.68[a] ± 0.02	0.59[b] ± 0.03	0.53[c] ± 0.01	0.74[d] ± 0.02
TI	0.32[a] ± 0.01	0.26[b] ± 0.05	0.30[a] ± 0.03	0.43[c] ± 0.04	0.34[a] ± 0.02	0.45[c] ± 0.01
h/H ratio	2.10[a] ± 0.01	1.59[b] ± 0.01	1.72[c] ± 0.04	2.10[d] ± 0.02	1.72[c] ± 0.03	1.86[d] ± 0.05

*Total saturated fatty acids; **Total monounsaturated fatty acids; ***Total polyunsaturated fatty acids.
Data presented as mean values of three samples (mean±SD).
Different superscripts (a-f) within same row indicate significant difference (p<0.05).

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Table 4. Mineral and vitamin compositions of the edible part of cephalopod species

Mineral composition / Species	*C. indicus*	*A. marginatus*	*A. aegina*	*S. pharaonis*	*S. elliptica*	*S. aculeata*
Macro elements (mg kg^{-1} dry tissue)						
Ca	5.37^{a} ± 0.11	5.18^{b} ± 0.18	4.21^{c} ± 0.04	4.49^{d} ± 0.08	5.70^{e} ± 0.05	6.11^{f} ± 0.08
P	528.6^{a} ± 0.05	489.50^{b}± 0.12	519.40^{c}±0.14	605.32^{d}±0.15	546.64^{e}±0.16	548.48^{f}±0.16
Na	170.79^{a} ±0.05	121.39^{b}± 0.15	106.12^{c}±0.09	90.22^{d}± 0.04	82.66^{e}±0.04	120.73^{f}±0.05
K	132.28^{a} ±0.09	94.63^{b} ± 0.04	120.56^{c}±0.04	120.13^{d}±0.08	74.26^{e} ± 0.04	92.43^{f} ± 0.12
Mg	83.54^{a} ± 0.07	58.23^{b} ± 0.03	59.04^{c}± 0.02	57.45^{d} ± 0.05	53.04^{e} ± 0.08	66.58^{f} ± 0.06
Micro elements (ppb)						
Fe	38.56^{a} ± 0.08	33.87^{b} ± 0.02	45.37^{c} ± 0.06	41.87^{d} ± 0.06	51.25^{e} ± 0.13	35.56^{f} ± 0.05
Zn	12.62^{a} ± 0.04	16.04^{b} ± 0.18	16.56^{c} ± 0.02	18.31^{d} ± 0.05	14.86^{e} ± 0.03	15.87^{f} ± 0.03
Cu	2.77^{a} ± 0.13	3.45^{b} ± 0.06	2.58^{c} ± 0.04	2.14^{d} ± 0.019	1.43^{d}±0.08	2.43^{e} ± 0.06
Mn	0.26^{a} ± 0.13	0.168^{b} ± 0.11	0.206^{c} ± 0.09	0.15^{d} ± 0.10	0.48^{e} ± 0.07	0.14^{f} ± 0.09
Se	BDL	BDL	BDL	BDL	BDL	BDL
Mineral indices						
Na/K	1.29^{a}± 0.09	1.28^{a}± 0.05	0.880^{b} 0.16	0.75^{c}±0.03	1.11^{d}±0.06	1.30^{f}±0.14
Ca+P	533.97^{a}± 0.05	495.68^{b}± 0.07	523.61^{c}±0.08	609.82^{d}±0.06	609.79^{e}±0.03	554.41^{f}±0.06
Ca/P	0.010^{a}± 0.09	0.010^{a}± 0.06	0.008^{b}± 0.13	0.007^{c}± 0.14	0.010^{f}± 0.04	0.011^{e}± 0.07
Vitamins						
Retinol A (IU)	102.39^{a}± 0.17	94.52^{b}± 0.14	97.82^{c}± 0.11	151.62^{d}±0.23	174.94^{e}±0.13	181.57^{f}± 0.19
Cholecalciferol D3 (IU)	92.21^{a}± 0.10	87.47^{b}± 0.14	96.23^{c}±0.16	84.23^{d}±0.36	87.49^{b}±0.25	81.23^{e}±0.12
α–tocopherol E (IU)	15.42 ± 0.13	16.11 ± 0.04	17.84±0.08	12.45±0.15	14.74±0.23	13.56±0.05
Phylloquinone K1 (μg $100g^{-1}$)	1.47^{a} ± 0.22	1.32^{b} ± 0.04	1.25^{c} ± 0.16	0.70^{d} ± 0.28	0.84^{e} ± 0.33	0.82^{e} ± 0.19
Ascorbic acid C (μg 100 g^{-1})	44.58^{a} ± 0.17	47.06^{b} ± 0.24	41.25^{c} ± 0.12	43.28^{d} ± 0.27	46.12^{e} ± 0.36	44.77^{f} ± 0.19

Data are expressed as mean ± standard deviation (n=3). Means followed by the different superscripts (a-f) within same row indicate significant difference ($p<0.05$).
BDL: Below detectable limit.

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