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First comparison of selected fat-soluble vitamins of edible tissues of invasive Chinese mitten crab (*Eriocheir sinensis*) in the Oder estuary (Baltic Sea)

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Abstract: In Europe, Chinese mitten crabs (*Eriocheir sinensis*) are invasive catadromous crustaceans that are increasingly prevalent and at the same time actively removed from the aquatic environment. In contrast, in Asia, the muscles, hepatopancreas, and gonads of these crustaceans are a traditional source of food with high nutritional value. A significant abundance of these crustaceans found in the southern Baltic Sea watershed, along with findings from previous studies on their nutritional value, indicate that the meat of these crabs could serve as an additional food source for both humans and animals, including in Europe. When evaluating the meat's worth, vitamin content plays a crucial role, which remains unknown in individuals from invasive populations. The aim of this study was to assess the content of fat-soluble vitamins A, E, and D in the edible parts of male and female crabs during two migratory seasons: spring and autumn. The results showed that the average content of vitamins A, D, and E in the edible parts of Chinese mitten crabs was 0.226 ±0.143 ng·mg^{-1}, 0.844 ±0.683 ng·mg^{-1}, and 1.418 ±1.199 µg·mg^{-1}, respectively. Muscles exhibited the highest content of vitamins A and D, while the hepatopancreas contained the most vitamin E. Smaller differences in vitamin content were noted between the sex of the crabs and the seasons of migration. The results show that Chinese mitten crabs can be a valuable source of vitamins A, E, and D, opening potential opportunities for utilizing their meat in the food industry and as a dietary supplement.

Keywords: Chinese mitten crab, edible parts, invasive species, nutritional value, vitamin A, vitamin D, vitamin E

INTRODUCTION

The Chinese mitten crab (*Eriocheir sinensis*) is a catadromous crustacean belonging to the *Varunidae* family (Clark, 2006), naturally distributed from the Fujian province in China (26°N) to the Korean Peninsula (40°N) (Dittel and Epifanio, 2009). In Europe, its presence was first observed in the German river Aller in 1912 (Panning, 1939). The species has two probable modes of spreading: (I) through the transport of juvenile individuals in ballast water of ships (Cohen and Carlton, 1997) or (II) through escapes or deliberate releases associated with the transport of this species (Herborg *et al*., 2005).

In the first half of the 20th century, the Chinese mitten crab occurred in all major rivers of the North Sea and Baltic Sea basin, as well as in the Gironde River on the French Atlantic coast (Herborg *et al*., 2005; Veilleux and Lafontaine de, 2007). Historical records indicate very high densities of this crab in newly colonised areas. For example, Panning (1939) reported that in the 1930s, the Elbe River (northern Germany) witnessed annual catches of 242 Mg, equivalent to an estimated 4.4 mln crabs. In the second half of the 20th century, it was also found in waters of the United Kingdom, Spain, Portugal, and Eastern Europe (Herborg *et al*., 2003; Herborg *et al*., 2005), and later in Italy, the Ukrainian part of the Black Sea, the adjacent Azov Sea, and Western Asia (Robbins *et al*., 2006; Veilleux and Lafontaine de, 2007). A similar spread of the Chinese mitten crab has been observed in North America since the 1960s (Hymanson, Wang and Sasaki, 1999).

Szczecin Lagoon (area of 687 km^2, average depth of 3.8 m, maximum depth of 8.5 m) is primarily fed by the waters of the Oder River. The water body is eutrophic and brackish, with salinity in the central part ranging between 0.5 PSU and 2 PSU (Radziejewska and Schrenewski, 2008). High riverine nutrient loads caused poor water quality, low water transparency, and an unsatisfactory ecological status in the Szczecin Lagoon. Moreover, the waters and bottom sediments have high levels of heavy metals (Nędzarek and Czerniejewski, 2024).

The rapid pace of its spread, negative impact on native organisms and their habitats, as well as hindrance to human activities (Dittel and Epifanio, 2009), have led to the classification of the Chinese mitten crab as an invasive species (Regulation, 2014), one of the world's 100 worst invasive alien species (Lowe *et al*., 2000). The EU enforces the mandatory removal of captured individuals from the environment, as well as the prohibition of collecting, transit, and trade of live specimens (Regulation, 2014). This means that Chinese mitten crabs caught in European waters are disposed of, despite being an excellent traditional food source for inhabitants in the Far East for centuries (Veilleux and Lafontaine de, 2007) thanks to their high nutritional value, high protein content with well-balanced amino acids, and lipids rich in n-3 polyunsaturated fatty acids (PUFA), as well as a unique aroma (Fei, Zhou and Qin, 2006; Chen, Zhang and Shrestha, 2007). An additional advantage of Chinese mitten crab meat is its high yield of edible parts (over 30%) (Czerniejewski, Bienkiewicz and Tokarczyk, 2023), with gonads and hepatopancreas being particularly esteemed for their flavour (Veilleux and Lafontaine de, 2007). The substantial demand for this species' meat in Asian countries has led to increased production of Chinese mitten crab in controlled conditions in China, constituting nearly 70% of Chinese crustacean aquaculture production (Chen *et al*., 2013), with production rising from 3,305 Mg to 808,000 Mg between 1989 and 2021 (Bureau of Fisheries and Fishery Management, MARA, 2022).

The annual catch of Chinese mitten crabs in Central European waters is approximately 180–200 Mg (Fladung, 2000), of which 4.0–5.0 Mg are individuals caught in the Oder Estuary (Czerniejewski and Wawrzyniak, 2006). The highest crab catches occur during the autumn and spring migrations (Czerniejewski and Wawrzyniak, 2006), and their improved utilisation in the food industry could lead to an increased demand for the meat of these crustaceans (Czerniejewski, Bienkiewicz and Tokarczyk, 2023). This, in turn, would diminish the population of this invasive species, thereby safeguarding biodiversity (Regulation, 2014). Especially noteworthy is the assertion by Nędzarek and Czerniejewski (2021) that Chinese mitten crab meat from European waters can be an excellent dietary supplement, providing essential elements at low levels of unnecessary and trace elements, ensuring human health and safety. Additionally, the diversity and good ratio of fatty acids, specifically n-3 to n-6, in their meat make the crabs a potential source of oil, suitable for food fortification and dietary supplement production (Czerniejewski, Bienkiewicz and Tokarczyk, 2023).

In general, aquatic products are known to contain ample fat-soluble vitamins (Semba, 2012), with crustaceans typically offering higher levels of vitamins A and E (Venugopal and Shahidi, 1996; Reksten *et al*., 2024). Thus, Chinese mitten crabs should also be a valuable source of these fat-soluble vitamins, vital for maintaining physiological balance, supporting bone health, vision, cell growth, and immune function, and acting as potent antioxidants in humans (Semba, 2012). Despite the lack of tradition in consuming Chinese mitten crabs in the Baltic Sea region, they can still serve as an additional vitamin source and be used for food fortification, as dietary supplements, or even for cosmetic purposes (Czerniejewski, Bienkiewicz and Tokarczyk, 2023). Such utilisation could positively impact the removal of these invasive organisms from the Baltic Sea watershed (Regulation, 2014).

However, the literature lacks information on the vitamin content in the edible parts of Chinese mitten crabs in European areas of their occurrence. Our knowledge in this regard is limited to a few crab species used in the food industry (Sakthivel, Vijayakumar and Anandan, 2014; Ardiansyah, Nugroho and Meirinawati, 2023). Variations in vitamin content exist among different crustacean species, and similarly, as in the case of the flavour quality of *E. sinensis* and fatty acid content (Wang *et al*., 2022; Czerniejewski, Bienkiewicz and Tokarczyk, 2023), differences may also occur between populations of the same species inhabiting different aquatic ecosystems.

The objective of this study was to determine the content of vitamins A, E, and D in the edible parts of male and female Chinese mitten crabs captured during two migratory seasons in the Baltic Sea basin, i.e. spring and autumn.

MATERIALS AND METHODS

STUDY AREA AND SAMPLING PROCEDURE

Chinese mitten crabs (*Eriocheir sinensis*) for the study were captured during commercial fishing operations conducted in the reproductive migration period of these crustaceans from September 11 to November 9, 2022 (autumn season) and from March 11 to April 28, 2023 (spring season) using fyke nets in the northern part of the Szczecin Lagoon (southern part of the Baltic Sea basin) (Fig. 1). The selection of these two fishing periods stemmed from the fact that over 90% of Chinese mitten crabs in the southern Baltic Sea watershed are caught during this time (Czerniejewski and Wawrzyniak, 2006). Immediately after capture, crabs were sexed according to the method proposed by Czerniejewski (2010), weighed (total weight to an accuracy of 0.1 g on an electronic scale type Axis 2000B), and measured for carapace length (CL) and width (CW) using a computer-coupled electronic caliper with an accuracy of ±0.01 mm. After measurements, crabs were transported in ice to the laboratory, where meat was sampled from the claws, hepatopancreas, and gonads of females. Samples were preserved by rapid freezing at −30°C.

BODY CONDITION

The Fulton's condition factor (K_F) was determined according to the Equation (1) (Czerniejewski, 2010):

$$K_F = \frac{W}{{C_w}^3} 1000 \tag{1}$$

where: W = body weight of Chinese mitten crab (g); C_w = carapace width (mm).

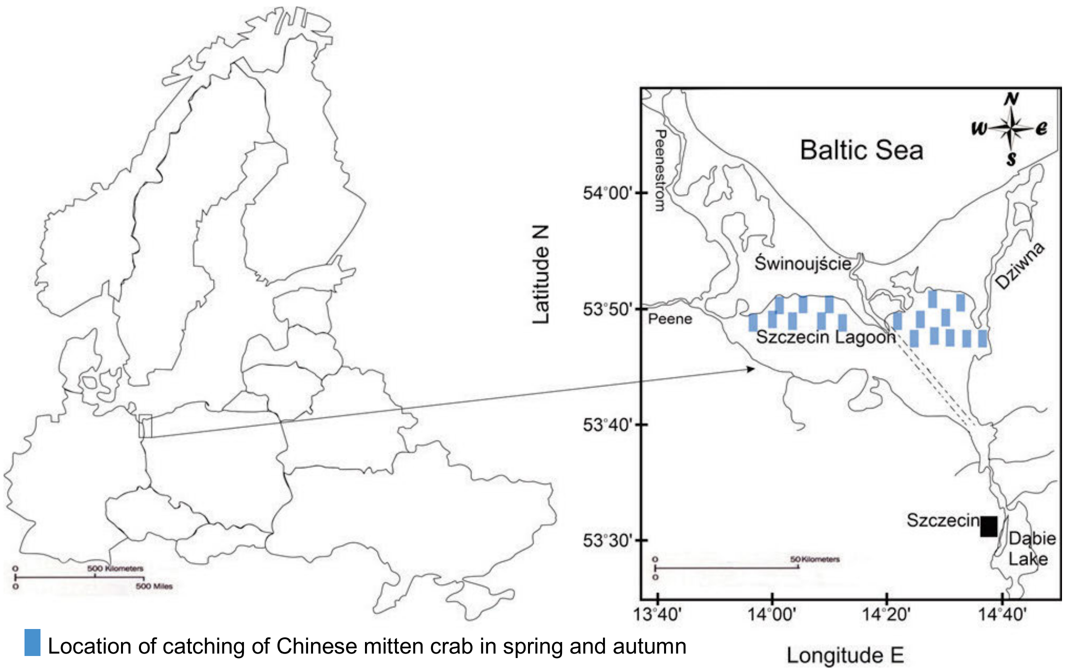

Fig. 1. Map with the location of crab catches, source: own elaboration

SAMPLE PREPARATION

Tissue homogenates were rinsed with ice-cold PBS (phosphate-buffered saline) to remove excess blood, homogenised, and stored overnight at <–20°C. A 10% homogenate (1 g of tissue in 10 mL of ice-cold PBS) was recommended. After two freeze-thaw cycles to break the cell membranes, the homogenates were centrifuged for 5 min at 5000 x g. The supernatant was used for the assays.

DETERMINATION OF VITAMIN CONTENT

For the determination of vitamin A, E, and D concentrations, samples from 31 females (15 individuals caught during the autumn migration and 16 during the spring migration) and 21 males (10 individuals caught during the autumn migration and 11 during the spring migration) were analysed.

The concentrations were determined using the enzyme-linked immunosorbent assay (ELISA) technique (EIAAB Science Inc kits, Wuhan, China) following the manufacturer's instructions (catalog No.: vitamin A – E0923Ge, vitamin E – E0922Ge, vitamin D3 – E0920Ge). Each kit included a polystyrene plate and all the necessary reagents.

A 96-well polystyrene plate coated with monoclonal antibodies specific to each vitamin was used in the assay. Standards and previously prepared samples were added to the wells. After one-hour incubation at 37°C, the plate was washed three times with a wash buffer. In the next step, specific polyclonal antibodies conjugated with horseradish peroxidase were added, followed by another 45-minute incubation at 37°C. After five additional washes, the plates were incubated for 20 min with a tetramethylbenzidine solution, an enzymatic substrate for horseradish peroxidase. The addition of sulfuric acid solution (Stop Solution) halted the colour reaction. Test results were read using an ELISA reader (ELx808 by BIO-TEK Instruments, Inc., USA) at a wavelength of 450 nm. ELISA requires a standard curve by mean optical density using computer software (KC Junior for Windows) capable of generating a four-parameter logistic (4-PL) curve-fit. The method's sensitivity was less than 0.052 ng·mL^{-1} for vitamin A; 0.33 μmol·L^{-1} for vitamin E; and 0.4 ng·mL^{-1} for vitamin D3. To increase the readability of the results presented, a different unit was used for vitamin E, one that the ELISA manufacturer recommends.

STATISTICAL METHODS

The normality of results distribution was assessed using the Shapiro–Wilk test, while the equality of variances was examined with Levene's test. Data were not normally distributed. Mann–Whitney U test was employed to evaluate differences in vitamin concentration between sexes and seasons. Variations in vitamin concentration between tissues were assessed using Kruskal–Wallis test with a Dunn's post-hoc test, because the homogeneity assumption of the variance is not met. Statistical analysis was conducted using Statistica 13.1 software.

RESULTS

SIZE AND CONDITION COEFFICIENT OF CHINESE MITTEN CRAB

In each season, males exhibited significantly higher body weight (W) and a higher Fulton's condition factor (K_F) (Tab. 1). Additionally, in autumn, the size, body weight, and condition factor of both male and female CMC were greater than in spring (Mann–Whitney U test, $p < 0.05$).

CONTENT OF FAT-SOLUBLE VITAMINS IN THE EDIBLE PARTS OF CHINESE MITTEN CRABS

The average content of vitamin A, D, and E in the edible parts of Chinese mitten crabs was 0.226 ±0.143 ng·mg^{-1}, 0.844 ±0.683 ng·mg^{-1}, and 1.418 ±1.199 μg·mg^{-1}, respectively, and differed significantly between different body parts (Kruskal–

Table 1. Size and condition factor of Chinese mitten crabs from Oder estuary in each season

Sex	Carapace				Body weight (W) (g)		Condition factor (K_F)	
	width (mm)		length (mm)					
	value	*SD*	value	*SD*	value	*SD*	value	*SD*
Autumn								
Female	72.31^a	±5.53	65.61^a	±6.25	166.35^a	±36.8	0.44^a	±0.03
Male	73.80^a	±5.34	67.12^a	±6.54	196.95^b	±41.2	0.49^b	±0.06
Spring								
Female	66.84^a	±5.78	60.14	±6.11	123.51^a	±39.4	0.41^a	±0.05
Male	67.62^a	±5.21	61.13	±6.06	145.35^b	±42.6	0.46^b	±0.07

Explanations: a, b = significant differences in size and condition factor of CMC between sexes (Mann–Whitney U test, $p < 0.05$), *SD* = standard deviation.
Source: own study.

Wallis test, $p < 0.05$) (Tab. 2). Muscles exhibited the highest level of vitamin A and D, while hepatopancreas showed the highest level of vitamin E. Regarding the vitamin content in the edible parts of crabs, the following descending order was observed: muscle > hepatopancreas > gonads for vitamin A, muscle > gonads > hepatopancreas for vitamin D, and hepatopancreas > muscle > gonads for vitamin E.

Upon dividing the examined crabs by sex, similar discrepancies in vitamin content in edible parts of crab bodies were noted (Tab. 3). In both females and males, the highest levels of vitamin A and D were observed in muscles, while vitamin E was highest in hepatopancreas. Regarding the vitamin content in the edible parts of crabs, the following descending order was observed for both females and males: muscle > hepatopancreas > gonads (for vitamin A), hepatopancreas > gonads > muscle (vitamin D), and hepatopancreas > muscle > gonads (vitamin E).

Differences in content of vitamin A, D, and E in individual edible parts of Chinese mitten crabs between females and males were not detected at significance level $p = 0.05$ (Mann–Whitney U test).

COMPARISON OF VITAMIN CONTENT IN CHINESE MITTEN CRAB DURING SPRING AND AUTUMN MIGRATION

Tables 4, 5, and 6 present the vitamin A, D, and E content in the edible parts of Chinese mitten crabs caught during spring and autumn reproductive migrations. Statistical analysis based on all

Table 2. Average content of vitamins in the edible parts of the Chinese mitten crab

Vitamin	Hepatopancrea		Muscle		Gonad	
	value	*SD*	value	*SD*	value	*SD*
A (ng/mg)	0.194^a	±0.141	0.336^b	±0.088	0.088^a	±0.043
D (ng/mg)	0.400^a	±0.220	1.508^b	±0.603	0.515^a	±0.442
E (μg/mg)	1.199^a	±1.562	1.535^{ab}	±0.0.31	0.039^b	±0.025

Explanations: a, b = significant differences between the edible parts of the Chinese mitten crab (without division by sex and fishing season) (Kruskal–Wallis test $p < 0.05$); *SD* = standard deviation.
Source: own study.

Table 3. Comparison of vitamin average content in the edible parts of female and male Chinese mitten crabs

Vitamin	Female						Male			
	hepatopancrea		muscle		gonads		hepatopancrea		muscle	
	value	*SD*	value	*SD*	value	*SD*	value	*SD*	value	*SD*
A (ng·mg^{-1})	0.207^{ab}	±0.163	0.312^a	±0.070	0.088^b	±0.043	0.181^a	±0.125	0.357^b	±0.100
D (ng·mg^{-1})	0.497^a	±0.229	1.301^b	±0.433	0.088^a	±0.045	0.312^a	±0.180	1.716^b	±0.698
E (μg·mg^{-1})	1.632^a	±1.306	1.468^a	±0.329	0.038^b	±0.019	1.955^a	±1.840	1.595^a	±0.296

Explanations: a, b = significant differences between individual edible parts of the Chinese mitten crab (with division by sex) (Kruskal–Wallis test and Mann–Whitney U test $p < 0.05$); *SD* = standard deviation.
Source: own study.

Table 4. Vitamin A average content (ng·mg^{-1}) in the edible body parts of crabs harvested in spring and autumn

Tissue	Spring		Autumn		Mann–Whitney U test results		
	value	*SD*	value	*SD*	U	Z	*p*
All individuals							
Muscle	0.347	±0.129	0.333	±0.070	36.00	−0.465	0.642
Hepatopancreas	0.086	±0.138	0.248	±0.112	12.00	−2.201	0.028
Gonads	0.074	±0.040	0.104	±0.044	9.00	−1.004	0.315
Males							
Muscle	0.388	±0.143	0.337	±0.067	10.00	0.320	0.749
Hepatopancreas	0.132	±0.195	0.205	±0.087	6.00	−0.645	0.519
Females							
Muscle	0.265	±0.265	0.330	±0.080	4.00	−1.162	0.245
Hepatopancreas	0.039	±0.058	0.291	±0.125	1.00	−1.936	0.053
Gonads	0.074	±0.040	0.104	±0.044	9.00	−1.004	0.315

Explanation: statistically significant differences at the significance level of $p < 0.05$ between autumn and spring samples are marked in red; *SD* = standard deviation, U = Mann-Whitney U statistic, Z = value of the normal U test approximation, *p* = level of significance.
Source: own study.

Table 5. Vitamin D average content (ng·mg^{-1}) in the edible body parts of crabs harvested in spring and autumn

Tissue	Spring		Autumn		Mann–Whitney U test results		
	value	*SD*	value	*SD*	U	Z	*p*
All individuals							
Muscle	1.766	±1.038	1.462	±0.299	29.00	−0.609	0.543
Hepatopancreas	0.306	±0.196	0.470	±0.219	30.00	−1.670	0.095
Gonads	0.124	±0.192	0.750	±0.375	1.00	−1.789	0.074
Males							
Muscle	2.348	±0.938	1.400	±0.262	3.00	1.420	0.155
Hepatopancreas	0.228	±0.187	0.383	±0.154	7.00	−1.369	0.171
Females							
Muscle	0.892	±0.073	1.524	±0.344	0.00	−2.195	0.028
Hepatopancreas	0.404	±0.180	0.558	±0.251	6.00	−1.173	0.241
Gonads	0.124	±0.192	0.750	±0.375	1.00	−1.789	0.074

Explanation: statistically significant differences at the significance level of $p < 0.05$ between autumn and spring samples are marked in red; *SD*, U, Z, P as in Tab. 4.
Source: own study.

individuals (without sex division) showed that crabs caught in the autumn season exhibited significantly higher vitamin A and E content in the hepatopancreas compared to those caught in the spring season. Additionally, the muscles of crabs caught in the autumn season showed significantly lower vitamin E content than those caught in the spring season.

Furthermore, when separated by sex, the muscles of males caught in the spring season displayed slightly higher vitamin A, D, and E contents ($p > 0.05$) compared to males from the autumn catches. Conversely, a reverse trend was observed in the hepatopancreas of males (Tabs. 4–6).

Analysis of vitamin A, D, and E content in females caught during spring and autumn migrations revealed significantly higher vitamin D content in muscles and vitamin E in the hepatopancreas of individuals from autumn catches.

DISCUSSION

In the rivers of the Baltic Sea basin, Chinese mitten crabs (CMC) are primarily harvested during the autumn migration and, to a lesser extent, in the spring (Czerniejewski and Wawrzyniak, 2006; Dittel and Epifanio, 2009). In the Oder River, these are periods when sexually mature individuals reach a carapace size of 45.8 to 97.6 mm (Czerniejewski, 2010), exhibiting the highest nutritional value (Wang *et al.*, 2022; Czerniejewski, Bienkiewicz and Tokarczyk, 2023). In our study, the crabs analysed for fat-soluble vitamin content in edible tissue displayed size, weight, and condition typical for this species in European waters (Panning, 1939; Czerniejewski and Wawrzyniak, 2006). Consistent with an early study by Czerniejewski (2010), males of this species showed higher body weight and condition factor (K_F) compared to

Table 6. Vitamin E average content (mean ±*SD*) (μg·mg^{-1}) in the edible body parts of crabs harvested in spring and autumn

Tissue	Spring		Autumn		Mann–Whitney U test result		
	value	*SD*	value	*SD*	U	Z	*p*
All individuals							
Muscle	1.697	±0.23	1.419	±0.297	14.50	2.283	0.022
Hepatopancreas	0.622	±0.925	2.752	±1.306	9.00	–3.039	0.002
Gonads	0.010	±0.088	0.043	±0.025	0.00	–1.945	0.051
Males							
Muscle	1.810	±0.194	1.452	±0.271	2.50	1.919	0.055
Hepatopancreas	0.653	±1.119	3.259	±1.457	3.00	–1.880	0.060
Females							
Muscle	1.457	±0.006	1.387	±0.148	5.00	0.904	0.366
Hepatopancreas	0.584	±0.778	2.330	±0.108	1.00	–2.239	0.025
Gonads	0.010	±0.002	0.043	±0.162	0.00	–1.945	0.052

Explanation: statistically significant differences at the significance level of $p < 0.05$ between autumn and spring samples are marked in red; *SD*, U, Z, P as in Tab. 4.
Source: own study.

females, attributed to the presence of larger and heavier claws in males (Giosa de, Czerniejewski and Tanski, 2013).

From the available literature, Chinese mitten crabs emerge as an excellent source of protein (exhibiting a favourable profile of exo- and endogenous amino acids) and fatty acids, owing to their advantageous ratio of n-3 to n-6 fatty acids. This makes them a significant nutritional resource capable of meeting human dietary needs (Wang *et al.*, 2022; Czerniejewski, Bienkiewicz and Tokarczyk, 2023).

Beyond macronutrients, the presence of minerals and vitamins is crucial in human nutrition. According to Nędzarek and Czerniejewski (2021), Chinese mitten crabs can serve as a notable source of trace elements. However, limited scientific information exists regarding the content of fat-soluble vitamins in edible parts of Chinese mitten crabs, hindering direct comparison with data from other regions worldwide. Consequently, our comparative analysis is based on information about the content of these vitamins in other species of aquatic crustaceans.

Vitamins, organic compounds essential for proper bodily functioning, regulate metabolic processes, strengthen the immune system, maintain healthy bones and skin, enhance psychological well-being, and protect against diseases (Semba, 2012). Vitamin A, encompassing various organic compounds with retinol as the active form sourced from animal products and plant-derived carotenoids that can be converted to retinol in human body, plays a pivotal role in visual and retinal processes, skin health, epithelial cell differentiation (Blaner, Shmarakov and Traber, 2021), reproductive system cell development (Youness *et al.*, 2022), and bone tissue growth (Green, Martin and Purton, 2016). Vitamin A also exhibits immune system support and contributes to erythrocyte production (Huang *et al.*, 2018).

Recent evidence underscores the crucial role of vitamin D not only in skeletal health but also in preventing cardiovascular diseases, autoimmune conditions, cancers, and certain mental illnesses (Chan *et al.*, 2022; Starska-Kowarska, 2023; Wassif *et al.*, 2023).

Vitamin E, the foremost antioxidant in lipid environments, acts as a robust defense against free radicals, stabilizing and protecting cell membranes and blood serum lipoproteins from oxidation (Blaner, Shmarakov and Traber, 2021). Tocopherols, a subset of vitamin E, demonstrate potent reducing properties against lipid peroxides, preventing cell apoptosis due to oxidative stress (Asbaghi *et al.*, 2020). All this shows the significance of the vitamin content in raw materials for human food production.

National health authorities in European countries recommend increased seafood consumption due to the beneficial nutritional value, vitamin content, and health effects associated with the consumption of seafood (EC, 2020). However, large differences in the vitamin content of different species of shellfish have been noted. For instance, the mean content of vitamin E varied from 0.75 mg·(100 g)$^{-1}$ in scallops to 28 mg·(100 g)$^{-1}$ in snow crab and vitamin B6 from 0.036 mg·(100 g)$^{-1}$ in blue mussels to 1.8 mg·(100 g)$^{-1}$ in Norway lobster (Reksten *et al.*, 2024). Unfortunately, there is little information about fat-soluble vitamin content in crabs.

Venugopal and Gopakumar (2017) evaluated fat-soluble vitamin content in various crustaceans, including blue crab and Alaskan king crab, revealing significant differences. Blue crab, for instance, had nearly three times less vitamin A (7 IU) than Alaskan king crab (24 IU), while vitamin E was only detected in the former at a level of 1800 ug·(100 g)$^{-1}$. A much higher content of vitamin A (19.64 mg·g^{-1}) was recorded in crab mangrove crab (*Sesarma brockii*) (Sakthivel, Vijayakumar and Anandan, 2014). Edible crabs, and mostly oysters, shrimps, and scallops serve as good sources of vitamin A (Venugopal and Shahidi, 1996; Souci, Fachman and Krant, 2008).

Vitamin A is synthesised in crustaceans from carotenoids, the quantity of which depends on their diet, as crustaceans cannot synthesise them endogenously (Venugopal, 2009; Carvalho de and Caramujo, 2017). Carotenoids constitute a diverse group of compounds, derivatives of unsaturated hydrocarbons and their oxygenated counterparts (xanthophylls), encompassing astaxanthin, astacene, canthaxanthin, cryptoxanthin, fucoxanthin, lutein, neoxanthin, violaxanthin, zeaxanthin, and all-trans-β-carotene (Venugopal and Gopakumar, 2017). Carotenoid content varies in different body parts of crustaceans, with xanthophylls being found in combination with proteins, concentrated in the shell and head, and less abundant in the meat (Vilchez *et al.*, 2011). According to Soumya and Sachindra (2015), the total carotenoid content in the raw meat, head, and shell of tiger shrimp (*Penaeus monodon*) was 17.4, 58.4, and 86.6 $mg \cdot g^{-1}$, respectively; for the Indian white prawn (*Parapeneopsis stylifera*) – 16.0, 153.0, and 104.0 $mg \cdot g^{-1}$; and for the Indo-Pacific coastal shrimp (*Solenocera indica*) – 15.0, 68.0, and 116 $mg \cdot g^{-1}$.

Bell *et al.* (2000) indicate that carotenoids and vitamin E are potent antioxidants, safeguarding unsaturated fatty acids from oxidation by quenching free radicals, including singlet oxygen. Among fat-soluble vitamins, shellfish have a high content of vitamin E (Reksten *et al.*, 2024). In crabs, Wilson, Jeyasanta and Patterson (2017) showed a vitamin E content of 4.23 $mg \cdot (100\ g)^{-1}$ in the muscles of *Portunus sanguinolentus* crab. A study by Vilasoa-Martinez *et al.* (2008) on crab *Chionoecetes opilio* indicated a higher content of vitamin E in shells (23.31 $mg \cdot (100\ g)^{-1}$) and in Snow crab from 1.8 $mg \cdot (100\ g)^{-1}$ in meat to 28.0 $mg \cdot (100\ g)^{-1}$ in hepatopancreas (Reksten *et al.*, 2024). In Mangrove crab *Sesarma brockii* from Pondicherry, southeast India, vitamin A content was 318 $mg \cdot (100\ g)^{-1}$ (Sakthivel, Vijayakumar and Anandan, 2014). Some research suggests that due to the high tocopherol content in crabs, they could be utilised in the production of supplements with anti-cancer effects (Palozza *et al.*, 2009). The aforementioned data, along with the results of Dias *et al.* (2003), emphasise significant variations in vitamin amounts between species.

Some authors indicated that crabs are not a good source of vitamin D (Adeyeye and Jegede, 2017; Reksten *et al.*, 2024), although Sakthivel, Vijayakumar and Anandan (2014) found the vitamin D content of about 6.28 $mg \cdot g^{-1}$ in Mangrove crab. In our study, the content of vitamin D in Chinese mitten crab was 0.844 ±0.683 $ng \cdot mg^{-1}$.

Considering the vitamin D content of other aquatic organisms (Schmid and Walther, 2013), it can be concluded that fish are a better source of this vitamin than crabs. Nevertheless, seafood, including crabs, remains a valuable source of fat-soluble vitamins, with quantities contingent on the total lipid content (Venugopal and Shahidi, 1996). While vitamins A, D, and E are present in the flesh of fish and crustaceans, they are more concentrated in the liver, organs, and eyes (Roos *et al.*, 2007). Also, considerable variation in specific fat-soluble vitamin content exists in the edible parts of crabs (Ardiansyah, Nugroho and Meirinawati, 2023; Reksten *et al.*, 2024). According to Reksten *et al.* (2024), the mean content of α-tocopherol (vitamin E) in Snow crab varied from 1.8 $mg \cdot (100\ g)^{-1}$ in leg meat to 28 $mg \cdot (100\ g)^{-1}$ in the hepatopancreas. In our study on Chinese mitten crab, the average vitamin A content was 0.194 ±0.141 $ng \cdot mg^{-1}$ in the hepatopancreas, 0.336 ±0.088 $ng \cdot mg^{-1}$ in the muscles, and 0.088 ±0.043 $ng \cdot mg^{-1}$ in the gonads. The average vitamin D content in Chinese mitten crabs was 0.400 ±0.220 $ng \cdot mg^{-1}$ in the hepatopancreas, 1.508 ±0.603 $ng \cdot mg^{-1}$ in the muscles, and 0.515 ±0.442 $ng \cdot mg^{-1}$ in the gonads. Notably higher amounts of both vitamins (A and D) were found in the muscles compared to the hepatopancreas and gonads. The highest average vitamin E content was observed in the hepatopancreas in males and females, significantly surpassing that in the gonads (0.029 ±0.025 $\mu g \cdot mg^{-1}$) and slightly exceeding that in the muscles (1.535 ±0.31 $\mu g \cdot mg^{-1}$). These differences in the vitamin content between the parts of Chinese crabs have also been found in other species of crustaceans (Ardiansyah, Nugroho and Meirinawati, 2023; Reksten *et al.*, 2024) and result from their physiological roles played in the body of crabs.

In the hepatopancreas, fat-soluble vitamins such as vitamin E are stored, providing the body with a reserve to meet its physiological demands (Sakthivel, Vijayakumar and Anandan, 2014). Additionally, this organ serves multiple functions, including the absorption and storage of lipids and cholesterol (Ponomareva *et al.*, 2021). Consequently, Chinese mitten crabs exhibit a notable lipid content in the hepatopancreas, ranging from 15.01 to 45.09% (Long *et al.*, 2020; Wang *et al.*, 2022), along with a higher concentration of vitamin D compared to other edible parts of the body, as indicated by our research. However, explaining the lower levels of vitamin A and D in the hepatopancreas compared to the muscles presents a challenge. It is likely that, similar to the findings of Czerniejewski, Bienkiewicz and Tokarczyk (2023), physiological changes during the maturation process result in reduced lipid content in the hepatopancreas of Chinese mitten crabs (Long *et al.*, 2020). Vitamins stored in this organ may also be transported to reproductive organs to facilitate sexual maturity for reproduction and to locomotor organs during reproductive migration. Furthermore, the primary lipids in the hepatopancreas serve as energy reserves, while muscle lipids, akin to lean fish meat, contain a higher proportion of phospholipids and sterols, i.e., non-saponifiable fractions, (Jankowska *et al.*, 2010) which may result in the differences in vitamin content between different body parts of the crabs.

To elucidate the differences in vitamin content in the edible parts of Chinese mitten crab, further sample division was conducted based on the fishing season (Tabs. 4–6). For vitamin A content, a noteworthy increase was observed in the hepatopancreas during autumn, from 0.086 ±0.138 $ng \cdot mg^{-1}$ to 0.248 ±0.112 $ng \cdot mg^{-1}$. Hence, environmental conditions, dietary factors, and the physiological state of the Chinese mitten crab play significant roles, as observed in other crustaceans (He *et al.*, 2016).

In our study, a nearly twofold increase in vitamin D content in the muscles of females was noted between the spring and autumn seasons (from 0.892 ±0.073 $ng \cdot mg^{-1}$ to 1.524 ±0.344 $ng \cdot mg^{-1}$). Conversely, for males, a decrease was observed, though not statistically significant, suggesting physiological changes during maturation (Long *et al.*, 2020).

Roos *et al.* (2007) indicate that vitamin E can accumulate in muscles and hepatopancreas. In our study, a significant increase in tocopherol content in the hepatopancreas of females between the spring and autumn seasons was observed (on average by 1.746 $\mu g \cdot mg^{-1}$). However, we found a decreasing trend in vitamin E content in the muscles of the Chinese mitten crab between spring and autumn. It is noteworthy that no available literature covers seasonal changes in the content of this vitamin in the fats of the Chinese mitten crab. Previous studies on seasonal variability in various crab species have been conducted only for lipid and amino acid content (Barrento *et al.*, 2009; Li, Li and Li, 2010).

In order to evaluate the Chinese mitten crab's suitability for meeting human nutritional requirements, we compared the vitamin content in the crab tissues with the current dietary standards for adults (Tab. 7). The calculated percentage of meeting these standards indicates that an adequate intake of

Table 7. Comparison of the average vitamin content in the examined tissues with the dietary reference values for vitamins (EFSA)

Dietary reference value	Norm	$\bar{x}$ ±*SD*	% of norm ±*SD*
Vitamin A, μg·(100 g)$^{-1}$			
Population Reference Intake (PRI)	750	0.0226 ±0.0143	0.003 ±0.0019
Vitamin D, μg·(100 g)$^{-1}$			
Adequate Intake (AI)	15	0.0844 ±0.0683	0.563 ±0.455
Vitamin E, mg·(100 g)$^{-1}$			
Adequate Intake (AI)	11–13	0.1418 ±0.1199	from 1.289 ±1.09 to 1.09 ±0.922

Explanations: $\bar{x}$ = mean values, *SD* = standard deviation.
Source: EFSA NDA Panel (2015a; 2015b; 2016).

vitamins can be ensured by consuming a diverse range of foods. The crabs can certainly complement a balanced diet but they should not be relied upon as the sole source of essential nutrients.

Crustaceans provide a variety of nutrients essential for human health. They serve as a valuable source of fat-soluble vitamins, with the distribution of these vitamins in different body parts depending on factors like species, sex, habitat, fishing season, diet, and preparation methods. The health benefits of consuming crabs are influenced by the specific species consumed, how often they are eaten, and the quantity consumed. Our findings highlight differences in vitamin content across various parts of the Chinese mitten crab. Despite the various factors affecting vitamin content in crabs, including them in one's diet is consistently beneficial, ensuring access to their vitamin-rich profile.

CONCLUSIONS

Despite their abundance, populations of Chinese mitten crab in Europe are not utilised for culinary purposes, although their meat is considered a delicacy in Far Eastern countries. This study presents the first results of the content of selected fat-soluble vitamins in different edible parts of the Chinese mitten crab from Europe, i.e. the hepatopancreas, gonads, and muscles. Generally, the average content of vitamin A, D, and E in the edible parts of Chinese mitten crabs was 0.226 ±0.143 ng·mg^{-1}, 0.844 ±0.683 ng·mg^{-1}, and 1.418 ±1.199 μg·mg^{-1}, but the content of vitamins depended on the edible parts and the fishing season. The highest amounts of vitamin A were found in the muscles and hepatopancreas (0.336 and 0.194 ng·mg^{-1}, respectively), vitamin D in the muscles and gonads (1.508 and 0.515 ng·mg^{-1}, respectively), while vitamin E in the hepatopancreas and muscles (4.164 and 3.564 μmol·dm^{-3}, respectively. Regarding the vitamin content in the edible parts of crabs, the following descending order was observed for both females and males: muscle > hepatopancreas > gonads (for vitamin A), hepatopancreas > gonads > muscle (vitamin D), and hepatopancreas > muscle > gonads (vitamin E). Crabs caught in the autumn season showed a higher content of vitamins A and E in the hepatopancreas. Considering previous reports on the nutritional value of Chinese mitten crabs (Czerniejewski, Bienkiewicz and Tokarczyk, 2023), low concentrations of essential and trace elements (Nędzarek and Czerniejewski, 2021), and the considerable vitamin content found in this study, the meat of this species can be an excellent addition to the human diet. It can serve as a raw material for the production of dietary supplements, pharmaceutical preparations, and cosmetics. In Europe, where this species is considered invasive, intensive commercial harvesting for consumption or further processing can help reduce the population of Chinese mitten crabs in these waters.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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