Assessment of Essential Elements Accumulation in Red Swamp Crayfish Revealing the High Efficient Enrichment of Se in Freshwater Animal

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Research

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Abstract

Background

Red swamp crayfish (*Procambarus clarkii*) is one of the important aquatic foods for human. Trace elements are indispensable for human to maintain health. They could be enriched by crayfish lived in benthic habitat. However, the trace essential element in crayfish was less reported. In this study, we investigated the trace elements of Fe, Mn, Cu, Zn and Se accumulation in red swamp crayfish.

Methods

Fifteen crayfishes in average, three samples of sediments and water were respectively collected in each location of the fifteen villages located on Hubei and Hunan province of China. Besides, fifteen individuals for red swamp crayfish (*Procambarus clarkii*), variegated carp (*Hypophthalmichthys nobilis*) and hairy crabs (*Eriocheir sinensis*) were respectively collected in the village of Zhutong of Hubei province in China. Inductively coupled plasma mass spectrometry (ICP-MS) was used to perform the examination of trace elements. SPSS software and Duncan test were employed to conduct statistical analysis, respectively.

Results

The concentrations of the five elements were highest in haptopancreas, but two of them (Fe and Mn) were lowest in abdominal muscle. The concentration of Cu, Zn and Se in abdominal muscle was higher than those in exoskeleton. The concentrations of Cu and Se in abdominal muscle of crayfish from Ensi region was highest comparing to the other three regions. There was a highly significant positive correlation for the concentrations of Cu and Se between crayfish and environment. In addition, we found crayfish could specifically enrich Se element. The similar situations were also found in the two investigated freshwater animals variegated carp (*Hypophthalmichthys nobilis*) and hairy crabs (*Eriocheir sinensis*).

Conclusion

The five essential elements were enriched in the abdominal muscle of crayfish, but no excess threshold of food safety standard. The supplement of selenium for human could be realized by consuming crayfish and other freshwater animals.

Introduction

Aquatic food safety and nutrient was concerned by the public. The metal element content of the aquatic product is one the hot topic of food safety. The metal element pollution was mainly derived from a variety of anthropogenic sources including mining and smelting activities, pesticide usage, and discharging of industrial waste water (Fu et al., 2013). The metal elements from sediments are integrated into the water by water flow changes or benthic agitation, which posed a sustained impact on the aquatic organism, finally on human beings through food chain (Jia et al., 2018). Due to the supplying protein and essential fatty acids, the freshwater animals including crayfish and fish were frequently consumed by human that resulted in the metal elements being transfer into human body. The heavy metal was frequently concerned and found the demersal species were closed to the sediment, which showed a higher concentration of heavy metals than those species living other water columns (Hosseini et al., 2015). Furthermore, in past decades, there has been a broad understanding of the importance and toxicity of trace elements in humans (Nordberg et al, 2016). Actually, the essential trace elements, such as copper (Cu), iron (Fe), manganese (Mn), zinc (Zn) and selenium (Se), are indispensable for human health, although the heavy metal is toxic and being suffering healthy risk to human (Antonietta et al, 2019).

Trace element is essential for human body to fulfill the important physiologic function. The role of Cu dependent proteins has been implicated in various physiological and developmental processes including neurotransmission and mitochondrial respiratory chain (Mendelsohn, 2006; Gaier, 2012; Rak, 2016). Fe is essential for forming the complex of Fe-bound hemoglobin to perform the transport of oxygen in blood (Crichton, 2016). Mn deficiency may result in birth defects, poor bone formation and increased susceptibility to seizures (Aschner, 2000 and 2002). Severe zinc deficiency results in symptoms like pustular dermatitis, alopecia, infections secondary to immune dysfunction and hypogonadism (Muhamed, 2014). Se is accounted to the important trace elements for homeostasis of the human system, in particular, for the proper functioning of the immune system (Stuss et al, 2017). However, there is a health risk when the concentration of these essential elements is excess to the threshold. Additional levels of Cu and Zn could cause the disease of nephritis and extensive lesions in the kidney (Sivaperumal et al., 2007). Occupational exposure to Mn could result in a closely resembling idiopathic Parkinson’s disease (Cersosimo, 2006). Excessive consumption of Se could cause classical symptoms of intoxication systemic including weakness, nausea, and even neurological disorders (Navarro-Alarcon, 2008; Fordyce, 2012).

Crayfish is an appropriate model organism to be used in studies of aquatic ecotoxicological (Fernández-Cisnal et al, 2018). Crayfish as an aquatic food had been consumed globally for human to obtain the protein and nutrients with a long history (Patoka et al., 2014). Nowadays, it is a popular food for the European and American. Especially, crayfish is also consumed as the supplementary of proteins and nutrients in Africa (Crandall and Buhay, 2008). In China, red swamp crayfish (*Procambarus clarkii*) derived from Louisiana of America have been widely used as a delicious food since the 1980s (Mu et al., 2007). Recent years, Red swamp crayfish is widely reared in paddy fields of Yangtze River basin in China which called rice-crayfish co-culture. At present, China is the world's largest producer and consumer of crayfish (Peng et al., 2016; FAO, 2019). Red swamp crayfish is thought to accumulate metal elements because of its high adaptability and tolerance to the complex environment. Owing to the food chain amplification, the metal element exposure for human has been greatly increased. Therefore, the metal content of red swamp crayfish and its safety as human food have become the focus of attention. Previous studies indicated that the health risk posed by the toxic heavy metals from red swamp crayfish in China is very low for human beings (Peng et al, 2016; Xiong et al, 2020). However, less investigation for the essential trace elements in tissues of crayfish was performed up to date. In general, the trace elements content of the various diets could be significantly different depending on the food items and their geographical environment. The objectives of this investigation were to: (1) investigate the concentration of the essential elements both in the three tissues of red swamp crayfish and the sediment of the corresponding environment, (2) examine the correlation of trace elements concentrations in crayfish tissue with those in the corresponding sediment, (3) compare the difference of the trace element accumulation in the tissues including abdominal muscle, haptopancreas and exoskeleton of red swamp crayfish from the different regions of China, (4) compare the difference of bioaccumulation factor for five trace elements (Cu, Fe, Mn, Zn and Se) in red swamp crayfish.

Materials And Methods

Sample collection

The rice-crayfish co-culture fields located on the eleven village of Baohe, Chetianping, Taolin, Liyushan, Hengshanzui, Haikou, Hujiawan, Futian, Hengtai, Pengjiatai and Bailuhu, and the wild ponds located on the four village of Lianhuachi, Chunmuying, Shima and Ganyan in Enshi of Hubei province that is called the place“□□”there is the most of selenium in the world, were selected to collect the specimens of sediments, water and red swamp crayfish (*Procambarus clarkii*) (Figure 1). Each village we collected 10-30 red swamp crayfish. Besides, fifteen individuals for red swamp crayfish (*Procambarus clarkii*), variegated carp (*Hypophthalmichthys nobilis*) and hairy crabs (*Eriocheir sinensis*) were respectively collected in the village of Zhutong of Hubei province. Three of sediment (500 g) and water (500 mL) were collected in each of the investigated place, respectively. Each of the collected water was mixed with 5 mL of 65% HNO_3 (SIGMA-ALDRICH USA CAS 30709).

Sample treatment and analysis

Sample treatment

The tissues of hepatopancreas and muscle of crayfish, hairy crabs and variegated carp were collected respectively. The exoskeleton of crayfish was additionally collected. All the samples of tissue and sediments were weighed, dried at 60°C to pulverize them into powder, then these samples were screened through 100 mesh. 0.2 g of the sample was mixed with 10 mL of 65% HNO3 (SIGMA-ALDRICH USA CAS 30709) to perform the digestion experiment using microwave digestion instrument (CEM MARS 6 USA), which was stopped by adding 50 mL ultrapure water (ddH_2O) when the digestive solution was cooled to room temperature.

Elements of sample to be tested concentration detection

Inductively coupled plasma mass spectrometry (Agilent 7700 series ICP-MS USA) was employed to examine the heavy metal elements. Before loading the sample, it is blasted for 5-10 min by the helium (5 mL min^{-1}) and argon (15 mL min^{-1}). Standard solution (Agilent Environmental Calibration Standard USA CAS 5183-4688 and Agilent ICP-MS Internal Std Mix USA CAS 5188-6525) and samples were prepared to examine the heavy metals elements, the standard curve is constructed based on the response signal value of the element to be measured to the selected internal standard. The heavy metal elements concentration was calculated according to the standard curve. The more detail information was cited the previous report (Yang et al. 2018).

Data calculation and analysis

SPSS software (v.20.0, SAS Institute, Inc. USA) was employed to perform statistical analysis. The correlation analysis was carried out by the Pearson correlation. The statistically differences were determined by a significant at $P < 0.05$. Multiple comparisons were conducted by Duncan test with two significant level of $P < 0.05$ and $P < 0.01$.

To know whether the habitat influence trace metal accumulation in the different population and species, the bioaccumulation factor (BAF) was used to standardize and the variability contributed by the cupture site and thus be able to compare the levels of metal accumulation among all the individuals and the different species. Crayfish and crab was benthic fauna that the habitat of them is contact with sediment. Thus, BAF values are calculated as the ratio between the element concentrations in organisms (mg kg^{-1}, Dry weight) and the element in sediment (mg kg^{-1}, Dry weight) (Garnero et al., 2018).

Results

Correlation of five essential elements in the three tissues of crayfish

The concentrations of five essential elements (Mn, Fe, Cu, Zn and Se) in the red swamp crayfish were examined and the results showed the wide variations for the concentration of the trace of Mn, Fe, Cu and Zn among the tissues of haptopancreas, abdominal muscle and exoskeleton (Table 1). The concentration of Mn in abdominal muscle was 21.02 mg kg^{-1}, significantly lower than those of in haptopancreas (236.07 mg kg^{-1}) and exoskeleton (274.67 mg kg^{-1}). The concentration of Fe (2517.94 mg kg^{-1}) in haptopancreas was highest, followed by that in exoskeleton (114.92 mg kg^{-1}), and the one in abdominal muscle (34.85 mg kg^{-1}) was lowest. The mean concentration of Cu, Zn and Se was highest in haptopancreas, medium in abdominal and lowest in exoskeleton (Table 1). The variation coefficient of the concentration of the five essential elements in the three tissues was arranged from 0.10 to 2.42 (Table 1). For the elements of Se and Fe, there is a highly significant association among muscle, hepatopancreas and exoskeleton ($P < 0.01$) (Supplementary table 1). The content of Mn in exoskeleton has the significant positive relevance with that of in muscle and hepatopancreas ($P < 0.01$). The content of Cu between exoskeleton and muscle has the significantly positive correlation and the content of Zn between muscle and hepatopancreas has the significantly positive correlation ($P < 0.01$).

Table 1
The concentrations of five essential elements in the different tissues of red swamp crayfish (*Procambarus clarkii*) (mg kg^{-1}, Dry weight)

Element	Am	He	Ex
Mn	21.02 ± 17.77b	236.07 ± 191.75a	274.67 ± 236.98a
CV	0.85	0.81	0.86
Fe	34.85 ± 17.72c	2517.94 ± 1571.74a	114.92 ± 108.81b
CV	0.51	0.62	0.95
Cu	19.62 ± 7.93b	116.85 ± 283.34a	16.52 ± 8.76c
CV	0.40	2.42	0.53
Zn	73.95 ± 7.72b	124.74 ± 60.43a	21.79 ± 8.55c
CV	0.10	0.48	0.39
Se	1.04 ± 0.47b	2.56 ± 0.89a	0.38 ± 0.16c
CV	0.45	0.35	0.42

Data were showed with mean ± SD; He, hepatopancreas, Am, abdominal muscle, Ex, exoskeleton; a, b and c, ranked by Duncan test at $P < 0.05$.

As shown in Supplementary table 2 and Supplementary table 3, the content of Mn in crayfish has a significant positive association with Cu ($P < 0.01$), Zn ($P < 0.05$) and Se ($P < 0.01$) in hepatopancreas, has a highly significant positive correlation with Cu, Zn and Fe ($P < 0.01$) in muscle, also has a highly significant positive correlation with Cu and Fe in exoskeleton ($P < 0.01$), but has a significant negative correlation with Zn in exoskeleton ($P < 0.05$). The content of Se both in heptopancreas and exoskeleton of crayfish has a highly significant positive correlation with Zn ($P < 0.01$). The content of Se have a highly significant positive correlation with Cu in exoskeleton ($P < 0.01$), and Fe in hepatopancreas ($P < 0.01$).

Correlation of the five essential elements between crayfish and environment

The significant difference for the five essential concentrations in each of the three tissues were examined among the four investigated geographic regions (Fig. 2, Supplementary Fig. 1 and Supplementary Fig. 2). Three of the five elements (Mn, Fe and Zn) in abdominal muscle showed the highest content in the region of northwest of Poyang Lake (NWPYL) where had the highest concentration of the five elements in haptopancreas among the four investigated regions. On the contrary, the concentrations of three elements including Mn, Zn and Se both in abdominal muscle and haptopancreas were lowest in the region of north of Dongting Lake (NDTL). But the concentration of Cu for three tissues was lowest in the region of south of Dongting Lake (SDTL). The concentrations of Se in two tissues of abdominal muscle and exoskeleton were the highest in the Enshi region (ESR) (Fig. 2 and Supplementary Fig. 2).

There was a highly significant positive correlation for the concentration of Se between sediment and abdominal muscle ($r = 0.68$) and exoskeleton ($r = 0.72$), respectively. A significant positive correlation was examined for the concentration of Cu between hepatopancreas and sediment (Table 2). The positive correlations were also identified for the concentration of Mn, Fe and Zn among abdominal muscle and sediments ($0.14 \le r \le 0.34$). Whereas, the negative correlations were examined for the concentration of Fe, Cu and Zn among exoskeleton and sediment ($-0.43 \le r \le -0.17$).

Table 2
The correlation of five essential elements concentrations between tissues and sediments.

Element	Mn	Fe	Cu	Zn	Se
Am	0.29	0.14	-0.09	0.34	0.68**
He	0.30	0.20	0.88**	0.27	0.28
Ex	0.34	-0.43	-0.17	-0.20	0.72**

He, hepatopancreas, Am, abdominal muscle, Ex, exoskeleton; “**”, represents $P < 0.01$.

Different enrichment level for the five essential elements in red swamp crayfish

To investigate the element distribution of the different sample environments, the sediments and culture water of sixteen sample locations were examined the five elements. In sediment, the concentration of Fe, Mn, Cu, Zn and Se was arranged from 20.46 mg g^{-1}(Hujiawan) to 86.34 mg g^{-1} (Liyushan), 79.91 mg kg^{-1} (Taolin) to 751.36 mg kg^{-1} (Chunmuying), 9.77 mg kg^{-1} (Futian) to 139.72 mg kg^{-1} (Liyushan), 27.20 mg kg^{-1} (Futian) to 146.02 mg kg^{-1} (Liyushan) and 0.11 mg kg^{-1} (Chetianping) to 0.68 mg kg^{-1} (Chunmuying), respectively (Supplementary table 4). The concentrations of the five elements in cultural water were far less than those of the sediment (data not shown). The bioaccumulation factors (BAF) of the five elements in crayfish were calculated, respectively. Three elements (Se, Zn and Cu) have been showed a high accumulation level in haptopancreas (BAF value more than 1) (Table 3). Interestingly, the accumulation level of Se elements was far more than those of the other four elements, the highest BAF value in haptopancreas was up to 17.65 (Table 3). Besides, the BAF values of the five elements in haptopancreas were higher than those in abdominal muscle. Furthermore, the similar accumulation situation was detected in the four investigated regions (Table 3).

Table 3
The bioaccumulation factor (BAF) values of five essential elements in haptopancreas and abdominal muscle to sediments

Region	Mn		Fe		Cu		Zn		Se	
	Am	H	M	H	M	H	M	H	M	H
SDTL	0.13	0.75	0.00	0.13	0.69	2.12	1.11	2.00	6.66	17.65
NWPYL	0.08	0.80	0.00	0.16	0.66	4.40	1.21	2.16	4.77	13.35
NDTL	0.05	0.29	0.00	0.12	1.07	3.97	1.44	2.13	4.18	11.68
ESR	0.06	1.29	0.00	0.09	1.28	4.63	1.31	2.57	2.77	6.31

SDTL, represents South of Dongting Lake region; NDTL, represents North of Dongting Lake region; NWPYL, represents Northwest of Poyang Lake region; ESR, represents Enshi region; Am, abdominal muscle; He, hepatopancreas.

The enrichment of the five essential elements in different aquatic species

To validate whether the accumulation level and pattern of the five elements is specific in crayfish, the concentrations of the five elements both in the three different freshwater animals (crayfish, *P. clarkii*, crab, *E. sinensis* and carp, *H. nobilis*) and the corresponding sediments were examined in the same ponds with three independent repeats. The concentrations of three elements including Mn, Fe and Cu in haptopancreas of crayfish were significant higher than those of crab and carp, but the concentrations of Mn and Cu in muscle of carp were significant lower than those of crayfish and crab (Table 4 and Supplementary table 5). The concentration of Zn for haptopancreas was highest in carp (189.27 mg kg^{-1}), and lowest in crayfish (77.50 mg kg^{-1}). On the contrary, the concentration of Zn for muscle was lowest in carp (27.58 mg kg^{-1}), but was the highest in crab (205.52 mg kg^{-1}) (Table 4). For element of Se, there was a significant higher concentration for liver (7.60 mg kg^{-1}) and muscle (1.16 mg kg^{-1}) of carp than those of crayfish (haptopancreas, 2.15 mg kg^{-1}, abdominal muscle, 0.74 mg kg^{-1}) and crab (haptopancreas, 2.48 mg kg^{-1}, muscle, 0.90 mg kg^{-1}) (Table 4 and Supplementary table 5), respectively. In addition, the accumulation level (BAF) and pattern of the five elements in liver / haptopancreas and muscle of the three freshwater animals were similar. The BAF values of Mn and Fe in the two tissues of three animals were respectively smaller than 0.40, but the BAF value of Se was more than 3.90 (Table 5). Especially, they were more than 11 in haptopancreas of the three animals. The BAF value of Cu in two tissues of carp was smaller than those in crayfish and crab. The similar situation was observed for BAF value of Zn in muscle of the three animals, but it was opposite situation in liver / haptopancreas (Table 5).

Table 4

The concentrations of five essential elements in different Specie's muscle (mg kg^{-1}).

Specie	Mn	Fe	Cu	Zn	Se
Crayfish	24.37 ± 6.14a	93.06 ± 29.55a	31.76 ± 4.55b	84.31 ± 6.18b	0.74 ± 0.09b
Carp	3.66 ± 1.02b	46.49 ± 16.84c	1.57 ± 0.26c	27.58 ± 2.33c	1.16 ± 0.10a
Crab	27.16 ± 11.01a	61.61 ± 16.05b	64.60 ± 14.76a	205.52 ± 14.6a	0.90 ± 0.13b

Carp, Bighead carp (*Hypophthalmichthys nobilis*); Carb, Chinese Mitten crab (*Eriocheir sinensis*); Crayfish, red swamp crayfish (*Procambarus clarkii*); Data were showed with mean ± SD; a, b and c, ranked by Duncan test at $P < 0.05$.

Table 5

The bioaccumulation factor (BAF) values of five essential elements in different tissues to sediments

Species	tissues	Mn	Fe	Cu	Zn	Se
Crayfish	Am	0.04	0.00	1.19	1.17	3.92
Carp		0.01	0.00	0.06	0.38	6.20
Crab		0.05	0.00	2.41	2.86	4.81
Crayfish	He	0.36	0.11	11.88	1.08	11.47
Carp		0.03	0.02	4.06	2.63	40.46
Crab		0.05	0.03	4.58	1.83	13.23

Carp, Bighead carp (*Hypophthalmichthys nobilis*); Carb, Chinese Mitten crab (*Eriocheir sinensis*); Am, abdominal muscle; He, hepatopancreas.

Discussion

The different distribution of the essential element in the different tissues of crayfish

It was reported that Cu and Zn as the metal cofactor functional as superodixde dismutase (Cu/Zn-SOD) to regulate the redoxreactions, mitochondrial energy metabolism to maintain normal reproduction (Uriu-Adams and Keen, 2005). Crayfish could increase the antioxidant response with the Se supplemented diets that showed a higher Se level in haptopancreas (Dörr et al., 2008 and 2013). Interestingly, Cu, Zn and Se were respectively examined the highest concentration in haptopancreas, the lowest in exoskeleton, and the medium in abdominal muscle. It is known that haptopancreas is the digestive gland to absorption of nutrients and excrete fluids enabling breakdown of nutrients (Dörr et al., 2013). However, Fe and Mn elements in exoskeleton were significant higher those in abdominal muscle. These results may suggest that the essential elements of Cu, Zn and Se from haptopancreas was prefer to be translated to abdominal muscle, but Mn and Fe elements translated to exoskeleton was more than those translated to abdominal muscle. It may imply that the element of Cu, Zn and Se are more important and necessary for crayfish to maintain the normal physiological function, such as growth and immune. However, the concentration of Fe and Mn in haptopancreas was far more than those of Cu, Zn and Se. Especially, the concentration of Fe was 20 times more than those of Cu and Zn in haptopancreas. It was reported that Fe in excess can cause the physiological dysfunctions and various diseases (Lesani et al., 2019). The stress of high concentration of Fe in crayfish may result in more Fe being translated to exoskeleton that could be molt away. Jiao et al (2019) analyzed the heptopancreas transcriptomes of crayfish after stimulation with $FeCl_3$. The results indicated that superoxide dismutase (SOD) and catalase (CAT) activities were all down-regulated comparing to the control. There is an assumption that crayfish are exposed to Fe^{3+} at a high concentration, and the body produces far more reactive oxygen species (ROS) than their ability of defending, leading to be a toxic state. In a word, there were the different distributions on the three tissues for the five essential elements, which are probably conducted by the genetic regulation.

Bioaccumulation of the essential element dependent of environmental factor

In past, most researchers were focused the heavy metal exposure on crayfish in lab (Shui et al., 2020; Zhang et al., 2020). There was less research on the *in situ* examining the trace elements of crayfish from the different regions. Crayfish were cultured in lots of regions in China (Yi et al., 2018). There were the different accumulation levels for the essential elements in crayfish from the different regions (Fig. 2, Supplementary Figs. 1 and 2). It suggested that these elements accumulation in crayfish may depend of the environmental conditions. For instance, the concentration Fe element was very far higher those of the other four elements in sediment, which was corresponding to the highest concentration of Fe in haptopancreas of the investigated crayfishes. It suggested that high concentration iron in sediment could result in the higher accumulation of iron in crayfish. Furthermore, accumulation of Cu in haptopancreas was highly significant positive correlation with that of the sediment (Table 2). It had a significant positive correlation for Mn element between the sediment and exoskeleton as well. Besides, all the five elements in the region of NWPYL showed the highest concentration in the heptopancreas, which is probably attributed to mining in region of NWPYL. Similarly, accumulation of Se in abdominal muscles and exoskeleton was the most in ESR where there is the highest Se concentration in sediment around the world. It was corresponding to the highly significant positive correlation for Se between sediment and both of abdominal muscle and exoskeleton (Table 2). Together, these results suggested that the five essential elements accumulation in crayfish was positive correlation with their concentrations in the environment.

Se is a specially accumulated essential element in freshwater animals

It is found that there is the distinct BAF value for the different essential elements in spite of crayfish is the same environment. The BAF value of Fe and Mn was smaller than those of the other three elements for the four investigated regions. As to the elements of Cu, Zn and Se, the BAF value of Se either in all regions or in all tissues was the most one (Table 3 and Table 5). This specific and high efficient accumulation of Se in the organisms was less reported in past research. Whether the other freshwater animal also have this accumulation ability for Se element, we performed the comparing among three freshwater animals, crayfish, carp and crab in the same environment, the result indicated that there are the similar situation that there was a very higher BAF value for Se than those of the other four essential elements among the three investigated animals (Table 5). Together, the results indicated that the freshwater animals including crayfish, crab and carp could specially and strongly accumulate Se elements due to some reason. It means that these freshwater animals could absorb and accumulate Se in their tissues even in the Se rare geographic regions. But a question could be easily raised that whether the feeding give some contribution to Se accumulation ? Actually, the similar results were also observed in the wild pond in the ESR. It further suggested that the higher BAF of Se in the different freshwater animals probably attributed to biological characteristics. It was corresponding to the report that no relation was observed between accumulation of Se and the feeding and habitat of the fish, the metal accumulation in tissues was associated with the detoxification and metabolism mechanisms of the organism, which is more species dependent (Garnero et al., 2018). However, it looks impossible to excess accumulation of Se in the crayfish even there is enough Se in the environment, because the lowest BAF value of Se was found in ESR where is the place of most enrichment of Se in the word (Table 3). Thus, it suggested that crayfish could highly enrich Se when there is a lower concentration in the environment, but not accumulate overdose.

Conclusion

Nowadays, Red swamp crayfish is favored by the most of people not only attributed to the protein and fatty acids, but also it’s delicious. However, the essential elements within the edible abdominal muscle are costly mined except for the health risk assessment to toxic heavy metals. Here, we found the five essential elements were enriched in the abdominal muscle, but no excess threshold of food safety standard for the normal daily consumption by human based on the standard of Evaluations of the Joint FAO/WHO Expert Committee on Food Additives (Data not shown). Especially, it was interestingly found that Se could be specially absorbed and accumulated by the three freshwater animals. It is significant to the formulated feed improvement that could reduce the Se supplement. This found give us a new insight of intake of essential nutrients in the freshwater animal, which also absorb us attentions for human food nutrition and safety control in the future. Especially, it is possible for the people who living in the Se rare region to uptake the indispensable trace element Se by consuming the freshwater animal.

Declarations

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Authors' contributions

X. F. Bai contributed to the design of the study. G.H. Peng and collected the samples and wrote the first draft with J. X. Sun. L.J. Xiong, B. Peng and Y. F. Tan collected the samples. Y. L. Wu analyzed the partly data. The paper and Supplementary Information were revised by X. F. Bai, and approved by all the authors.

Ethical Approval and Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of supporting data

The data are available from the corresponding author upon reasonable request.

Conflict of interest

We declare that there is no conflict of interest.

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Figures

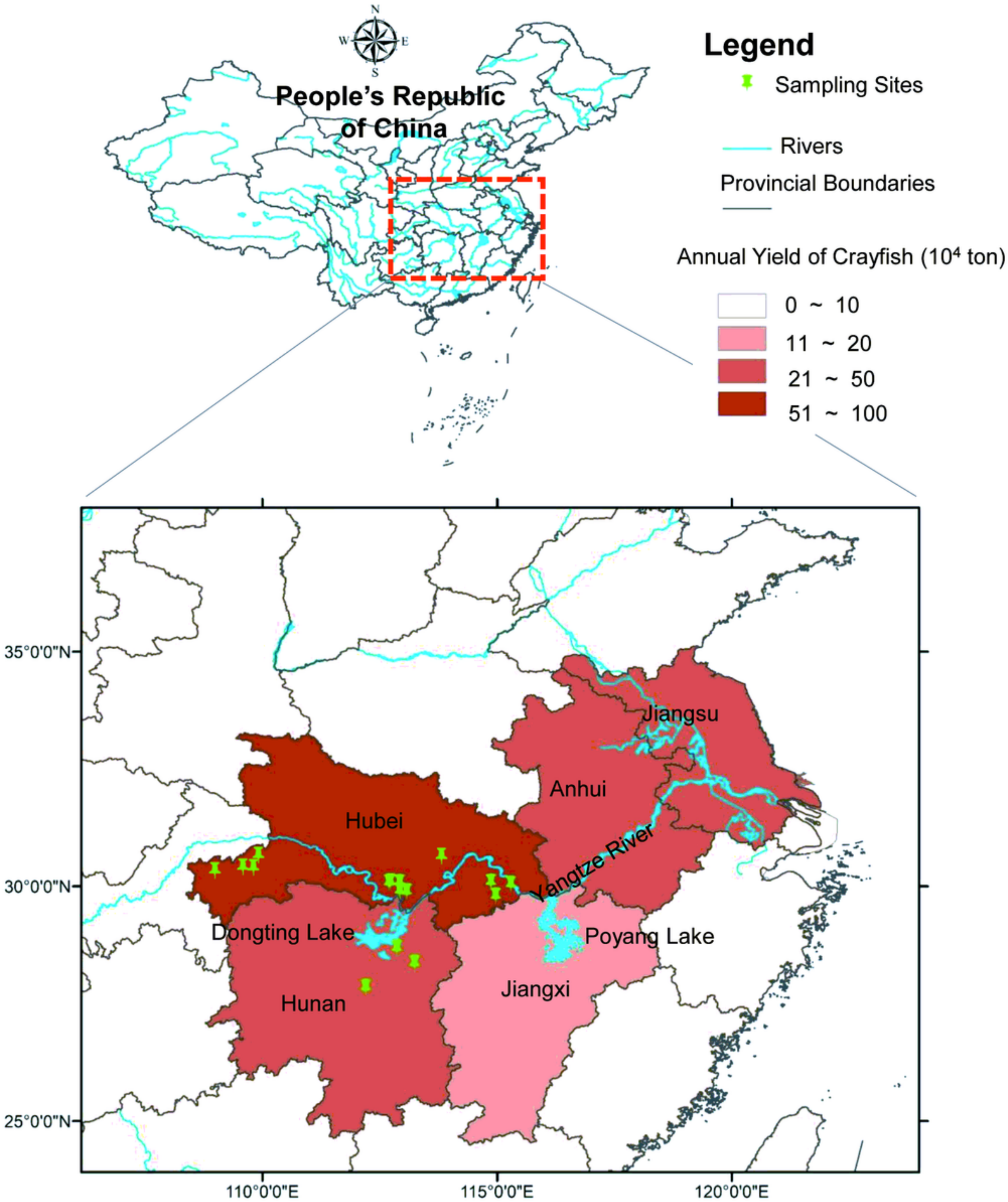

Figure 1

The sixteen locations map of specimen collection. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

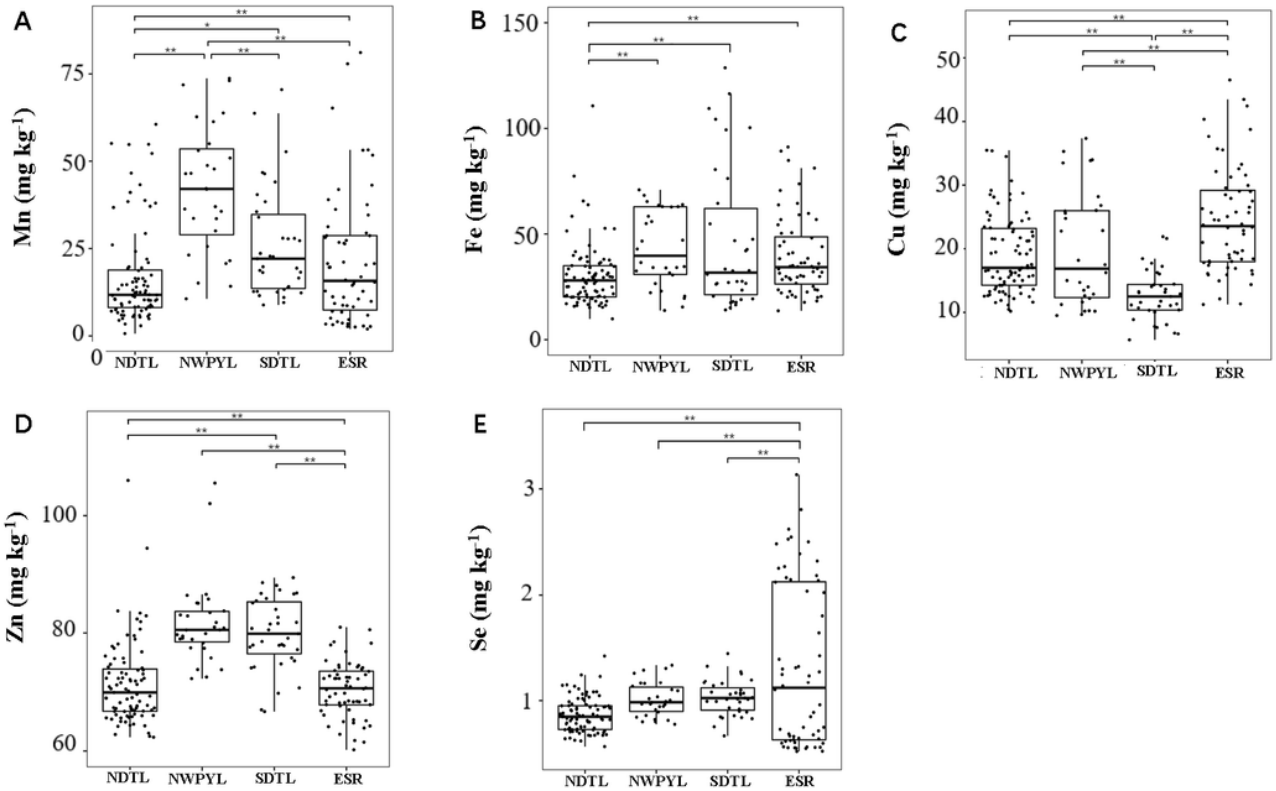

Figure 2

The concentrations of Mn, Fe, Cu, Zn and Se in abdominal muscle of the four investigated regions The horizontal lines within the boxes represent the 50th values; the upper and lower limits of the boxes represent the 75th and 25th values; SDTL, represents South of Dongting Lake region; NDTL, represents North of Dongting Lake region; NWPYL, represents Northwest of Poyang Lake region; ESR represents Enshi region. “*”, represents P<0.05; “**”, represents P<0.01.

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