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# Screening and evaluation of bamboo shoots: Comparing the content of trace elements from 100 species

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ABSTRACT

Hundreds of bamboo shoots have been reported to be edible, but the accumulation of trace elements and hazardous elements in bamboo shoots is poorly understood. Here, 100 bamboo species have been evaluated by screening elements including B, Fe, Mn, Cu, Zn, Cd, Pb and As in bamboo shoots using different assessment systems. Bamboo shoots displayed different morphological characteristics, and large differences were found in the concentration of elements. Most bamboo shoots were rich in Fe and Zn and low concentrations of hazardous elements, but the concentration of Cd and Pb exceeded the maximum permissible limits of tuber vegetables in some bamboo species. Different bamboo shoots were ranked differently in the four assessment systems, and the comprehensive evaluation assigned final scores to all 100 bamboo shoots. This study provides valuable recommendations for selecting high-quality bamboo shoots that are rich in trace elements nutrition while minimizing the potential for hazardous element accumulation.

## 1. Introduction

Bamboo shoot refers to the juvenile aerial bud emerging from the nodes of the pseudorhizomes of bamboo plants (Wang et al., 2020). In fact, it is a culm that contains entire nodes and internodes in a vertically miniaturized form (Das, 2019). Bamboo shoots are typically harvested when they reach an appropriate height (15–30 cm), and the tender, ivory-yellow shoot, which is wrapped in sheaths, is the edible part (Satya et al., 2012). There is a long history of using bamboo shoots as a source of food in Asian countries (Wang et al., 2020). In Japan, the bamboo shoot is called the "King of Forest Vegetables", while in China, people have considered bamboo shoots a treasure dish since the Tang Dynasty (Das, 2019). The cultural significance of bamboo shoots in China dates back thousands of years, as mentioned in ancient Chinese texts such as the Shijing (Book of Songs) and the Liji (Classic of Rites), which consider bamboo shoots as an integral part of Chinese culinary culture (Campbell, 2023). Nowadays, bamboo shoots are still popular in Asian countries, and their consumption has spread to Africa, Europe, and North America due to the worldwide popularity of Chinese cuisine (Chongtham et al., 2021).

Bamboo shoots not only serve as a delicious vegetable but also have been commercially utilized to produce a variety of products such as bamboo pickle, bamboo shoot powder, bamboo shoot juice, canned bamboo shoots, and fermented shoots (Satya et al., 2012; Sangija and Wu, 2022). The annual consumption of bamboo shoot and its products is estimated to be over 2 million tons, and is widely regarded as beneficial for health due to its high fiber and low fat content, rich protein source, and abundance of bioactive compounds (Bajwa et al., 2021; Nirmala et al., 2014). Thus, the consumption of bamboo shoot continues to increase.

As a traditional food item, bamboo shoot is not only flavorful but also rich in nutrients. With an average protein content of approximately 2.65 g per 100 g of fresh bamboo shoots and some bamboo shoots containing more than 4.0 g of protein per 100 g, they are higher in protein than normal bovine milk (which contains about 3.5 g protein per 100 g) (Jenkins and McGuire, 2006; Thomas, 1983). Additionally, bamboo

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shoots are abundant in amino acids, containing 17 amino acids, some of which, such as arginine and tyrosine, are major amino acids that are otherwise minor components in common fruits and vegetables (Nirmala et al., 2018). Furthermore, bamboo shoots are a good source of edible fiber, containing about 6 to 8 g of fiber per 100 g of fresh bamboo shoots, which is much higher than common vegetables, for instance, cabbage, radish, and cucumber only contain 1.0, 0.6, and 0.4 g of fiber per 100 g, respectively (Chongtham et al., 2011). In fact, bamboo shoots are also reported to contain higher mineral nutrients than common vegetables such as cauliflower, brinjal, tomatoes, potatoes, peppers, and spinach (Chandramouli and Viswanath, 2012; Wang et al., 2020). However, most of the studies on mineral nutrients have only surveyed a few bamboo species, and most have ignored the effects of external factors such as growth site and agro-climatic conditions on mineral nutrient accumulation in bamboo shoots (Chongtham et al., 2021; Wang et al., 2020).

On the other hand, the issue of food safety when consuming bamboo shoots has recently gained attention. In addition to the nutritional benefits of bamboo shoots, some fresh bamboo shoots may contain certain anti-nutrients and even toxins such as oxalate, cyanogenic substances, pesticides, and heavy metals (Muhammad et al., 2021; Nongdam and Tikendra, 2014; Wang et al., 2020). Therefore, it is not recommended to consume raw bamboo shoots, and it is essential to process them before consumption (Wang et al., 2020). For example, boiling can effectively eliminate most toxins (Wang et al., 2020), but, it is difficult to eliminate heavy metals in bamboo shoots. According to a survey conducted in China, some bamboo shoot samples contained hazardous heavy metals, including cadmium (Cd) and lead (Pb), exceeding the maximum permissible limits of Chinese legislation (Mo et al., 2021; Yang et al., 2023). The long-term consumption of these bamboo shoots may potentially pose health risks. Although trace element malnutrition has been reported to cause public health problems, there is limited focus on the investigation of trace elements in bamboo shoots. Therefore, this study aims to concentrate solely on the analysis of trace mineral elements and hazardous heavy metals in bamboo shoots, comparing and evaluating their concentrations in bamboo shoots harvested from the same site. The objectives of this study are: 1) to investigate the concentration of trace mineral elements (iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B)) in 100 bamboo shoots collected from the same field; 2) to evaluate the risk of hazardous heavy metal accumulation in bamboo shoots under similar external conditions; 3) to find superior bamboo shoots with high potential for accumulating trace mineral nutrients and low risk of harmful element contamination.

## 2. Materials and methods

### 2.1. Bamboo shoots collection and site description

Bamboo shoots of 100 species without any fertilization and phytosanitary treatments were collected from Bamboo Botanical Garden in Lin'an (30°15′58″ N, 119°35′50″ E), Hangzhou, northwest of Zhejiang Province. The sampling site is characterized by a subtropical monsoon climate with an average annual precipitation of 1613.9 mm and an average temperature of 16 °C. The soil type is classified as a Ferrosol with pH about 4.8. The shoots of bamboo used in this study were harvested after attaining an appropriate height (15–30 cm). Shoots were washed and photographed and separated from sheath to shoot. Then the shoots were dried at 105 °C in an oven (1100 W; DHG-9070A, Shaying Co., Ltd) for 3 days.

### 2.2. Determination of Fe, Zn, Cu, Mn, B, Pb, Cd and arsenic (As) in bamboo shoots

The above dried shoots were microwave-digested in a mixture of 2 ml of $HNO_3$ and 2 ml of $H_2O_2$ at temperature up to 180 °C in TFM tubes for 50 min (1800 W; Microwave Closed System MAR6, SEM Co., Ltd). All concentration of elements was determined by inductively coupled plasma mass spectroscopy (ICP-MS, X-series 2; Thermo Scientific) after the digested solution was diluted by ultrapure water to 20 ml. A certified standard ICP-MS calibration solution 2 was used for quality control. The recovery rates of elements in the certified reference material ranged from 98 % to 100 % during the determination. The concentration of above elements was showed as mg/kg which was calculated by the following formula: (element concentration in solution × 20 ml/1000 ml/1000)/(dry weight of bamboo shoots for determination/1000).

### 2.3. Analytical methods and calculations

In this study, the trace elements were divided into three categories according to Chinese dietary reference intakes-part 3: Trace element. The first category is "Trace Element 1" (TE1), which includes elements such as Fe, Zn that are essential and beneficial for human healthy; The second category is "Trace Element 2" (TE2), which includes elements such as Mn, B that are possibly essential but beneficial for human body; The third category is "Trace Element 3" (TE3), which includes elements such as Cd, As that are toxic for human health. According to the *Dietary Guidelines for Chinese Residents 2022*, 300 g of fresh vegetables are recommended for daily need for an adult. Therefore, in this study, the content of different elements in 300 g of bamboo shoots was used and calculated below.

The trace elements index (TEI) of the trace elements which adapted from Zhou et al. (2019) were determined by the following formula: (1) and (2)

$$\mathrm{TEI} = \sqrt[n]{\frac{a^p}{a^s} \times \cdots\cdots \times 100} \tag{1}$$

$$\text{Total TEI} = \mathrm{TEI1} + \mathrm{TEI2} - \mathrm{TEI3} \tag{2}$$

Where: **a** means trace element; **p** means content of trace element in sample; **s** means content of trace element in standard; **n** means the number of trace element; TEI1 means TEI of TE1; TEI2 means TEI of TE2; TEI3 means TEI of TE3.

The nutrition index (NI) of the trace elements which adapted from Desai et al. (2018) were determined by the following formula: (3) and (4)

$$\mathrm{NI} = \frac{\mathrm{TEI} \times \mathrm{TEP}}{100} \tag{3}$$

$$\text{Total NI} = \mathrm{NI1} + \mathrm{NI2} - \mathrm{NI3} \tag{4}$$

Where: **TEP** means trace element percentage in the respective category; NI1 means NI of TE1; NI2 means NI of TE2; NI3 means NI of TE3.

The chemical scores (CS) of the trace elements which adapted from Marj et al. (2015) were determined by the following formula: (5) and (6)

$$\mathrm{CS} = \frac{\mathrm{A_X} \times \mathrm{E_X}}{\mathrm{A_e} \times \mathrm{E_e}} \times 100 \tag{5}$$

$$\text{Total CS} = \mathrm{CS1} + \mathrm{CS2} - \mathrm{CS3} \tag{6}$$

Where: $\mathbf{A_x}$ means content of one or other element in the sample; $\mathbf{E_x}$ means content of one or other element in standard; $\mathbf{A_e}$ means content of all elements; $\mathbf{E_e}$ means content of all elements in standard; CS1 means CS of TE1; CS2 means CS of TE2; CS3 means CS of TE3.

The score of ratio coefficient of trace elements (SRCTE) which adapted from Marj et al. (2015) were determined by the following formula: (7) to (11)

$$\mathrm{SV} = \frac{\mathrm{A_X}}{\mathrm{E_x}} \tag{7}$$

$$\mathrm{RCTE} = \frac{SV}{SV^A} \tag{8}$$

$$CV = \frac{RCTE^S}{RCTE^A} \quad (9)$$

$$SRCTE = CV\text{-}100 \times RCTE \quad (10)$$

$$\text{Total SRCTE} = SRCTE1 + SRCTE2 - SRCTE3 \quad (11)$$

Where: $\mathbf{A_x}$ means content of one or other element in the sample; $\mathbf{E_x}$ means standard content of one or other element; SV means specific value in (7); **A** means average; S means stdev; CV means coefficient. SRCTE1 means SRCTE of TE1; SRCTE2 means SRCTE of TE2; SRCTE3 means SRCTE of TE3.

To minimize and eliminate errors caused by various scoring methods, the final evaluation results are obtained using the following formula: (12)

$$\text{Final scores} = (CS + SRCTE + \text{award } marks)*NI \quad (12)$$

Where the award marks for the trace elements in bamboo shoots were determined as the follows. For TE1 and TE2: (1) If the SV of one element is higher than average of SV, add 5 points for this bamboo species. (2) If the SV of one element is excessively high (exceeding 25 % of the average SV), subtract 1 point for this bamboo species.

For TE3: (1) If the SV of one element is higher than average of SV, subtract 2 points for this bamboo species. (2) If the SV of one element is excessively high (exceeding 25 % of the average SV), subtract 3 points for this bamboo species. (3) If two or three elements reach criterion (1), an additional 1 point will be deducted for this bamboo species.

### *2.4. Statistical analysis*

Data were analyzed using one-way ANOVA, followed by Tukey's multiple comparison tests. Data were analyzed by Excel (Microsoft, USA) and they were expressed as the means ± SD of three biological replicates. $P < 0.05$ was considered to be statistically significant. Heatmap and principal components analysis were plotted by https://www.bioinformatics.com.cn (last accessed on 10 Jul 2023), an online platform for data analysis and visualization.

## 3. Results and discussion

### *3.1. Overview of bamboo shoots morphology*

Bamboo shoots come in various shapes and sizes with different appearance colors (Fig. 1; Fig. S1-4). Some of bamboo shoots have high diameter such as *Dendrocalamus. sapidus* Q. H. Dar et D. Y. Huang which were suitable for canning processing. While some bamboo shoots were thin and slender, which were suitable for slicing and dicing. The appearance colors of bamboo shoots also vary from species. For example, *Phyllostachys edulis 'Heterocycla'* has a black sheath color, *Thyrsostachys oliveri Gamble* has a green sheath color, while *Phyllostachys aureosulcata 'Aureocaulis'* Z.P.Wang et N.X.Ma has a white appearance and *Oligostachyum sulcatum* Wang et Ye has a fuchsia appearance. The different appearance and morphology of bamboo shoots mainly attribute to the different genotype of bamboo species. It is presumed that this is also one of the foundations for classifying bamboo species based on bamboo shoots.

### *3.2. Concentrations of Fe, Zn and Cu in bamboo shoots of 100 species*

The results showed that bamboo shoots are rich in Fe and Zn, containing more than 20 mg/kg of Fe and Zn with the exception of species *Sasa palmata* 'Nebulosa'. The concentration of Fe ranged from 18.34 to 116.89 mg/kg and the Zn concentration ranged from 24.18 to 169.35 mg/kg (Fig. 2 A, B; Table S1, S2). These results are similar with previous studies (Chongtham et al., 2020). In a study of nineteen Indian bamboo species, the Fe concentration ranged from 47 to 100 mg/kg and the Zn concentration ranged from 60 to 100 mg/kg, respectively (Chongtham et al., 2020), which is within the range of the current study. There was a large difference of Fe and Zn concentration in shoots from species to species. For example, *Chimonobambusa marmorea* (Mitf.) Makino accumulated 6.2-fold higher of Fe than *S. palmata* 'Nebulosa', while *Melocanna humilis* Kurz accumulated 7-fold higher of Zn than *Bambusa subaequalis* H. L. Fung et C.Y. Sia. In general, the concentration of Cu in bamboo shoots is lower than Fe and Zn, which ranged from 2.19 to 36.89 mg/kg (Fig. 2 C; Table S3), but similarly, the difference of Cu concentration in bamboo shoots was large from different bamboo species. Fe, Zn and Cu are essential micronutrients for human health. As the co-factors of many critical enzymes, Fe, Zn and Cu are involved in numerous human metabolic processes (Kong et al., 2022; Tsang et al., 2021). Generally, people can acquire enough of these micronutrients in daily diet, but billions of people around the world are still suffer from deficiencies of Fe and Zn (Bouis et al., 2011). This work provides us with the optional to select bamboo shoots contain high concentration of Fe and Zn. For example, some of bamboo species such as *Dendrocalamus asper* (Schultes & J. H. Schultes) Backer ex K. Heyne maintain both high concentration of Zn (103.30 mg/kg) and Fe (66.72 mg/kg) (Fig. 2 A, B).

### *3.3. Concentrations of B and Mn in bamboo shoots of 100 species*

The results showed that the concentration of B in bamboo shoots ranged from 3.36 to 102.86 mg/kg, while the concentration of Mn ranged from 7.86 to 689.12 mg/kg (Fig. 3; Table S4, S5). A similar range of Mn concentration (12 to 97 mg/kg) was observed in other bamboo species in previous studies (Chongtham et al., 2020). Bamboo shoots accumulated the highest of B in *Pseudosasa japonica* cv. tsutsumiana which was 30-fold higher than the lowest one (*Pleioblastus gramineus* (Bean) Nakai). Mn reached the highest concentration in *P. edulis* 'Heterocycla' which was more than 87-fold higher than the *P. gramineus* (Bean) Nakai. B and Mn are both essential elements for plant growth and development. B plays a critical role in cell wall formation and Mn participates in many enzymes activities (Shao et al., 2017; Shao et al., 2021). But the required for B and Mn is species-specific, with significant differences between different bamboo species. Therefore, in this study, it can be found that the concentration of B and Mn in shoots have several decuples difference from different bamboo species. On the other hand, B and Mn are considered to be possibly essential but beneficial for human health. They are both good for skeleton development and antioxidant defenses (Aschner and Erikson, 2017; Gorustovich and Nielsen, 2019). But the exact required amount of boron for humans is still being determined. Consuming bamboo shoots as a vegetable may provide us with a range of recipes that contain different concentrations of B and Mn.

### *3.4. Concentration of Cd, Pb and As in bamboo shoots of 100 species*

Cd, Pb and As are toxic metal/loid to all organism, reducing intake of these toxic trace element is beneficial for human healthy. Therefore, investigating the concentration of Cd, Pb, and As in bamboo shoots will help us to evaluate the quality of bamboo shoots. There was a large difference of Cd concentration in the bamboo shoots, ranging from 0.004 to 1.675 mg/kg (Fig. 4 A; Table S6). Most of bamboo shoot accumulated low Cd, but there were nine bamboo species that accumulated Cd higher than the threshold value for rice grains (0.4 mg/kg) although they were grown in a non-Cd-contaminated soil. There was also a large difference of Pb and As concentration in different bamboo shoots. Ranging from 0.029 to 0.918 mg/kg and 0.011 to 0.564 mg/ kg for Pb and As, respectively (Fig. 4 B, C; Table S7, S8). Compared to Cd and Pb, less As was accumulated in bamboo shoots. Some bamboo shoots accumulated small amounts of Cd, Pb, and As, simultaneously, such as *Sinobambusa tootsik* (Sieb.) Makino, while some of bamboo shoots accumulated high amount of all three trace elements, such as


**Fig. 1.** Morphology and agronomic traits of 20 species bamboo shoots. Bar = 10 cm.

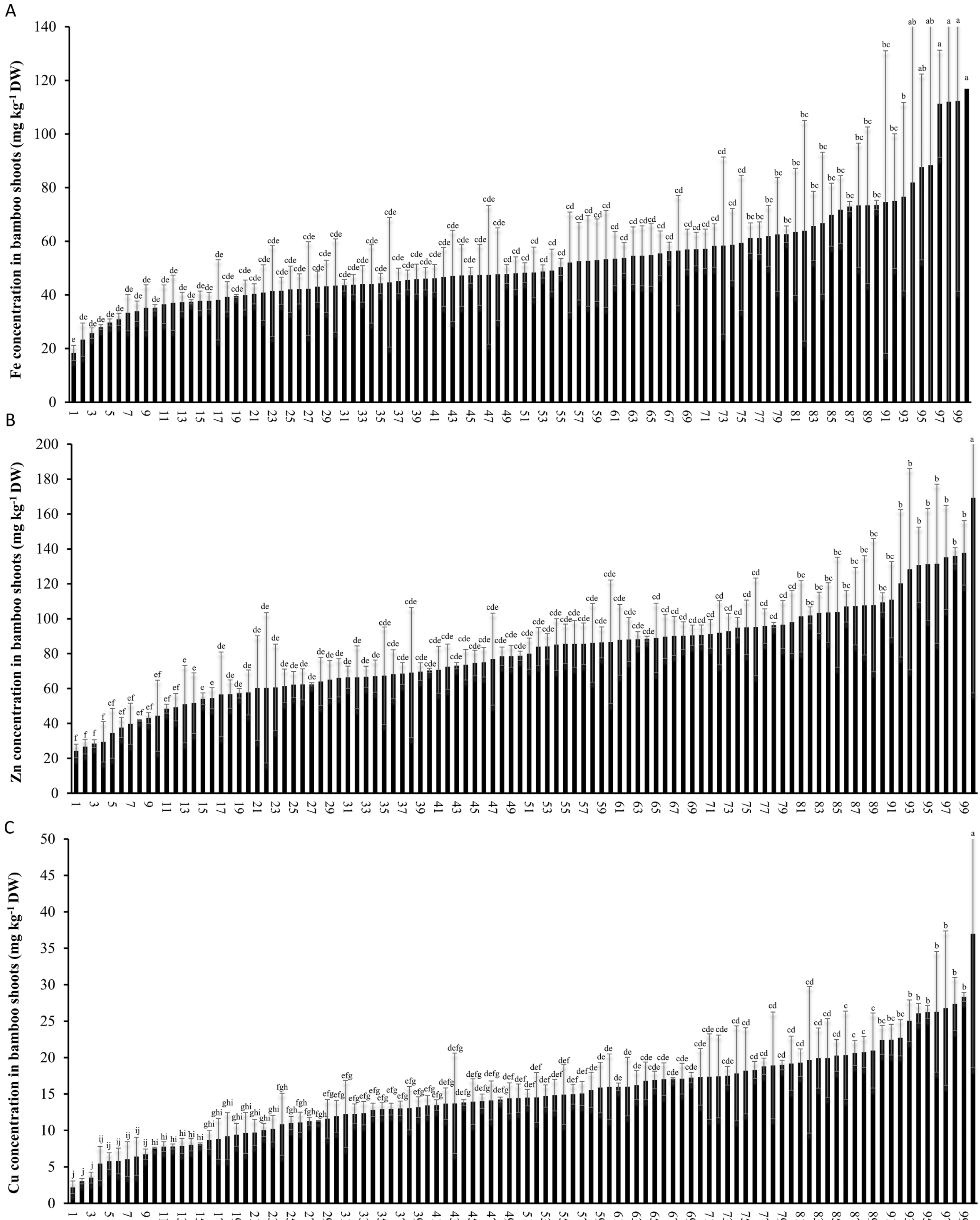


**Fig. 2.** Concentration of TE1 in 100 species bamboo shoots. Concentration of Fe (A), Zn (B) and Cu (C). The bamboo shoots are harvested by stripping the bamboo clums. Values are means ± SD (n = 3). Number 1–100 means the list of the ranking for bamboo species in table 1–3. Statistical comparison was performed for the 1st, 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th by one-way ANOVA followed by the Tukey's multiple comparison test. Different letters indicate significance ($P < 0.05$).

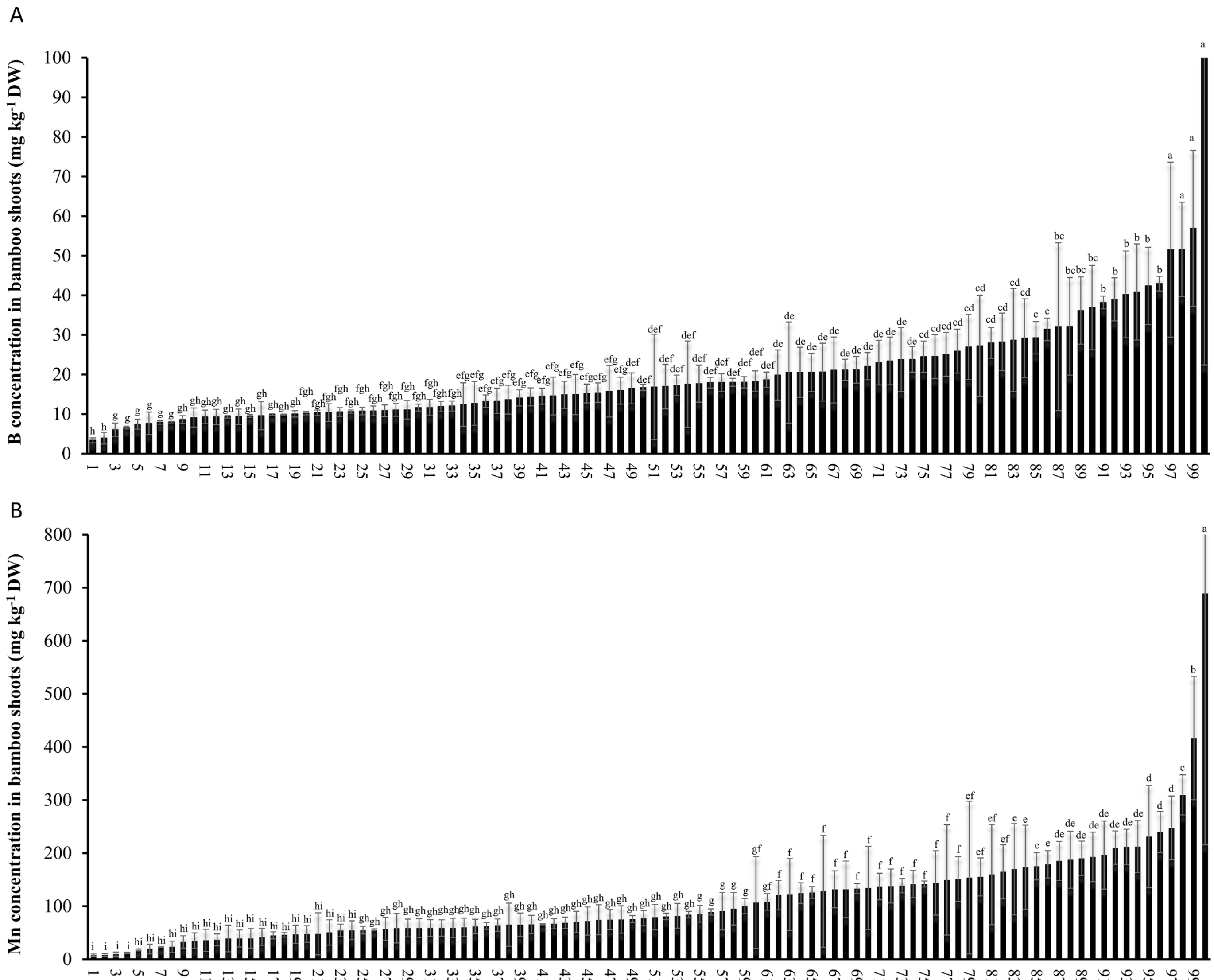


**Fig. 3.** Concentration of TE2 in 100 species bamboo shoots. Concentration of B (A) and Mn (B). The bamboo shoots are harvested by stripping the bamboo clums. Values are means ± SD (n = 3). Number 1–100 means the list of the ranking for bamboo species in table 4, 5. Statistical comparison was performed for the 1st, 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th by one-way ANOVA followed by the Tukey's multiple comparison test. Different letters indicate significance ($P < 0.05$).

*C. marmorea* (Mitf.) Makino. As hazardous elements, exposure to Cd can cause lesions of kidney and skeleton (Satarug et al., 2010) while Pb and As are neurotoxic and cancerogenic (Hall et al., 2002; Santa Maria et al., 2019). According to the GENERAL STANDARD FOR CONTAMINANTS AND TOXINS IN FOOD AND FEED issued by Agriculture Organization of the United Nations and World Health Organization (FAO and WHO 1995), maximum permissible levels for Cd, Pb and As have been established for many foods. For example, the maximum level of Cd and Pb is 0.1 mg/kg in root and tube vegetables and the maximum level of As is 0.2 mg/kg in polished rice. Therefore, monitoring of hazardous elements accumulation in bamboo shoots is very important for food safety. In this study, to better evaluate the quality and safety of bamboo shoots the concentration of Cd, Pb and As in bamboo shoots was analyzed and investigated.

### 3.5. Heat map and cluster analysis of 100 species of bamboo shoots in trace elements

Fe, Zn, Cu, B, Mn, Cd, Pb, and As were divided in two group: the non-toxic and toxic groups (Fig. 5 A, B). The heat map of two groups elements was shown in different colors by using the values of different trace elements of 100 species of bamboo shoot. From the heat map, it is obviously to see that the concentration of Mn, Zn, and Fe is much higher than B and Cu in non-toxic group while the concentration of Pb is higher than As and Cd in toxic group, in general. The concentration of some elements shows an opposite trend in bamboo shoots. For example, most of bamboo shoots accumulate a high concentration of Mn have a low concentration of Zn, while bamboo shoots that accumulate a low concentration of Mn have a high concentration of Zn (Fig. 5 A). Similar opposite trends was also found for element Cd and Pb: bamboo shoots usually accumulate a high concentration of Cd contain low Pb, while low Cd accumulation bamboo shoots contain high Pb (Fig. 5 B). The heat map also reveals that the variability of Cu and B concentration in bamboo shoots is narrow but huge variability was found in other elements in bamboo shoots (Fig. 5).

Two-way hierarchal clustering analysis was performed based on the values of different elements among the bamboo shoots. The results showed that in group one, bamboo shoots were primarily clustered into three clusters, while in group two, bamboo shoots were clustered into four clusters (Fig. 5 A, B; Table S9, S10). Based on the different values of elements, different bamboos shoots are group into different clusters. However, numerous factors have been proposed to greatly influence the

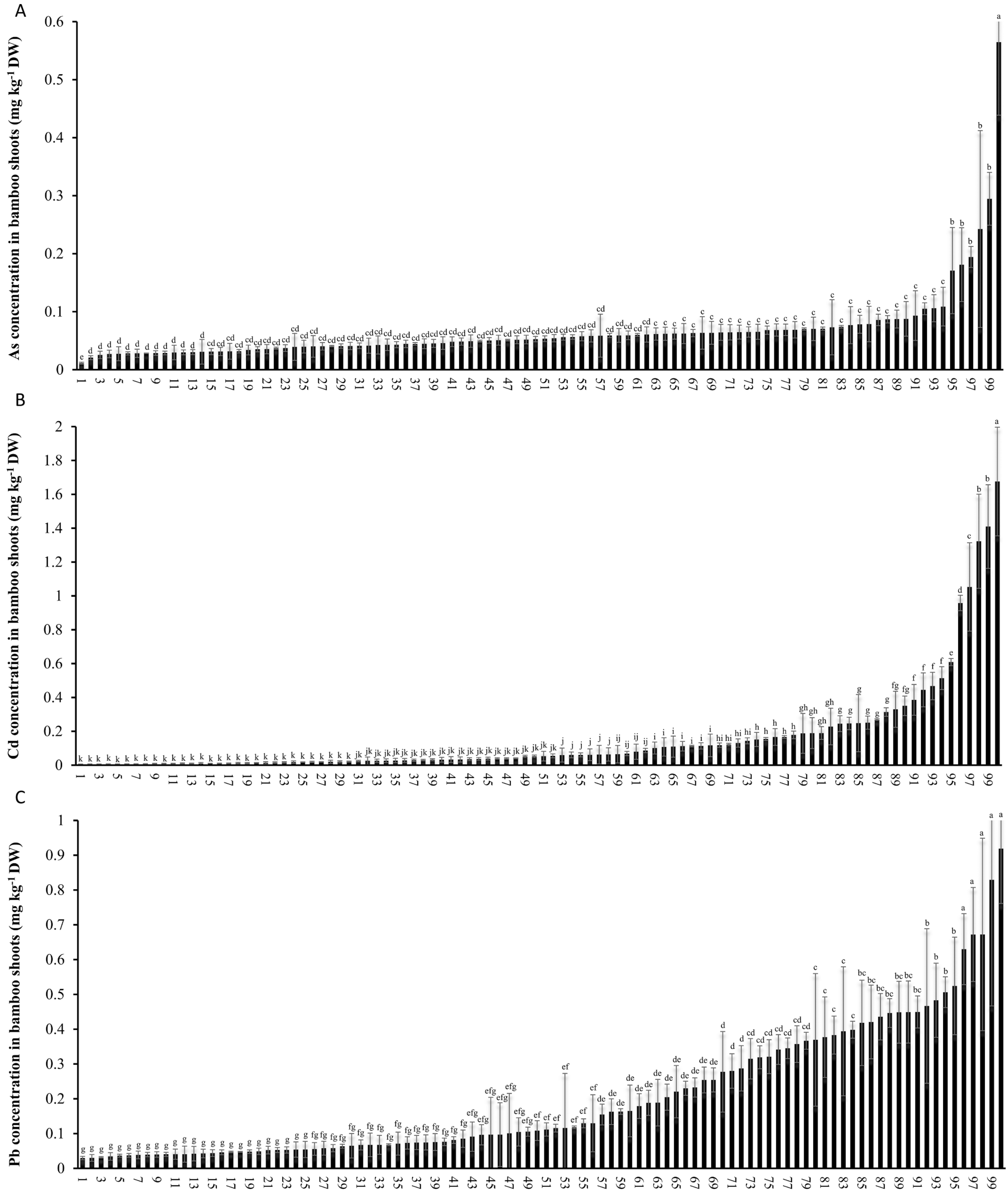


**Fig. 4.** Concentration of TE3 in 100 species bamboo shoots. Concentration of AS (A), Cd (B) Pb (C). The bamboo shoots are harvested by stripping the bamboo clums. Values are means ± SD (n = 3). Number 1–100 means the list of the ranking for bamboo species in table 6–8. Statistical comparison was performed for the 1st, 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th by one-way ANOVA followed by the Tukey's multiple comparison test. Different letters indicate significance ($P < 0.05$).

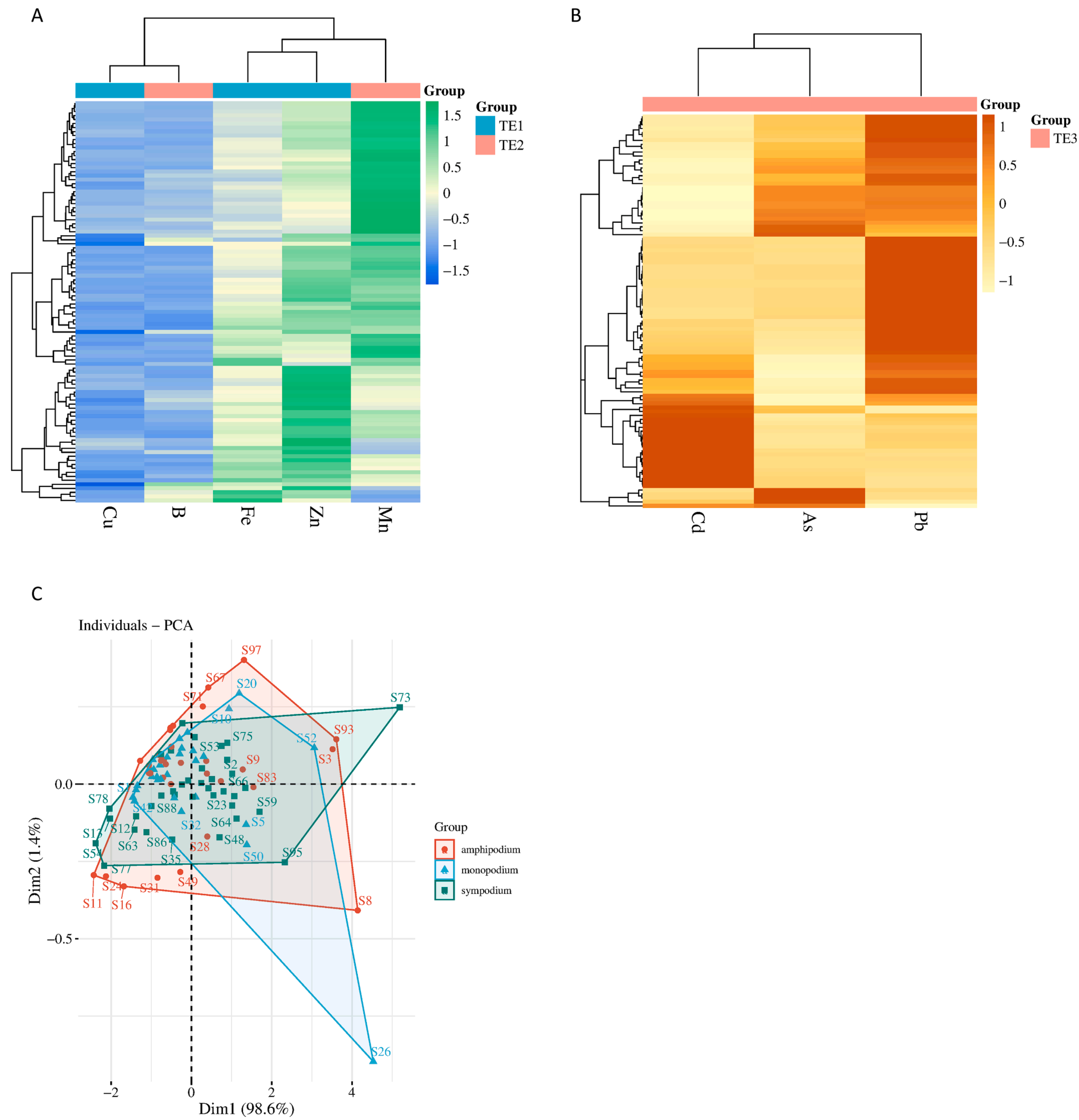


**Fig. 5.** Cloistering and PCA analysis of 100 species of bamboo shoots. (A,B) Heat maps represented hierarchical clustering of TE1, TE2(A), TE3 (B). The colour scale shows the z-score associated with 100 species of bamboo. Scale for concentration of trace elements (after centralized) is indicated by color bars near the heat maps, with blue representing the lowest expression levels, yellow medium expression and green the highest expression level (A). Scale for concentration of trace elements (after centralized) is indicated by color bars near the heat maps, with brown representing the lowest expression levels, orange medium expression and yellow the highest expression level (B). See table 9, 10 for a list of bamnboo species. PCA analysis based on first two principal component axes for nutritional index and trace element index of trace elements and distribution of 100 species bamboo shoots based on the first two components obtained from principal component analysis (C). See table 11 for a list of bamnboo species. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

elemental value of bamboo shoots. For instance, soil conditions such as pH, organic matter content, cation exchange capacity, and Eh have a direct or indirect impact on the availability of elements, which subsequently influence the accumulation of elements in plants (Ma et al., 2021). Taking Cd as an example, when Eh increases from 0 to 300 mV, Cd concentrations in soil solutions increase from 0.2 to 0.8 μg/L. As a result, plants can absorb more Cd from the soil and accumulate higher levels of it (Ma et al., 2021). Additionally, agro-climatic conditions like precipitation, temperature, and moisture may affect the accumulation of elements in plants as well (Kudrevatykh et al., 2021). Since the external condition was similar for the bamboo growth sit, it is presumed that the bamboo genotypes may be the main factor influencing the accumulation of elements in shoots.

### 3.6. Evaluation of 100 species of bamboo shoots by TEI and NI and PCA analysis

TEI and NI were used for evaluating of bamboo shoots. From the results it can be found that *P. japonica* cv. tsutsumiana, *Semiarundinaria yashadake* (Makino) Makino, and *Pseudosasa amabilis* (McClure) Keng f. ranking the top three in all 100 bamboo shoots in TEI scores (Table S12), and *P. edulis* 'Heterocycla', *P. japonica* cv. tsutsumiana, and *P. amabilis* (McClure) Keng f. ranking the top three in NI scores (Table S13). Inversely, *P. gramineus* (Bean) Nakai, *B. subaequalis* H. L. Fung et C.Y. Sia, *Dendrocalamus sapidus* Q. H. Dar et D. Y. Huang, *B. Subaequalis* H. L. Fung et C.Y. Sia, *P. gramineus* (Bean) Nakai and *O. sulcatum* Wang et Ye showed the lowest of TEI and NI scores among all 100 bamboo shoots. Some of bamboo shoots showed the similar ranking trends in TEI and NI (Table S12, S13). For example, *P. japonica* cv. tsutsumiana, which had the highest TEI score of 8.19, also ranked second in NI with a score of 4.56 (Table.S12, S13). While *B. Subaequalis* H. L. Fung et C.Y. Sia and *P. gramineus* (Bean) Nakai showed lowest ranking in both TEI and NI. The PCA was further applied to analyze the data from TEI and NI because similar calculate methods in TEI and NI. (Fig. 5 C). The first dimension (Dim1) connected these two dimensions of data with different types of rhizome. And the Dim2 contributed 98.6 %, explaining the variability of almost all the data. These two dimensions can be traced back and correspond to TEI and NI. In addition, compared with TEI, NI seems more suitable to be used for evaluation. Then NI is considered for evaluating final scores instead of TEI. The result of PCA suggests that bamboo shoots with different type of rhizome did not significantly vary. The X-axis represents the main direction of the evaluation. It can be easily found that S73 (*P. japonica* cv. tsutsumiana), S26 (*P. edulis* 'Heterocycla'), S8 (*P. amabilis* (McClure) Keng f.), S93 (*S. yashadake* (Makino) Makino), S3 (*Pleioblastus simonii* f. albo-striatus (Munroi)H. Okamura), S52 (*Phyllostachys reticulata* f. castillonis), S95 (*Bambusa multiplex* f. silverstripe (R. A. Young) T. P. Yi) have high nutritional value in elements according to the TEI and NI scores. On the contrary, S11 (*P. gramineus* (Bean) Nakai), S54 (*B. subaequalis* H. L. Fung et C.Y. Sia), S77 (*D. sapidus* Q. H. Dar et D. Y. Huang), S24 (*Bambusa multiplex* var. riviereorum R.Maire), S13 (*Bambusa vario-striata* (W. T. Lin) L. C. Chia & H. L. Fung), S78 (*O. sulcatum* Wang et Ye), S16 (*Chimonobambusa quadrangularis* (Fenzi) Makino) get low nutritional value of elements in TEI and NI scores (Table.S11, S12, S13).

### 3.7. Scoring of 100 species of bamboo shoots by CS and SRCTE

CS and SRCTE were used to evaluation the richness and stability of trace element for different bamboo shoots. The results showed that different bamboo shoots scored differently in CS and SRSTE evaluation system (Table.S14, S15). In CS, *P. japonica* f. akebonosuji received the highest score (76.5), indicating that it had a relatively close content of beneficial elements to the standard value and a lower toxic element content to a certain extent. While *Bambusa multiplex* f. fernleaf (R. A. Young) T. P. Yi got the lowest point (Table.S15) in all 100 bamboo shoots. In SRCTE, *Hibanobambusa tranguillans* f. *shiroshima* H.Okamura received the highest point (245.5), indicating that compared to other bamboo shoots, its trace element content is stable and there is only minimal variation between the elements in the trace element group. Furthermore, to better evaluation the bamboo shoot, an awarded mark was introduced into the whole scoring system based on the matching level of nutrients element content to the recommended nutrient intakes of our daily needs. After calculated the final score (calculation formula 12), a list of total score point for 100 bamboo shoots can be obtained (Fig. 6; Table S16). The results showed that *P. amabilis* (McClure) Keng f. scored the highest among all bamboo shoots (929.8). The next ten species of bamboo shoots were *P. reticulata* f. castillonis (902.6), *Pseudosasa japonica* var. tsutsumiana (825.3), *S. yashadake* (Makino) Makino (821.8), *B. multiplex* f. silverstripe (R. A. Young) T. P. Yi (773.5), *Drepanostachyum. melicoideus* (P. C. Keng) D. Z. Li & Stapleton (720.0), *Pleioblastus simonii* f. albo-striatus (Munroi) H.Okamura (755.6), *Phyllostachys kwangsiensis* W. Y. Hsiung et al. (730.2), *P. edulis* 'Heterocycla' (711.3), *H. tranguillans* f. shiroshima H.Okamura (685.6), *Dendrocalamus latiflorus* Munro (657.2). While *O. sulcatum* Wang et Ye and *Semirundinaria yashadake* f.ogon got the lowest score point.

It is can be found that the results of CS and SRCTE (Table 1 S4, S15) are different from that TEI and NI (Table S12, S13), this difference can be attributed to the differences in calculation principles. TEI and NI mainly compare the distance between trace element and standard index, representing direct nutritional value. While CS and SRCTE focus on the richness and stability as well as the potential proportion of biological value contribution of trace elements (Marj et al., 2015). CS and SRCTE were selected as one of the indicators for the total score, and NI and awarded marks were used for evaluating the final score, but not TEI. However, this evaluation system still has some limitations. For instance, *P. amabilis* (McClure) Keng f. ranking the first place in the overall evaluation. But to our knowledge, as a native bamboo species in China, *P. amabilis* (McClure) Keng f. is not popular as a vegetable due to the bitter flavor of its shoots (Ou, 2000; Wagner and Byrd, 2012). Some bamboo shoots like *Phyllostachys edulis* (Carriere) J. Houzeau (Ma et al., 2018), *Phyllostachys violascens* 'Prevernalis' S.Y.Chen et C.Y.Yao (Yang et al., 2021), *C. quadrangularis* (Fenzi) Makino (Chen et al., 2019), which are favored and popular in market but got a medium score. Therefore, there are still some limitations that should be addressed in this work. Firstly, the flavor of bamboo shoots was not taken into consideration. For example, some bamboo shoots taste sweet, some have a pungent smell, some have a sour taste, while others have a bitter taste. If the flavor of bamboo shoots is not suitable for consumption, it is meaningless even if the bamboo species receives a high score in this evaluation system. Secondly, a single evaluation index was used. This study only focused on the trace elements to evaluate bamboo shoots, but there are many other nutritional indicators such as protein, amino acids, fiber, etc. that were not considered. Thirdly, the economic value of bamboo species was not taken into account. In order to evaluate the nutritional value of various bamboo shoots more scientifically and realistically, the flavor of the shoots, more nutritional indicators, and economic value should be taken into account. In this study, most bamboo shoots were found to be rich in Fe and Zn. Therefore, it is necessary to assess the bioaccessibility and bioavailability of Fe and Zn in different bamboo shoots in next step. And a further comprehensive evaluation should be conducted to evaluate more ideal bamboo species in the future.

## 4. Conclusion

Bamboo shoots are widely popular in Asian countries. China produces the majority production of bamboo shoots with the largest variety of bamboo species in the world. Screening and evaluation the bamboo shoots with high trace mineral nutrients and low in toxicity element is an important issue for sustainable development and multiple uses of bamboo shoots. Most of bamboo shoots investigated in this work are rich in Fe and Zn which are good sources of Fe and Zn for daily consumption. However, some bamboo shoots accumulate high concentrations of Cd and Pb, which poses a potential threat to food safety. Therefore, a regulatory and inspection system for the safety of bamboo shoots needs to be established. Especially, for the bamboo species *C. marmorea* (Mitf.) Makino, *Chimonobambusa. quadrangularis* 'Joseph de Jussieu', *C. quadrangularis* (Fenzi) Makino. with high hazardous element accumulated in shoots. The comprehensive evaluation suggested that *P. amabilis* (McClure) Keng f., *P. reticulata* f. castillonis, *P japonica* var. tsutsumiana, *S. yashadake* (Makino) Makino, *B. multiplex* f. silverstripe (R. A. Young) T. P. Yi, *D. melicoideus* (P. C. Keng) D. Z. Li & Stapleton, *P. simonii* f. albo-striatus (Munroi) H.Okamura, *P. kwangsiensis* W. Y. Hsiung et al., *P. edulis* 'Heterocycla', *H. tranguillans* f. shiroshima H. Okamura are top ten bamboo species, which are good candidate bamboo


**Fig. 6.** Total points of evaluation for 100 species bamboo shoots. Total points are calculated by NI, CS, SRCTE, Award masks. (Bamboo shoots which get the same points are not in any particular order in this list.)

species for higher trace element nutrition and lower risk of hazardous element accumulation, but the flavor, production, and economic value of bamboo shoots should be taken into consideration.

## CRediT authorship contribution statement

**Xianyu Pan:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Haibao Ji:** Investigation. **Xiu Xiu Gong:** Investigation, Formal analysis. **Wang Ting Yang:** Investigation. **Zetao Jin:** Investigation. **Yiting Zheng:** Investigation. **Sijie Ding:** Investigation. **Haitao Xia:** Investigation. **Zhenming Shen:** Investigation, Funding acquisition, Conceptualization. **Ji Feng Shao:** Conceptualization, Writing – original draft, Writing – review & editing, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2023.101071.

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