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RESEARCH

Analysis of Heavy Metal Characteristics and Health Risk Assessment of Dried Fish Marketed in Guangzhou, China

Yifei Bai[1] · Dimei Zhang[1] · Kang Wang[1] · Fangfei Li[1] · Nachuan Chen[1] · Zhifeng Zhou[2] · Jufeng Ye[3]

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Abstract
This study investigated heavy metal contamination in dried fish sold in Guangzhou, China, and evaluated the resultant non-carcinogenic and carcinogenic health risks. Dried fish samples were purchased from Baiyun, Tianhe, Panyu, and Yuexiu districts in Guangzhou, where the population is substantial. They were randomly acquired in bustling supermarkets and farmers' markets, targeting the most popular dried fish in these areas. Sixty samples from five dried fish types (*Stolephorus chinensis*, *Thamnaconus modestus*, *Nemipterus-virgatus*, *river fish*, *Ctenopharyngodon idella*) were analyzed for chromium (Cr), arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg) content. Quantification of the heavy metals were carried out by inductively coupled plasma mass spectrometry (ICP-MS) for Cr, As, Cd, and Pb, and an automatic mercury analyzer for Hg. The median concentration of these heavy metals in dried fish were 0.358 mg/kg, 2.653 mg/kg, 0.032 mg/kg, 0.083 mg/kg, and 0.042 mg/kg, respectively. Pollution severity was ranked as *dried Nemipterus-virgatus* > *dried Stolephorus chinensis* > *dried Thamnaconus modestus* > *dried river fish* > *dried Ctenopharyngodon idella*, with As being the most predominant pollutant. All fish types showed severe As pollution. Non-carcinogenic risks were identified in the consumption of *dried Nemipterus-virgatus* and *dried Stolephorus chinensis* for both genders, while potential carcinogenic risks were associated with four of the fish types. Women faced higher health risks than men from dried fish consumption. Consequently, we advise consumers to minimize their intake of dried fish and regulatory agencies conduct regular monitoring of heavy metal levels in commercially available dried fish to avert potential health risks.

Keyword Dried fish · Heavy metals · Non-carcinogenic risk · Carcinogenic risk

Introduction

Fish is renowned for its abundance of complete protein, polyunsaturated fatty acids like omega-3, minerals, and various other nutrients, making it a vital component of a well-balanced diet in modern lifestyles [1, 2]. The consumption of fish is prevalent, and dried fish, in particular, in warm tropical and subtropical regions, is widely enjoyed. However, when water pollution has become an urgent concern, with heavy metals emerging as major pollutants, fish are more susceptible to the accumulation of heavy metals as a result of factors such as their habitat and biological characteristics [3]. The multi-step process of dried fish production leads to an increase in the concentration of heavy metals per kilogram of fish weight. Consequently, the concentration of heavy metals is more significant in dried fish than in fresh fish.

Typically, the heavy metals of concern in dried fish include chromium (Cr), arsenic (As), cadmium (Cd), lead

Yifei Bai and Dimei Zhang contributed equally to this work.

✉ Zhifeng Zhou
zfzhoucn@163.com

✉ Jufeng Ye
yjfws@163.com

1 Department of Preventive Medicine, School of Public Health, Southern Medical University, Guangzhou, China

2 Department of Hygiene Inspection and Quarantine Science, Center for Hygiene Testing and Analysis, School of Public Health, Southern Medical University (Guangdong Provincial Key Laboratory of Tropical Disease Research), Guangzhou 510515, Guangdong, China

3 Experimental Teaching Center of Preventive Medicine, School of Public Health, Southern Medical University (Guangdong Provincial Key Laboratory of Tropical Disease Research), National Preventive Medicine Experimental Teaching Demonstration Center, Guangzhou 510515, Guangdong, China

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(Pb), and mercury (Hg). These heavy metals possess the potential to impose substantial risks on human health. The detrimental effects of heavy metals encompass a wide range of conditions, including digestive system diseases, impaired liver and kidney function, reduced reproductive abilities, nervous system disorders, cardiovascular diseases, endocrine abnormalities, cancer, and in severe cases, even fatality [4–7]. Therefore, individuals who habitually consume dried fish face a significantly amplified risk [8].

Given the health risks posed by heavy metals to humans, the safety of consuming dried fish requires careful consideration, specifically the evaluation of heavy metal concentrations and associated health risks. Researches in Bangladesh focused on examining heavy metal levels in dried fish and assessing the consequent health risks [2, 9]. However, health risk assessments using the same indicators yielded inconsistent findings. Rakib et al. analyzed 10 widely consumed local dried fish varieties in triplicate, detecting essential and non-essential metals using EDXRF analysis, including Cr, As, Pb, and so on, and determined that both non-carcinogenic and carcinogenic risks are within established safety thresholds [2]. Differently, Hoque et al.'s study examined two common types of dried fish for the same heavy metals, in triplicate, employing graphite furnace atomic absorption spectrometry (GF-AAS). It revealed no non-carcinogenic risk in all samples, while a potential carcinogenic risk exists for all metals [9]. Additionally, several studies from Pakistan indicated that fresh fish muscles have elevated concentrations of heavy metals such as Cr, Pb, and Cd. This study also implied that the consumption of fish as a food source could potentially lead to health issues for consumers [10–12]. Studies from China on fresh fish present inconsistent conclusions [13, 14], yet some suggest that heavy metals in fresh fish may pose potential health risks [15].

These studies above suggested that the consumption of certain commonly eaten fish species in specific regions poses health risks due to heavy metal contamination. Notably, dried fish appeared to present a greater health hazard due to its inherent properties. However, most previous literatures predominantly concentrated on the investigations and studies of live fish, with limited attention to dried fish, particularly regarding research conducted in China. Thus, in the context, the objectives of this study are (1) to investigate the heavy metal content and pollution levels of different dried fish varieties in Guangzhou, China, (2) to evaluate the potential health risks, both carcinogenic and non-carcinogenic, posed by heavy metals to the residents of Guangzhou, and (3) to assess the food hygiene quality, provide foundational information for dietary choices, and offer crucial insights for the development of food hygiene standards by relevant authorities.

Materials and Methods

Instruments and Reagents

The concentration of metals (Pb, Cr, As and Cd) was determined using an inductively coupled plasma mass spectrometry (ICP-MS) (Thermo Fisher Technologies, USA). The total mercury concentration was measured using an automatic mercury analyzer (Milestone DMA-80 Direct mercury meter, Milestone, Italy). The efficient breakdown of the sample matrix was achieved through the utilization of the Jupiter-B series multi-flux sealed microwave digester (Xinyi Microwave Chemical Company, Shanghai) and an acid drive meter.

The study employed the following chemicals and reagents: 42% nitric acid (Guangzhou Chemical Reagent Factory, China), 30% hydrogen peroxide (Guangzhou Chemical Reagent Factory, China), ultra-pure water, multielement internal standard solution consisting of Cr-Sc (45), As-Ge (72), Cd-In (115), and Pb-Bi (209), as well as standard storage liquids for Pb, Cr, As, Cd, and Hg (1000 μg/mL). All the mentioned standard solution were acquired from Guobiao (Beijing) Testing & Certification Co., Ltd.

Sample Collection and Storage

Sampling Area Description

The sampling locations for this study primarily focused on specific areas with the high population density in Guangzhou, namely Baiyun District, Tianhe District, Panyu District, and Yuexiu District [16]. Fig. 1 illustrates the exact locations chosen for sampling.

Sample Collection and Storage

The acquisition of commercially available dried fish was conducted in large and medium-sized supermarkets and large farmers' markets within the designated sampling areas [17] , due to the high volume of transactions. Each area randomly selected a total of 4 to 5 supermarkets and large farmers' markets that met the criteria [17]. The sampling process considered factors like consumption frequency, quantity of each fish purchased, and the specific location where consumers made their purchases [18]. Five types of dried fish were carefully selected for this study due to their high market sales and popularity among residents of Guangzhou: *dried Stolephorus chinensis (pond smelt), dried Nemipterus-virgatus, dried Thamnaconus modestus, dried river fish, and dried Ctenopharyngodon*

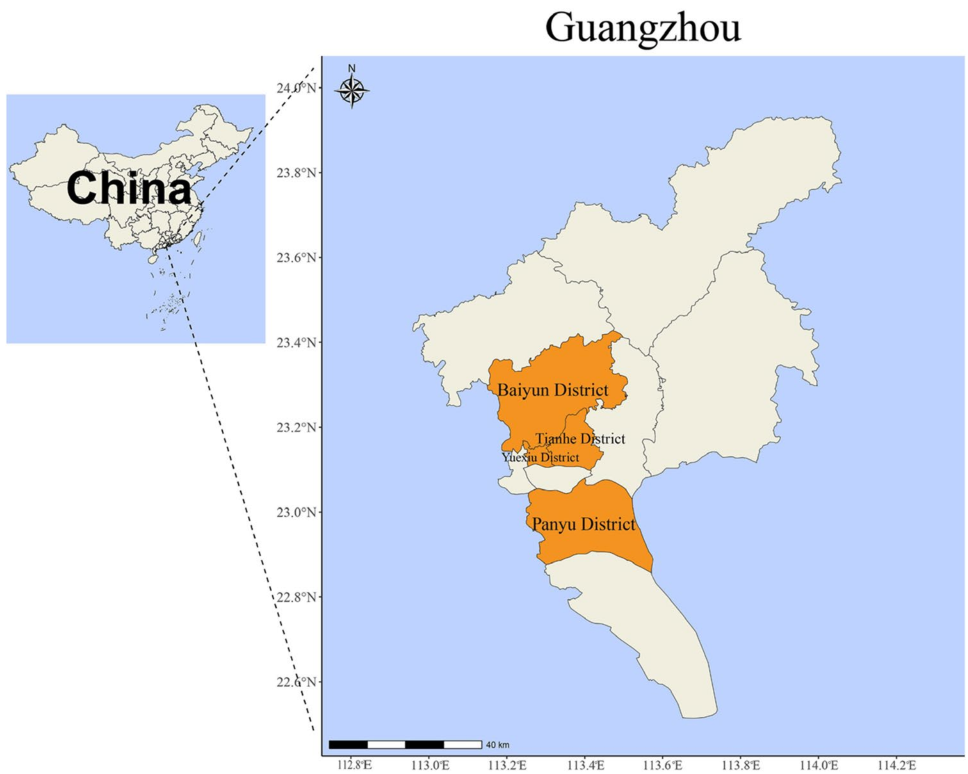

Fig. 1 Sampling points of dried fish in Guangzhou, China. The orange markings indicate the specific sampling areas within Guangzhou, namely Baiyun District, Tianhe District, Panyu District, and Yuexiu District

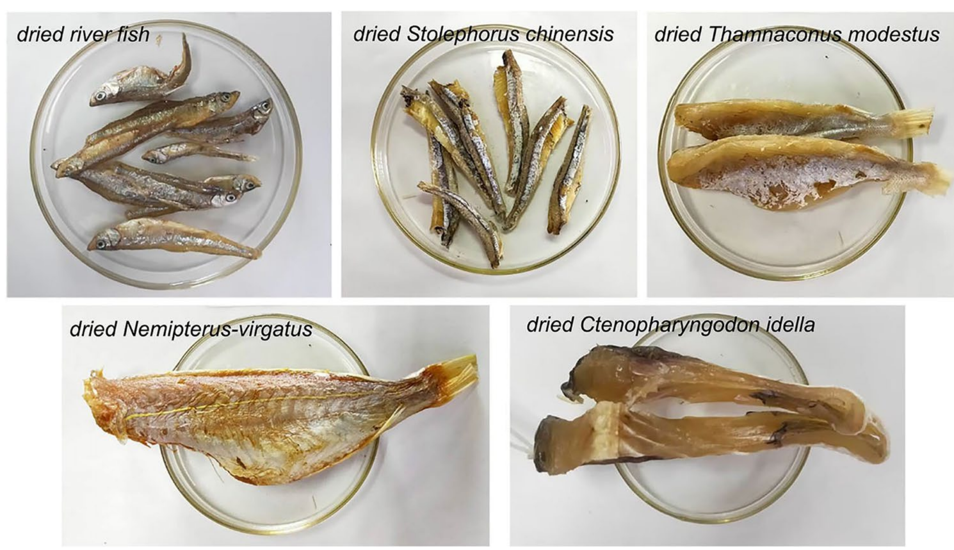

Fig. 2 Samples of Dried Fish Sold in Guangzhou, China. The five figures correspond to the five types of dried fish selected for the study, including *dried river fish*, *dried Stolephorus chinensis*, *dried Thamnaconus modestus*, *dried Nemipterus-virgatus*, and *dried Ctenopharyngodon idella*

idella (Fig. 2). At each site, we collected the five types of dried fish under study, adhering to the principle of random sampling. A total of 60 samples were acquired, with twelve samples obtained for each type of dried fish. To ensure representativeness, the muscle parts of large fish were uniformly trimmed using scissors [19]. For smaller fish that can be consumed whole, they were all cut and ground into powder using a mortar.

Sample Processing and Analysis

Approximately 0.5 g of dried fish powder was carefully weighed and subsequently transferred into the digestion tank. Following that, 8 mL of a 42% nitric acid solution was added, and the digestion tank was positioned on the acid digestion instrument for the purpose of pre-digestion. The mixture was subsequently heated at 100 ℃ for 20 minutes and then allowed to cool to room temperature. Following this, 1 mL of 30% hydrogen peroxide solution was added to the digestion tank, and the tube cover was tightly sealed. The sample underwent digestion using a microwave digestion instrument. For the digestion procedure for dried fish samples, they can be heated at 150 ℃ for 10 minutes, followed by heating at 180 ℃ for 8 minutes, utilizing a microwave digester. After completion of the digestion process and the pressure and temperature in the digestion tank reached 0 kPa and room temperature respectively, the digestion tank was positioned on the acid digestion meter, and the acid was digested at 100 ℃ for 0.5 hours. Following that, 1mL of ultra-pure water was added, and the acid was digested at 100 ℃ for 1 hour. After the solution cooled, a fixed volume operation was performed. ICP-MS is extensively utilized in the analysis of metal elements, characterized by high sensitivity, minimal interference, precision, and accuracy [20]. The DMA-80 direct mercury analyzer is widely used for determining total mercury levels in tissue samples. It is rapid, cost-effective, and offers excellent specificity and sensitivity [21]. In this study, ICP-MS was employed to analyze the concentration of Pb, Cd, Cr and As elements in the digestion solution of dried fish powder. Furthermore, the levels of Hg elements in the dried fish powder were determined using the DMA-80 direct mercury analyzer. The specific parameters of ICP-MS were set with the flow rates of auxiliary gas, the carrier gas, and cooling gas adjusted to 0.7 L/min, 0.75 L/min, and 13 L/min, respectively. The DMA-80 direct mercury analyzer was set with specific determination parameters: drying temperature at 200 ℃ for 90 seconds; decomposition temperature at 750 ℃ for 80 seconds; vaporization temperature at 900 ℃ with a vaporization tube heating time of 12 seconds; rinse time of 60 seconds; and recording time of 30 seconds.

Quality Control and Quality Assurance

Instruments were cleaned prior to use to minimize heavy metal contamination. The sample blank was measured under identical conditions. For each metal, the limits of detection (LOD) and limits of quantification (LOQ) were calculated based on three and ten times the standard deviation (SD) of blank measurements, respectively [22]. The LODs (LOQs) obtained for Cr, As, Cd, Pb, and Hg were 0.00450 ng/ml (0.01500 ng/ml), 0.00054 ng/ml (0.00180 ng/ml), 0.00097 ng/ml (0.00323 ng/ml), 0.00227 ng/ml (0.00757 ng/ml), and 0.00436 mg/kg (0.01453 mg/kg). Calibration curves were prepared for the elements Cr, As, Cd, and Pb at concentrations of 0, 0.1, 1, 2, 5, 10, 50, 100 and 200 ng/ml, and for the element Hg at concentrations of 0, 0.5, 1, 2.5, 5, 10, 15 and 20 ng. For all metals assessed, the calibration regression line exhibited a correlation coefficient above 0.99. In order to determine the precision of each type of dried fish, six consecutive measurements were conducted on individual samples to calculate their precision based on the relative standard deviations (RSDs). The RSDs were below 10%, indicating reliable repeatability. The linear range of Cr, As, Cd, and Pb were all 0.1–200 µg/L, while for Hg, the range was 0–20 ng. A sample was randomly selected and divided into four portions. Two portions were analyzed for parallel background determination, while another two portions were subjected to parallel recovery assays. Recovery analysis was conducted by spiking the samples with Cr at a concentration of 3.5 ng/mL, As at 25 ng/mL, and Cd, Pb, and Hg at 0.5 ng/mL each. The recovery rate from the standard addition method ranged from 90 to 110%, demonstrating satisfactory recovery efficiency.

Risk Assessment Indicators

Pollution Assessment Methods

The Single Factor Pollution index (SPI) is utilized to quantitatively assess the level of pollution for each individual heavy metal. On the other hand, the Nemerow Comprehensive Pollution Index (NCPI) is employed to mitigate the influence of subjective factors and provide an overall evaluation of the combined pollutants' risk [23]. SPI(P) was calculated using Eq. (1)

$$P = C/S \tag{1}$$

P is the single factor pollution index of heavy metal, C (mg/kg) is the concentration of heavy metal, S (mg/kg) is the standard limit value of heavy metal. According to the National Standards of the Limits of Pollutants in Food of the People`s Republic of China [24], the limits of heavy metals Pb, Cr, Cd, As and Hg in dried fish are 1.0, 2.0, 0.1, 0.1 and 0.5 mg/kg, respectively. According to the Pollution Index (P_i) values, the level of contamination in the food can be categorized as follows: $P_i < 1.0$ indicates that the food is considered clean and safe for consumption. When P_i falls within the range of 1.0 to less than 2.0, it suggests that the food is mildly contaminated and therefore unfit for consumption. Similarly, if P_i ranges from 2.0 to less than 3.0, it indicates that the food is moderately contaminated and should not be consumed. Finally, if P_i is equal to or greater than 3.0, the food is classified as severely contaminated and should not be consumed due to the associated health risks [25].

NCPI(PN) was calculated using Eq. (2)

$$PN = \sqrt{\left(P_{ave}^2 + P_{max}^2/2\right)} \tag{2}$$

P_{ave} and P_{max} represent the average and maximum concentrations of heavy metals, respectively. The risk of heavy metal pollution is divided into five categories: Clean

($PN \leq 0.7$), Preventive ($0.7 < PN \leq 1.0$), Light Pollution ($1.0 < PN \leq 2.0$), Moderate Pollution ($2.0 < PN \leq 3.0$), and Heavy Pollution ($PN > 3.0$) [26].

Health Risk Assessment Methods

The Estimated Daily Intake (EDI) of a heavy metal, measured in milligrams per kilogram of body weight per day ($mg/kg \cdot BW^{-1} \cdot day^{-1}$), is calculated using the following variables: C (mg/kg), the concentration of the heavy metal in dried fish, DI (kg/day), the average intake rate of dried fish by local residents (which is 5.33×10^{-3} kg/day) [27]; and BW, the average weight of the population. In 2015, the average weight of Chinese adult males was recorded as 66.2 kg, while the average weight of Chinese adult females was 57.3 kg [28]. EDI values for adult males were calculated using Eq. (3).

$$EDI = (C \times DI)/BW \tag{3}$$

The target hazard quotient (THQ) is widely utilized in the evaluation of noncarcinogenic risks associated with heavy metals. $THQ \geq 1$ indicates that a certain heavy metal poses a non-carcinogenic risk to human health, and $THQ < 1$ indicates that the risk is negligible. Considering the cumulative impact of multiple heavy metals in aquatic products, the total non-carcinogenic risk posed by these metals can be assessed by calculating the aggregate non-carcinogenic risk index (HI) of heavy metals. Similarly, an HI value of ≥ 1 implies a potential risk to human health, while any value below 1 indicates a negligible risk [15, 29]. The THQ and HI was estimated using Eq. (4) and Eq. (5).

Non-carcinogenic health risks:

$$THQ = (EDI \times EF \times ED)/(RfD \times AT) \tag{4}$$

$$HI = \sum_{i=1}^{n} THQ_i \tag{5}$$

The Oral Reference Dose (RfD) represents an estimated daily oral exposure over a chronic period, potentially a lifetime, for the human population that is anticipated to be without significant risk of adverse effects over a lifetime, derived from the No-Observed-Adverse-Effect Level, the Lowest-Observed-Adverse-Effect Level, or a benchmark dose [30]. The RfD for each element is as follows: $Cd = 1.0 \times 10^{-3}$ mg/kg day^{-1}, $Cr = 3.0 \times 10^{-3}$ mg/kg day^{-1}. $Pb = 3.6 \times 10^{-3}$ $mg/kg \cdot day^{-1}$, $As = 3.0 \times 10^{-4}$ mg/kg day^{-1}, and $Hg = 3.0 \times 10^{-4}$ mg/kg day^{-1} [31]. EF represents the exposure frequency (365 days/year), ED represents the exposure duration (70.1 years for males and 77.5 years for females), and AT represents the average exposure time (365 days/year multiplied by the duration of exposure) [32–34].

Carcinogenic risk (CR) can be estimated by the potency and exposure level of the carcinogen, and total carcinogenic risk (TCR) can be used to assess the carcinogenic risk of mixed pollutants [33]. Due to the lack of carcinogenic slope factors for Pb and Hg, this paper will evaluate the carcinogenic risk of As, Cd and Cr to human health. CR and TCR can be calculated based on the following equation [35]:

The CR is calculated by Eq. (6).

$$CR = EDI \times CSF \tag{6}$$

The TCR is defined by Eq. (7).

$$TCR = \sum_{i=1}^{n} CR_i \tag{7}$$

where CR is a carcinogenic risk, EDI is the average dietary intake (mg/kg day^{-1}). The Cancer Slope Factor (CSF) is a parameter used in human risk assessment to describe potential carcinogenicity, typically derived from the lower confidence limit of the dose at the data-supported lowest specified risk level of 95% [36, 37]. The CSF of Cr, As and Cd is 0.5, 1.5 and 6.3 (kg·day/mg), respectively [15]. CR and TCR values greater than 1e-04 are considered to be possibly carcinogenic. A risk ranging from 1×10^{-4} to 1×10^{-6} is deemed acceptable, while a risk below 1×10^{-6} is considered negligible [38].

Statistical Analysis

In the study, the Shapiro-Wilk test was used to assess the normality of the datasets, while the Levene test was employed to test the homogeneity of variance. The results of the concentration levels of heavy metals revealed that the data did not follow a normal distribution. As a result, descriptive statistics for the content of five heavy metals use median, and 1st and 3rd quartile values, and the between-group comparisons were conducted using the non-parametric Wilcoxon signed rank test, which is appropriate for analyzing data that deviate from normality. The outcomes of health risk assessment indicators such as EDI, THQ, HI, CR, and TCR indicated a normal distribution of the data. Consequently, the mean $\pm$ 1.96 standard deviations were reported. The confidence intervals are represented as mean $\pm$ 1.96 standard deviations. Pearson Correlation analysis was employed to investigate the relationships between the concentrations of heavy metals in dried fish. This method was chosen because it provides a measure of the linear relationship between variables, which is essential for understanding how the presence of one heavy metal might be associated with the presence of others. To explore the trends among different metal elements in dried fish, Principal Component Analysis (PCA) was conducted, with the ' prcomp' package. This technique helps to reduce the dimensionality of the dataset, highlighting the main components that explain the most variance in metal concentrations. All statistical analyses, including the computation of test statistics and P-values, were conducted using the R programming language. In this study, the significance level for statistical tests was set at α = 0.05. P-values less than 0.05 were considered statistically significant. All tests were conducted as two-tailed tests to account for the possibility of effects in either direction .

Results

Heavy Metal Analysis

Heavy Metal Levels in Dried Fish

The descriptive data for heavy metal content in dried fish, including the median, quartile, and exceeding rate, are presented in Table 1. The average levels of heavy metals in various species of dried fish are as follows: As >Cr >Pb >Hg >Cd. Specifically, the values are 2.653 mg/kg, 0.358 mg/kg, 0.083 mg/kg, 0.066 mg/kg, and 0.032 mg/kg. Among the different species of dried fish, *dried Nemipterus-virgatus* exhibits the highest median levels of As and Hg, with values of 4.459 mg/kg and 0.491 mg/kg, respectively. The highest median concentration of Cr is 0.770 mg/kg in *dried Ctenopharyngodon idella*, whereas the highest median concentrations of Cd and Pb are 0.065 mg/kg and 0.139 mg/kg in *dried river fish*, respectively. According to the national standard of "Limits of Pollutants in Food" of the People`s Republic of China [24], the permissible limits for heavy metals in dried fish are as follows: Cr (2.0 mg/kg), As (0.1 mg/kg), Cd (0.1 mg/kg), Pb (1.0 mg/kg), and Hg (0.5 mg/kg). Out of these metals, only the median concentration of As (2.653 mg/kg) exceeds the standard limit, resulting in the highest exceeding rate (88.33%). Furthermore, among different species, the median concentrations of As in *dried Thamnaconus modestus* (2.902 mg/kg), *dried Stolephorus chinensis* (4.030 mg/kg) and *dried Nemipterus-virgatus* (4.459 mg/kg) also significantly exceed the standard limit. The medians of other heavy metals are below the standard limit, but the 3rd quartile (P_{75}) values for Cd and Hg still exceed the standard. Table 1 shows that the P_{75} value for Cd in *dried Thamnaconus modestus* (0.105 mg/kg), *dried Stolephorus chinensis* (0.205 mg/kg), and *dried river fish* (0.144

Table 1 Heavy metal content in different species of dried fish

Fish		Cr (mg/kg)	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Hg (mg/kg)
dried Stolephorus chinensis	median	0.120	4.030	0.041	0.097	0.056
	1st Quartile	0.066	1.769	0.025	0.073	0.049
	3rd Quartile	0.443	5.028	0.205	0.166	0.106
	Exceeding rate	0	100%	41.67%	0	0
dried Thamnaconus modestus	median	0.209	2.802	0.062	0.082	0.047
	1st Quartile	0.038	2.410	0.049	0.073	0.040
	3rd Quartile	0.565	3.409	0.105	0.098	0.084
	Exceeding rate	8.33%	100%	33.33%	0	0
dried Nemipterus-virgatus	median	0.414	4.459	0.027	0.064	0.491
	1st Quartile	0.190	3.097	0.022	0.038	0.316
	3rd Quartile	1.002	4.979	0.043	0.168	1.008
	Exceeding rate	8.33%	100%	16.67%	0	50.00%
dried river fish	median	0.288	1.252	0.065	0.139	0.103
	1st Quartile	0.082	0.905	0.021	0.064	0.062
	3rd Quartile	1.374	3.150	0.144	0.381	0.158
	Exceeding rate	16.67%	100%	41.67%	16.67%	0
dried Ctenopharyngodon idella	median	0.770	0.665	0	0.045	0.030
	1st Quartile	0.455	0.015	0	0	0.016
	3rd Quartile	2.485	0.153	0	0.137	0.057
	Exceeding rate	25%	41.67%	0	8.33%	0
total	median	0.358	2.653	0.032	0.083	0.066
	1st Quartile	0.073	0.929	0	0.044	0.042
	3rd Quartile	0.836	4.368	0.103	0.204	0.187
	Exceeding rate	11.67%	88.33%	26.67%	1.67%	10.00%

As, arsenic; Cd, cadmium; Cr, chromium; Hg, mercury; Pb, lead

Data are given as mean, 1st and 3rd quartile values and exceeding rate

Table 2 Multiple comparisons of concentration levels of heavy metals in different species of dried fish

Fish 1	Fish 2	Cr		As		Cd		Pb		Hg	
		W	*P*	*W*	*P*	*W*	*P*	*W*	*P*	*W*	*P*
dried Stolephorus chinensis	*dried Thamnaconus modestus*	65	0.707	79	0.713	69	0.885	83	0.551	87.5	0.386
	dried Nemipterus-virgatus	47	0.157	61	0.551	95	0.193	86	0.436	15	< 0.001
	dried river fish	52	0.260	110	0.028	82	0.583	58	0.443	54	0.319
	dried Ctenopharyngodon idella	28	0.012	142	< 0.001	132	< 0.001	97	0.156	104	0.068
dried Thamnaconus modestus	*dried Stolephorus chinensis*	79	0.707	65	0.713	75	0.885	61	0.551	56.5	0.386
	dried Nemipterus-virgatus	57	0.410	41	0.078	103	0.078	82	0.583	12	< 0.001
	dried river fish	61	0.551	98	0.143	74	0.931	54	0.319	48	0.178
	dried Ctenopharyngodon idella	34	0.028	144	< 0.001	138	< 0.001	92	0.259	101	0.101
dried Nemipterus-virgatus	*dried Stolephorus chinensis*	97	0.157	83	0.551	49	0.193	58	0.436	129	< 0.001
	dried Thamnaconus modestus	87	0.410	103	0.078	41	0.078	62	0.583	132	< 0.001
	dried river fish	81	0.644	119	0.006	51	0.236	50	0.214	130	< 0.001
	dried Ctenopharyngodon idella	51	0.242	144	< 0.001	132	< 0.001	82	0.580	135	< 0.001
dried river fish	*dried Stolephorus chinensis*	92	0.260	34	0.028	62	0.583	86	0.443	90	0.318
	dried Thamnaconus modestus	83	0.551	46	0.143	70	0.931	90	0.319	96	0.178
	dried Nemipterus-virgatus	64	0.644	25	0.006	93	0.236	94	0.214	14	< 0.001
	dried Ctenopharyngodon idella	46	0.143	138	< 0.001	132	< 0.001	99	0.124	113	0.017
dried Ctenopharyngodon idella	*dried Stolephorus chinensis*	116	0.012	2	< 0.001	12	< 0.001	47	0.156	40	0.068
	dried Thamnaconus modestus	110	0.028	0	< 0.001	6	< 0.001	52	0.259	43	0.101
	dried Nemipterus-virgatus	93	0.242	0	< 0.001	12	< 0.001	62	0.580	9	< 0.001
	dried river fish	98	0.143	6	< 0.001	12	< 0.001	45	0.124	31	0.017

All data are shown as W values and P-values. Statistical analysis was performed using the non-parametric Wilcoxon signed rank test. P-values < 0.05 were considered statistically significant

mg/kg) is higher than the standard limit. Additionally, the P_{75} value for Hg in *dried Nemipterus-virgatus* (1.008 mg/kg) and the P_{75} value for Cr in *dried Ctenopharyngodon idella* (2.485 mg/kg) also exceed the standard limit (Table 1). These findings are noteworthy and indicate potential risks. Furthermore, there are significant variations in the heavy metal content among different species of dried fish. The results suggest that the concentration levels of As, Cd, and Hg vary significantly across different species of dried fish (Table 2).

PCA Analysis and Correlation Analysis

PCA was conducted on the heavy metal content of 60 dried fish samples. To assess the suitability of PCA analysis, a Kaiser-Meyer-Olkin (KMO) test and Bartlett test were performed. The results indicate that the Bartlett significance value was less than 0.01, confirming the validity of the PCA analysis. The first three PCA components accounted for 84.95% of the total variance. PC1 exhibited the highest loadings for Cr and Pb, explaining 32.34% of the overall variance. PC2 displayed the maximum loadings for As, explaining 30.30% of the total variance. (Fig. 3) Based on the correlation analysis of the five heavy metals, positive correlations were observed between Pb-Cr (r=0.56), Cd-As (r=0.49), and Hg-As (r=0.35). Additionally, in different species of dried fish, a positive correlation between As-Cr (r=0.89) and Pb-As (r=0.73) was found in dried Nemipterus-virgatus.

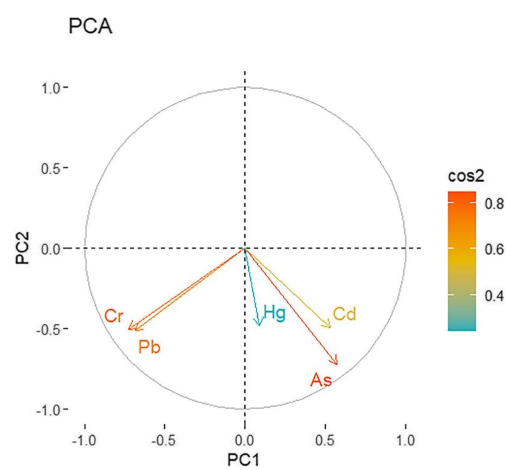

Fig. 3 Biplot for heavy metal content measured in 60 dried fish samples. This plot is a visual representation of the first two components (PC1 and PC2). The x-axis represents the PC1 explaining 32.34% of the total variance, and the y-axis represents the PC2 explaining 30.30% of the total variance. The colors of the elements represent the element's contribution to the respective component. As, arsenic; Cd, cadmium; Cr, chromium; Hg, mercury; Pb, lead; PCA, Principal Component Analysis. Statistical analysis was performed using PCA

Furthermore, a positive correlation between Hg and Cd was observed in dried Thamnaconus modestus (r=0.61). (Fig. 4)

Pollution Level Evaluation

The SPI and NCPI can evaluate the pollution degree of individual heavy metals and the overall pollution degree of heavy metals. The results of these assessments are presented in Table 3. The SPI values for Cr (0.444), Cd (0.711), Pb (0.251), and Hg (0.397) in the five dried fish samples are all less than 1, indicating that these elements do not pose a pollution risk to the dried fish. However, the SPI value for As (28.973) is greater than 3, suggesting severe pollution by As in each of the dried fish samples. The order of heavy metal pollution degree is As > Cd > Cr > Hg > Pb. Due to the significant pollution by As, its contribution to

Fig. 4 Relation between 5 heavy metals including Cr, As, Cd, Pb and Hg. The distribution of heavy metals in different dried fish shown in the diagonal squares. The heavy metal content against the other heavy metal in different dried fish below the central diagonal proportion plots. The correlation between each heavy metals is shown on the opposite side of the diagonal. The correlation coefficients between each pair of heavy metals are shown above the diagonal. *P < 0.05, ** P < 0.01, *** P < 0.001. Statistical analysis was performed using Pearson correlation

Table 3 SPI and NCPI values of heavy metal pollution in dried fish

Fish	SPI					NCPI
	Cr	As	Cd	Pb	Hg	
Dried Stolephorus chinensis	0.060	40.300	0.410	0.097	0.112	29.080
Dried Thamnaconus modestus	0.105	28.020	0.620	0.082	0.094	20.231
Dried Nemipterus-virgatus	0.207	44.590	0.270	0.064	0.982	32.197
Dried river fish	0.144	12.520	0.650	0.139	0.206	9.061
Dried Ctenopharyngodon idella	0.385	6.650	0.000	0.045	0.060	4.809
Total	0.444	28.973	0.711	0.251	0.397	20.944

NCPI, Nemerow Comprehensive Pollution Index; SPI, Single Factor Pollution index the NCPI is substantial, resulting in an NCPI value (20.944) also exceeding 3. The comprehensive level of heavy metal pollution is classified as severe pollution. Additionally, when considering the NCPI values of dried fish, the order is as follows: *dried Nemipterus-virgatus* (32.197) > *dried Stolephorus chinensis* (29.080) > *dried Thamnaconus modestus* (20.231) > *dried river fish* (9.061)> *dried Ctenopharyngodon idella* (4.809).

Health Risk Assessment

Non-carcinogenic Risk Assessment

According to the Joint FAO/WHO Expert Committee on Food Additives (JECFA) [39] and the European Food Safety Authority (EFSA) [40], the Provisional Tolerable Daily Intake (PTDI) values for Cr, As, Cd, Pb, and Hg are 0.3, 0.003, 8e-04, 0.0015, and 1.4e-04 mg/kg BW^{-1} day^{-1}, respectively. On the other hand, the EDI values for Cr, As, Cd, Pb, and Hg in adult males were 7.15e-05, 2.33e-04, 5.72e-06, 2.02e-05, and 1.60e-05 mg/kg BW^{-1} day^{-1}, while the EDI values for Cr, As, Cd, Pb, and Hg in adult females were 8.26e-05, 2.70e-04, 6.61e-06, 2.34e-05, and 1.85e-05 mg/kg BW^{-1} day^{-1} (Table 4). It is evident that the EDI values for both males and females are significantly lower than corresponding PTDI at the average exposure level.

This study aimed to evaluate the non-carcinogenic health risks associated with heavy metal exposure from dried fish using the THQ and HI calculations in Fig. 5A-B and Table 4. Based on the findings presented, the non-carcinogenic risks associated with different species of dried fish can be ordered as follows: *dried Nemipterus-virgatus* > *dried Stolephorus chinensis* > *dried Thamnaconus modestus* > *dried river fish* > *dried Ctenopharyngodon idella*. The average THQ values of As for *dried Stolephorus chinensis* and *dried Nemipterus-virgatus* were found to be higher than 1 for both males (1.05, 1.32) and females (1.21, 1.52), indicating potential health risks. However, the average THQ values for other heavy metals in different species of dried fish were lower than 1, suggesting a lower risk of non-carcinogenic health effects. In both male and female groups, the 95% upper limit of THQ of As for *dried Thamnaconus modestus* (1.06, 1.23) exceeded 1. Additionally, the 95% upper limit of THQ of As for *dried river fish* in women (1.07) surpassed 1 as well. Moreover, based on the HI values, the HI values for *dried Nemipterus-virgatus* were higher than 1 in both male (1.52) and female (1.75) groups ($P < 0.05$), suggesting the potential occurrence of non-carcinogenic health risks. In both gender groups, the average HI for *dried Stolephorus chinensis* (male: 1.09, female: 1.26) exceeded 1. Additionally, in women, the average HI for *dried Thamnaconus modestus* (1.05) also exceeded 1. On the other hand, the mean HI for other dried fish samples was less than 1. However, it is important to note that the 95% upper limit of the HI for *dried Thamnaconus modestus* in men (1.11) and *dried river fish* in male (1.01) and female (1.16) also exceeded 1. This implies that individuals at the upper end of the exposure range may face potentially higher health risks.

Carcinogenic Risk Assessment

It is evident that the CR associated with the ingestion of As in *dried Stolephorus chinensis* (male: 4.72e-04, female: 5.54e-04), *Thamnaconus modestus* (male: 3.86e-04, female: 4.46e-04), *Nemipterus-virgatus* (male: 5.93e-04, female: 6.85e-04), and *river fish* (male: 2.76e-04, female: 3.19e-04)all exceed 1e-04, indicating a potential risk of carcinogenesis, showed in Table 5 and Fig. 5C-D. However, the CR value for As in *dried Ctenopharyngodon idella* (male: 2.31e-05, female: 2.67e-05) falls in the range of 1e-06 to 1e-04, demonstrating that the carcinogenic risk associated with As exposure in *dried Ctenopharyngodon idella* was within acceptable limits. Additionally, the CR value of Cd in *dried Ctenopharyngodon idella* (male: 0, female: 0) was found to be less than 1e-06, indicating that the associated carcinogenic risk is negligible, while the CR value of Cr and Cd in other dried fish samples ranged between 1e-06 and 1e-04, signifying that the carcinogenic risk posed by these metals is deemed acceptable. However, in both males and females, the 95th percentile upper limit (P_{95}) for the CR value of Cd in *dried Stolephorus chinensis* (male: 1.24e-04, female: 1.44e-04) also exceeded 1.00e-04. When considering the TCR of heavy metals, the order of carcinogenic risk was observed to be *dried Nemipterus-virgatus* (male: 6.48e-04, female: 7.49e-04) > *dried Stolephorus chinensis* (male: 5.55e-04, female: 6.42e-04) > *dried Thamnaconus modestus* (male: 4.50e-04, female: 5.20e-04) > *dried river fish* (male: 3.59e-04, female: 4.15e-04) > *dried Ctenopharyngodon idella* (male: 9.57e-05, female: 1.11e-04). The ingestion of heavy metals in *dried Stolephorus chinensis*, *dried Thamnaconus modestus*, *dried Nemipterus-virgatus* and *dried river fish* may be carcinogenic for men and women. Additionally, apart from the types of dried fish that may be carcinogenic for men, heavy metal ingestion in *dried Ctenopharyngodon idella* may also be carcinogenic for women. However, it is worth noting that the P_{95} for TCR values, when ingested by men, also exceeds 1e-04. The analysis of the cancer risk associated with heavy metal ingestion in dried fish reveals that both men and women face a risk of carcinogenic. Notably, the risk of carcinogenesis in women is higher compared to men.

Table 4 EDI, THQ, and HI values for heavy metals in different dried fish by gender and metal types and the overall totals

Fish	Heavy metal	EDI		THQ		HI	
		Male	Female	Male	Female	Male	Female
dried Stolephorus chinensis	Cr	2.21e-05 (7.90e-06,3.63e-05)	2.55e-05 (9.12e-06,4.19e-05)	7.36e-03 (2.63e-03,1.21e-02)	8.50e-03 (3.04e-03,1.40e-02)	1.09 (0.71,1.48)	1.26 (0.82,1.71)
	As	3.14e-04 (2.01e-04,4.28e-04)	3.63e-04 (2.32e-04,4.94e-04)	1.05 (6.70e-01,1.43)	1.21 (7.74e-01,1.65)		
	Cd	1.15e-05 (3.33e-06,1.98e-05)	1.33e-05 (3.85e-06,2.28e-05)	1.15e-02 (3.33e-03,1.98e-02)	1.33e-02 (3.85e-03,2.28e-02)		
	Pb	1.14e-05 (5.77e-06,1.70e-05)	1.31e-05 (6.67e-06,1.96e-05)	3.16e-03 (1.60e-03,4.71e-03)	3.65e-03 (1.85e-03,5.44e-03)		
	Hg	6.79e-06 (4.32e-06,9.26e-06)	7.85e-06 (5.00e-06,1.07e-05)	2.26e-02 (1.44e-02,3.09e-02)	2.62e-02 (1.67e-02,3.57e-02)		
dried Thamnaconus modestus	Cr	4.27e-05 (8.96e-06,7.63e-05)	4.93e-05 (1.03e-05,8.82e-05)	1.42e-02 (2.99e-03,2.54e-02)	1.64e-02 (3.45e-03,2.94e-02)	0.91 (0.70,1.11)	1.05 (0.81,1.28)
	As	2.58e-04 (1.96e-04,3.19e-04)	2.98e-04 (2.26e-04,3.69e-04)	8.58e-01 (6.52e-01,1.06)	9.92e-01 (7.53e-01,1.23)		
	Cd	6.77e-06 (3.40e-06,1.01e-05)	7.82e-06 (3.93e-06,1.17e-05)	6.77e-03 (3.40e-03,1.01e-02)	7.82e-03 (3.93e-03,1.17e-02)		
	Pb	8.58e-06 (5.10e-06,1.21e-05)	9.91e-06 (5.89e-06,1.39e-05)	2.38e-03 (1.42e-03,3.35e-03)	2.75e-03 (1.64e-03,3.87e-03)		
	Hg	7.12e-06 (3.17e-06,1.11e-05)	8.23e-06 (3.66e-06,1.28e-05)	2.37e-02 (1.06e-02,3.69e-02)	2.74e-02 (1.22e-02,4.26e-02)		
dried Nemipterus-virgatus	Cr	6.42e-05 (1.35e-05,1.15e-04)	7.42e-05 (1.56e-05,1.33e-04)	2.14e-02 (4.49e-03,3.83e-02)	2.47e-02 (5.19e-03,4.43e-02)	1.52 (0.98,2.05)	1.75 (1.13,2.37)
	As	3.95e-04 (2.46e-04,5.44e-04)	4.57e-04 (2.85e-04,6.29e-04)	1.32 (8.21e-01,1.81)	1.52 (9.48e-01,2.10)		
	Cd	3.72e-06 (1.26e-06,6.18e-06)	4.30e-06 (1.46e-06,7.14e-06)	3.72e-03 (1.26e-03,6.18e-03)	4.30e-03 (1.46e-03,7.14e-03)		
	Pb	1.11e-05 (3.57e-06,1.86e-05)	1.28e-05 (4.13e-06,2.15e-05)	3.08e-03 (9.92e-04,5.17e-03)	3.56e-03 (1.15e-03,5.98e-03)		
	Hg	5.16e-05 (2.91e-05,7.40e-05)	5.96e-05 (3.36e-05,8.55e-05)	1.72e-01 (9.69e-02,2.47e-01)	1.99e-01 (1.12e-01,2.85e-01)		
dried river fish	Cr	8.34e-05 (1.67e-05,1.50e-04)	9.64e-05 (1.93e-05,1.73e-04)	2.78e-02 (5.57e-03,5.01e-02)	3.21e-02 (6.44e-03,5.78e-02)	0.69 (0.38,1.01)	0.80 (0.44,1.16)
	As	1.84e-04 (9.01e-05,2.78e-04)	2.12e-04 (1.04e-04,3.21e-04)	6.13e-01 (3.00e-01,9.26e-01)	7.08e-01 (3.47e-01,1.07)		
	Cd	6.57e-06 (3.34e-06,9.81e-06)	7.59e-06 (3.85e-06,1.13e-05)	6.57e-03 (3.34e-03,9.81e-03)	7.59e-03 (3.85e-03,1.13e-02)		
	Pb	4.70e-05 (-8.75e-07,9.49e-05)	5.43e-05(-1.01e-06,1.10e-04)	1.31e-02 (-2.43e-04,2.63e-02)	1.51e-02 (-2.81e-04,3.04e-02)		
	Hg	9.62e-06 (5.77e-06,1.35e-05)	1.11e-05 (6.66e-06,1.56e-05)	3.21e-02 (1.92e-02,4.49e-02)	3.71e-02 (2.22e-02,5.19e-02)		
dried Ctenopharyngodon idella	Cr	1.45e-04 (4.53e-05,2.45e-04)	1.68e-04 (5.24e-05,2.83e-04)	4.84e-02(1.51e-02,8.16e-02)	5.59e-02 (1.75e-02,9.43e-02)	0.12 (4.81e-02,0.20)	0.14 (5.56e-02,0.23)
	As	1.54e-05 (-2.72e-06,3.35e-05)	1.78e-05 (-3.14e-06,3.88e-05)	5.14e-02 (-9.07e-03,1.12e-01)	5.94e-02 (-1.05e-02,1.29e-01)		
	Cd	0.00	0.00	0.00	0.00		
	Pb	2.32e-05 (-6.62e-06,5.29e-05)	2.67e-05 (-7.65e-06,6.11e-05)	6.43e-03 (-1.84e-03,1.47e-02)	7.43e-03 (-2.12e-03,1.70e-02)		
	Hg	4.89e-06(1.31e-06,8.47e-06)	5.65e-06 (1.51e-06,9.79e-06)	1.63e-02 (4.36e-03,2.82e-02)	1.88e-02 (5.04e-03,3.26e-02)		
Total	Cr	7.15e-05(4.32e-05,9.97e-05)	8.26e-05(4.99e-05,1.15e-04)	2.38e-02(1.44e-02,3.32e-02)	2.75e-02(1.66e-02,3.84e-02)	0.87 (0.68,1.05)	1.00(0.78,1.22)
	As	2.33e-04(1.80e-04,2.87e-04)	2.70e-04(2.08e-04,3.31e-04)	7.78e-01(5.99e-01,9.56e-01)	8.98e-01(6.92e-01,1.10)		
	Cd	5.72e-06 (3.60e-06,7.84e-06)	6.61e-06(4.16e-06,9.06e-06)	5.72e-03(3.60e-03,7.84e-03)	6.61e-03(4.16e-03,9.06e-03)		
	Pb	2.02e-05(8.60e-06,3.19e-05)	2.34e-05(9.93e-06,3.68e-05)	5.62e-03(2.39e-03,8.86e-03)	6.49e-03(2.76e-03,1.02e-02)		
	Hg	1.60e-05(9.56e-06,2.24e-05)	1.85e-05(1.10e-05,2.59e-05)	5.33e-02(3.19e-02,7.48e-02)	6.16e-02(3.68e-02,8.64e-02)		

EDI, Estimated Daily Intake; HI, aggregate non-carcinogenic risk index; THQ, target hazard quotient

All data are represented as mean (95% confidence intervals) and were calculated using mean ± 1.96 standard deviations

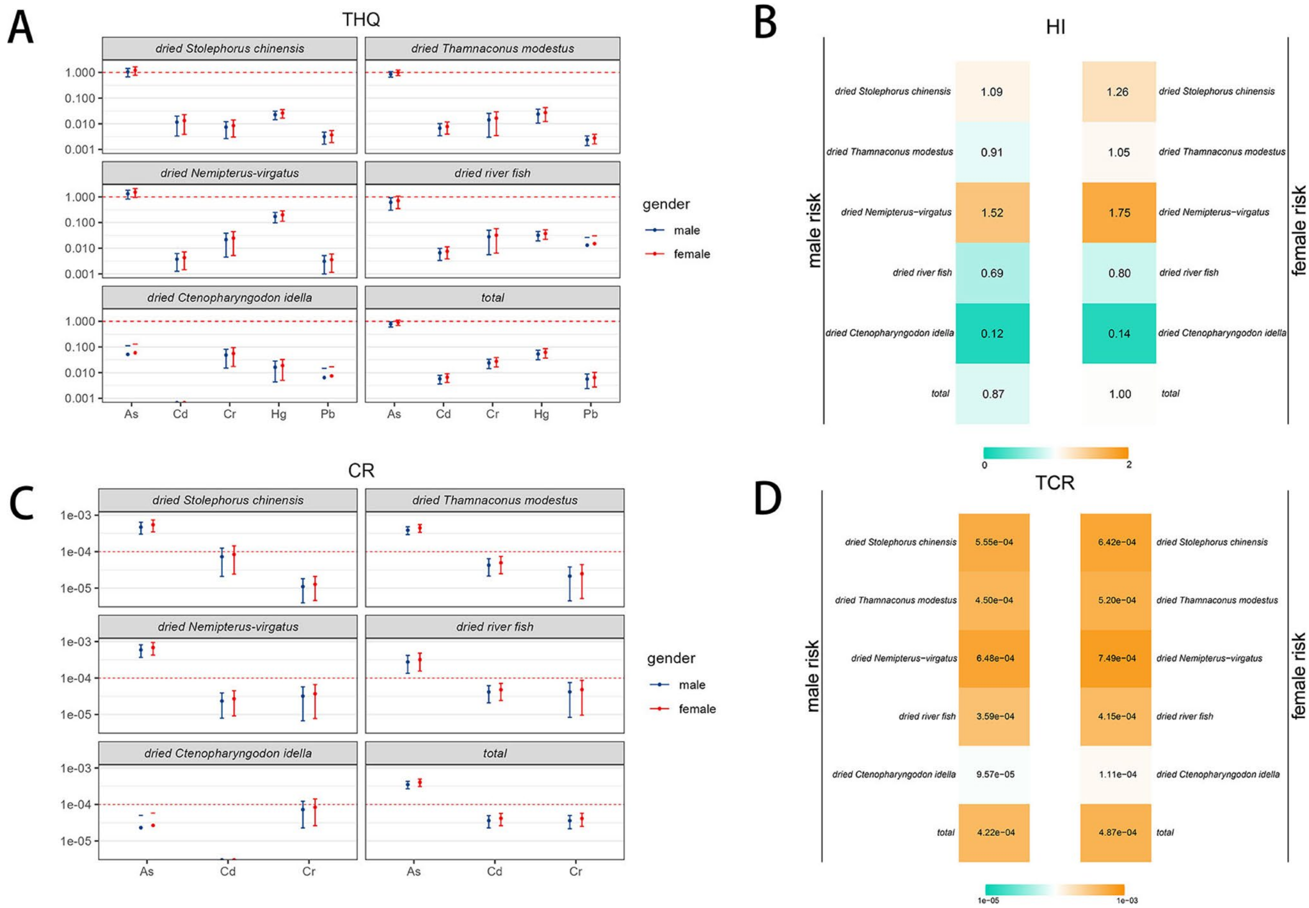

Fig. 5 Forest plot demonstrates the non-carcinogenic health risks associated with heavy metal exposure from dried fish using the THQ and HI calculations in Fig. 5A-B. The CR and the TCR values were showed in Fig. 5C-D. The average and 95% confidence interval of THQ (A) and CR (C) between dried fish and heavy metals is shown compared with the standard (dashed line). The heatmaps are colored according to (B) the HI (HI < 1, teal; HI ≥ 1, orange), and (D) the TCR (TCR < 1e-04, teal; TCR ≥ 1e-04, orange). Confidence intervals are calculated as mean ± 1.96 standard deviations. CR, carcinogenic risk; HI, aggregate non-carcinogenic risk index; TCR, total carcinogenic risk; THQ, target hazard quotient

Discussion

Given the limited research had been conducted specifically on the health risks related to the consumption of heavy metals in dried fish in China, this study seeks to address this research gap by examining the extent of heavy metal contamination in dried fish samples and evaluating the potential health risks posed to consumers. In this study, we measured five heavy metals (Cr, As, Cd, Pb, Hg) in common dried fish in Guangzhou, China. All types of the dried fish exceeded safety limits, with As showing the highest exceedance rate. The SPI indicated severe As contamination, particularly in *dried Nemipterus-virgatus*. The NCPI ranked as follows: *dried Nemipterus-virgatus* > *dried Stolephorus chinensis* > *dried Thamnaconus modestus* > *dried river fish* > *dried Ctenopharyngodon idella*. The heavy metal pollution degree was As > Cd > Cr > Hg > Pb. The EDI values were well below the PTDI limits. The ranking of non-carcinogenic and carcinogenic health risks caused by various dried fish corresponds to their degree of contamination. As posed a potential non-carcinogenic risk for certain fish species, and carcinogenic risk was noted for As in specific dried fish, particularly affecting males and females differently. Women may be at greater risk due to variations in body weight and life expectancy. However, other heavy metals showed minimal health risks.

We investigated the content of heavy metals in dried fish. These results align with a prior survey on coastal fish in China, where As was identified as the most heavily polluted trace element [41]. Studies from China have indicated that Cr, Pb, and As are among the heavy metals with significant contamination in fresh fish [14, 15]. While these findings slightly differ from our results, it is important to note that the level of contamination for each heavy metal can vary greatly by region and year [14]. For instance, in our study, As, Cd, and Cr were found at higher

Table 5 CR and TCR values for heavy metals in different dried fish by gender and metal types and the overall totals

Fish	Heavy metal	CR		TCR	
		Male	Female	Male	Female
dried Stolephorus chinensis	Cr	1.10e-05(3.95e-06,1.81e-05)	1.28e-05(4.56e-06,2.09e-05)	5.55e-04(-9.99e-04,2.11e-03)	6.42e-04(-1.15e-03,2.44e-03)
	As	4.72e-04(3.01e-04,6.42e-04)	5.45e-04(3.48e-04,7.41e-04)		
	Cd	7.27e-05(2.10e-05,1.24e-04)	8.40e-05(2.42e-05,1.44e-04)		
dried Thamnaconus modestus	Cr	2.13e-05(4.48e-06,3.82e-05)	2.46e-05(5.17e-06,4.41e-05)	4.50e-04(-5.16e-04,1.42e-03)	5.20e-04(-5.96e-04,1.64e-03)
	As	3.86e-04 (2.93e-04,4.79e-04)	4.46e-04 (3.39e-04,5.54e-04)		
	Cd	4.26e-05 (2.14e-05,6.39e-05)	4.93e-05 (2.47e-05,7.38e-05)		
dried Nemipterus-virgatus	Cr	3.21e-05(6.74e-06,5.75e-05)	3.71e-05 (7.79e-06,6.64e-05)	6.48e-04(-1.44e-03,2.74e-03)	7.49e-04(-1.67e-03,3.17e-03)
	As	5.93e-04(3.69e-04,8.16e-04)	6.85e-04(4.27e-04,9.43e-04)		
	Cd	2.34e-05(7.95e-06,3.89e-05)	2.71e-05(9.19e-06,4.50e-05)		
dried river fish	Cr	4.17e-05(8.36e-06,7.51e-05)	4.82e-05(9.66e-06,8.67e-05)	3.59e-04(-1.29e-02,1.37e-02)	4.15e-04(-1.49e-02,1.58e-02)
	As	2.76e-04(1.35e-04,4.17e-04)	3.19e-04(1.56e-04,4.81e-04)		
	Cd	4.14e-05(2.10e-05,6.18e-05)	4.78e-05(2.43e-05,7.14e-05)		
dried Ctenopharyngodon idella	Cr	7.25e-05(2.27e-05,1.22e-04)	8.38e-05(2.62e-05,1.41e-04)	9.57e-05(-8.17e-03,8.36e-03)	1.11e-04(-9.44e-03,9.66e-03)
	As	2.31e-05(-4.08e-06,5.03e-05)	2.67e-05(-4.72e-06,5.81e-05)		
	Cd	0.00	0.00		
Total	Cr	3.57e-05(2.16e-05,4.99e-05)	4.13e-05(2.50e-05,5.76e-05)	4.22e-04(3.33e-04,5.10e-04)	4.87e-04(3.85e-04,5.89e-04)
	As	3.50e-04(2.69e-04,4.30e-04)	4.04e-04(3.11e-04,4.97e-04)		
	Cd	3.60e-05(2.27e-05,4.94e-05)	4.16e-05(2.62e-05,5.71e-05)		

CR, carcinogenic risk; TCR, total carcinogenic risk

All data are represented as mean (95% confidence intervals) and were calculated using mean ± 1.96 standard deviations

concentrations in fresh fish from the Pearl River Basin, which may not be consistent in other areas [14]. Research from other countries, such as Bangladesh and India, has reported different results, with Pb, Hg, and Cr being the heavy metals of significant concern in dried fish [2, 9, 42]. The observed discrepancies may arise from variations in regional water pollution levels, as well as variances in abiotic factors including water pH, temperature, and biological factors such as fish species, feeding habits, and reproductive cycles. Out of the five fish species considered in this study, only *Ctenopharyngodon idella* primarily feeds on vegetation and occupies a lower trophic level. Interestingly, this ecological characteristic leading to the lowest pollution level suggests the potential influence of biological enrichment on heavy metal contamination [43]. Thus, as humans occupy the highest trophic level, they exhibit increased vulnerability to the impacts of heavy metal exposure. Guangdong Province, characterized by a high degree of industrialization and severe water pollution [44], displays elevated levels of heavy metal content, requiring increased attention. The production process of dried fish entails multiple steps, leading to a higher concentration of heavy metals per kilogram. Furthermore, dried fish available in the market may come into contact with atmospheric sediments, which often contain trace metals. These particles eventually settle on the surface of dried fish [45].

Similar to the PCA analysis conducted in this study, a study conducted in India on the consumption of dried fish also focused on the same five elements, along with the inclusion of nickel (Ni) [42]. The results demonstrated that PC1 was significantly influenced by Cr, As, and Pb, with Pb showing a negative load, which is in agreement with the findings of the present study. However, PC2 primarily exhibited positive loads for Cr, Ni, and Cd, which contradicts the results obtained in this study. This variation is likely attributed to regional disparities in water pollution. Furthermore, the study findings indicate a correlation between multiple heavy metal elements, which may be attributed to local geological conditions and pollution sources. This correlation is consistent with the findings of Arisekar et al., who conducted Pearson correlation analysis on heavy metals in dried fish and revealed a significant positive correlation between As-Cd and As-Hg [42].

The heavy metal elements of concern in this study are detrimental to human health, with their carcinogenicity warranting attention. Additionally, they adversely affect multiple organs and systems, including the nervous system and kidneys [46–49]. Consequently, our study focused on the potential health risks associated with heavy metal intake through dried fish consumption. Given the variations in average body weight and lifespan between adult men and women, the lifetime intake of heavy metals from dried fish may vary, resulting in different health risks. Therefore, this study examined the disparity in heavy metal intake from dried fish between adult males and females, as well as evaluating the associated health risks separately. The EDI values are compared against the corresponding PTDI as a method of assessment. The EDI value calculated in this study was found to be considerably lower than the PTDI value established by the JECFA and the EFSA. However, it is important to note that these results are specific to the fish analyzed in this study and do not take into account other sources of heavy metal intake [50]. Other studies have demonstrated that humans are exposed to significant amounts of heavy metals through various food sources, including rice, vegetables, and fruits [51]. Considering these additional sources, the ingestion of heavy metals by humans may pose a greater health risk. Several Chinese studies have analyzed fish from Hong Kong, coastal provinces, major river basins, and other provinces in China, focusing on heavy metals such as Hg, As, Cd, Cr, Pb [13–15, 52]. The EDI of these metals from fish consumption generally falls below the limits. Studies from India and Bangladesh have examined dried fish, with a similar focus on heavy metals. Studies from Bangladesh indicate that EDI for these metals from dried fish is below the limits [2, 9], while some Indian studies suggest that EDI for Pb, Cd, Hg may exceed limits [42, 53]. Overall, the majority of these findings are consistent with our results, indicating that EDI values were below PTDI limits, although Chinese studies lack analysis of dried fish.

The extent of heavy metal contamination corresponded to the non-carcinogenic and carcinogenic risk levels observed in different types of dried fish. In this study, the pollution level of heavy metals in dried fish was assessed using the SPI and NCPI. SPI was used to assess the pollution degree of individual heavy metals, while NCPI was used to evaluate the overall pollution degree of heavy metals. The results indicated that among the five elements, As posed the largest non-carcinogenic and carcinogenic risks. The other elements also exhibited levels that exceeded the standard, but their associated non-carcinogenic and carcinogenic risks were deemed acceptable. With regards to the total non-carcinogenic and carcinogenic risks, nearly all dried fish, except for *dried Ctenopharyngodon idella*, presented health risks. Both non-carcinogenic and carcinogenic risks were higher in women than in men. These findings emphasize the need for heightened awareness among women regarding the potential health risks associated with heavy metal intake. Furthermore, it was observed that although the average health risks posed by certain heavy metal elements and specific types of dried fish might be deemed negligible, individuals at the upper limit of the exposure range (P_{95} upper limit) still faced potential health risks that demand attention. Several studies about China report varying results on fresh fish, with research from coastal provinces, and major river basins suggesting negligible health risks from heavy metals including Hg, As, Cd, Cr, Pb [13, 14]. However, high exposure to Cr and As may pose a higher carcinogenic risk compared to other aquatic products [15]. A Hong Kong study indicates that health risks from heavy metal intake in processed shark fins warrant attention [52]. Dried fish, due to its processing, typically have higher heavy metal content, potentially leading to increased non-carcinogenic and carcinogenic health risks. Other countries research on heavy metals in dried fish, particularly from India and Bangladesh, also shows mixed findings. A study in Chennai, India, found no non-carcinogenic risk from heavy metal pollution in dried fish, but a potential carcinogenic risk due to Cd and Pb [53]. Conversely, another study concluded no non-carcinogenic or carcinogenic risks from dried fish [42]. Two studies from Bangladesh, one examining essential and non-essential metals including Cr, As, Pb, found risks within established safety thresholds [2], while another detected similar heavy metals in dried fish, including Hg, As, Cd, Cr, Pb, and suggested potential carcinogenic risks for all metals [9]. These discrepancies may arise from regional differences in environmental factors affecting heavy metal content in both fresh and dried fish, as well as variations in consumption patterns, particularly between different countries.

Based on the aforementioned results, it is imperative for both producers and consumers to increase their awareness of the health risks associated with heavy metals in dried fish. We propose that consumers minimize their consumption of dried fish [9], especially for high-risk groups such as children and pregnant women [2], or alternatively, rinse dried fish thoroughly before consumption, focusing specifically on the fish scales [45]. Moreover, methods such as Microwave cooking can be employed to process dried fish before intake, thereby reducing the bioaccessibility of heavy metals and mitigating health risks [54]. Additionally, one can opt for dried fish with lower levels of heavy metal contamination and reduced health risks, such as *dried Ctenopharyngodon Idella.* Simultaneously, it is highly recommended that local regulatory agencies consistently monitor the production and storage conditions of commercial processors, as well as the heavy metal content in dried fish. Additionally, these agencies should implement appropriate control and technical measures to reduce industrial heavy metal discharge and limit the direct release of pollutants into water sources. Public health authorities should promptly assess and communicate the health risks of heavy metals in dried fish and recommend consumption levels, while also educating consumers on the importance of minimizing their intake of dried fish.

This research evaluated the health hazards linked to heavy metal intake through the consumption of dried fish. The study utilized a total of 60 samples from the five most consumed dried fish varieties in the four most populous districts of Guangzhou city. The diversity and quantity of samples enhanced the credibility and generalizability of the results. Additionally, advanced analytical techniques, including ICP-MS and the DMA-80 direct mercury analyzer, were employed to detect various heavy metal concentrations, further enhancing the rigor and reliability of the study. The findings of this study contribute to a deeper comprehension of the health risks linked to consuming heavy metals in dried fish, thereby offering valuable insights for establishing regulatory measures to ensure food safety. Nevertheless, it is important to acknowledge the limitations of this study. Firstly, there is a lack of data regarding the daily intake of the five types of dried fish consumed by residents in Guangzhou. The daily intake of dried fish considered in this study is an average estimation derived from the daily consumption of dried squid and dried octopus in China. In China, the intake of fish and shrimp, particularly fish, constitutes a significant proportion of aquatic product consumption [55, 56]. Consequently, we surmise that based on this dietary habit the daily intake of dried fish may exceed that of dried squid and dried octopus in China. This implies that the actual health risks from consuming dried fish might be higher, necessitating attention. Additionally, it is important to note that the detection of heavy metal levels in dried fish and risk assessment, as conducted in this study, does not precisely depict the absorption and metabolism of these heavy metals in the human body. Not all ingested heavy metals are absorbed; the bioaccessibility of heavy metals such as Pb, As, Cd, and Cr is also related to the intake of various nutrients [57]. Essentially, the biological availability of heavy metals within the human body was not explored, nor were individual differences considered. For instance, age differences, aside from the gender differences we focused on, can also affect intake through dietary habits. More importantly, different age groups exhibit varying sensitivities to heavy metals. For example, children are typically at a higher risk of health hazards, which deserves attention [58]. Furthermore, the uncertainties and variabilities inherent in quantitative risk assessment methods should be taken into consideration [59]. Assessing non-carcinogenic and carcinogenic health risks using RfD and CSF seldom considers uncertainties in interspecies extrapolation and human variability, nor does it account for more nuanced dose–response relationships [60, 61]. This implies that future improvements in risk assessment methods could be considered, such as employing probabilistic approaches to address these limitations [61].

Conclusion

In this study, five heavy metal elements such as Cr, As, Cd, Pb and Hg in five common types of dried fish sold in Guangzhou, China, were measured. The results showed that all the five elements exceeded the limit, but As exceeding rate is highest. The SPI showed that As was seriously polluted among the five kinds of dried fish, and the *dried Nemipterus-virgatus* was the most seriously polluted. The NCPI showed that all the five kinds of dried fish were seriously polluted by heavy metals. The comprehensive pollution degree of dried fish was *dried Nemipterus-virgatus* > *dried Stolephorus chinensis* > *dried Thamnaconus modestus* > *dried river fish* > *dried Ctenopharyngodon idella*, and the heavy metal pollution degree was As>Cd>Cr>Hg>Pb. The EDI values for various heavy metals in this study are significantly below PTDI limits. The ranking of non-carcinogenic and carcinogenic risks associated with the consumption of various dried fish corresponds to the order of the comprehensive pollution degree. The non-carcinogenic risk of As in *dried Nemipterus-virgatus*, *dried Stolephorus chinensis* and *dried Thamnaconus modestus* in female intake and *dried Nemipterus-virgatus*, *dried Stolephorus chinensis* in male intake may occur. As in male and female intake of *dried Stolephorus chinensis*, *dried Thamnaconus modestus*, *dried Nemipterus-virgatus* and *dried river fish* may cause carcinogenic risk. However, other heavy metals have shown minimal health risks in terms of non-carcinogenic and carcinogenic effects. It should be noted that due to disparities in average weight and life expectancy, women face higher non-carcinogenic and carcinogenic risks compared to men. Attention should be given to reducing the intake of dried fish and enhancing regulatory supervision.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing Interests The authors declare no competing interests.

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