EVALUATION OF COPPER AND ZINC CONCENTRATIONS IN DRIED FRUITS COLLECTED FROM MARKETPLACES OF PENINSULAR MALAYSIA: HEALTH RISK ASSESSMENT, FOOD SECURITY IMPLICATIONS, AND THE NECESSITY FOR REGULAR MONITORING

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Abstract. This study investigates the concentrations of Copper (Cu) and Zinc (Zn) in five types of dried fruits (raisins, kiwis, dates, figs, and apricots) collected from marketplaces in Peninsular Malaysia, while assessing their potential health risks based on the maximum permissible limits (MPLs) set by Malaysian Food Regulations (1985). After converting from the dry weight basis, the results show that figs exhibited the highest levels of Cu (9 mg/kg wet weight) and Zn (9.95 mg/kg wet weight), while kiwis had the lowest concentrations for both metals. Estimated daily intake (EDI) and target hazard quotient (THQ) values were calculated for each metal, revealing low health risks, with THQs for all fruits remaining below 1. Figs had the highest THQs for Cu (0.61) and Zn (0.08), suggesting moderate caution in frequent consumption. The study also emphasizes the importance of regularly monitoring metal concentrations in dried fruits, improved agricultural and post-harvest practices, and the need for clear labelling to inform consumers about potential metal content. These findings provide critical insights into ensuring food safety, reducing metal exposure, and promoting dietary diversity for better public health outcomes.
Keywords: *heavy metal exposure, dietary contamination, toxicological impact, consumer safety, regulatory standards*

Introduction

Trace metals like Copper (Cu) and Zinc (Zn) are essential micronutrients needed for numerous physiological processes in the human body, including enzyme activation, immune function, and cellular metabolism (Ogabiela et al., 2010; Basha et al., 2014; Aremu et al., 2022; Guan et al., 2024). However, both deficiency and excessive intake of these metals can lead to adverse health effects. Dried fruits, prized for their convenience, extended shelf life, and nutrient density, are widely consumed worldwide, particularly in regions where fresh produce is less accessible (Kulluk et al., 2023; Jáudenes-Marrero et al., 2024). The drying process concentrates nutrients and trace metals, raising potential health concerns about prolonged dried fruit consumption.

Evaluating Cu and Zn levels in dried fruits is crucial, as previous studies have shown that high metal concentrations can pose health risks, especially with frequent, high intake (Asukwo et al., 2020). Excessive Cu intake can cause liver damage, gastrointestinal issues, and neurological symptoms, while excessive Zn intake can disrupt the absorption

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of other essential minerals and impair immune function. Therefore, it is essential to assess the levels of these metals in dried fruits to ensure they are within safe consumption limits.

This study evaluates Cu and Zn concentrations in five popular dried fruits namely figs, raisins, dates, apricots, and kiwis. Monitoring these essential metals is crucial for allowing consumers to gain the nutritional benefits of dried fruits without exceeding the safety thresholds set by regulatory bodies.

The findings from this study will enhance understanding of essential trace metal concentrations in dried fruits, offering valuable information to consumers and policymakers (Alkarkhi et al., 2020; Zainol et al., 2020). This knowledge can inform public health recommendations, influence regulatory standards, and support the development of strategies to maximize the nutritional value and safety of dried fruit products (Ogabiela et al., 2010; Asukwo et al., 2020; Aremu et al., 2022).

This article aims to evaluate the concentrations of Cu and Zn in five commonly consumed dried fruits—raisins, kiwis, dates, figs, and apricots—purchased from various marketplaces in Peninsular Malaysia. The study aims to assess the potential health risks associated with the consumption of these dried fruits by calculating the estimated daily intake (EDI) and target hazard quotient (THQ) for each metal and comparing the results against established safety guidelines. Additionally, the article seeks to provide insights into the implications of these findings for food safety, public health, and the need for regular monitoring of trace metal levels in dried fruits.

Materials and methods

Sample collection

From March to May 2021, five types of dried fruits—raisins, kiwis, dates, figs, and apricots—were randomly purchased from various marketplaces across Peninsular Malaysia. At least 45 samples (at least 9 from each fruit type) were collected to ensure a broad representation of the products available in the region. The common names of the fruits, source locations, and purchase dates were recorded (*Table 1; Figure 1*). Upon collection, the samples were placed in sealed plastic bags to prevent contamination and were immediately stored in a cool, dry environment to preserve their quality until analysis.

Sample preparation

Measurements of weights (g) and size (length (cm) x width (cm)) in the five types of dried fruits are presented in *Table 2*. Each dried fruit sample in the laboratory was rinsed with deionized water to remove any external contaminants. The samples were then blotted dry using clean paper towels. Approximately 10 to 20 grams of each fruit sample was weighed using an electronic scale. The samples were then dried in an oven at 60°C for 72 hours to ensure complete moisture removal. After drying, the dry weight of each sample was recorded. The dried samples were ground into a fine powder using a clean mortar and pestle to ensure homogeneity. The powdered samples were stored in acid-washed plastic containers and kept at room temperature until further analysis.

Cu and Zn analysis

The analysis of Cu and Zn concentrations in the dried fruit samples followed the method described by Yap et al. (2016). For each fruit sample, 0.50 g of the dried and

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homogenized powder was accurately weighed and placed into a digestion vessel. Five mL of concentrated nitric acid (HNO_3, 69% purity, BDH AnalaR grade) were added to the samples. The digestion process involved pre-digestion at 40°C for one hour and complete digestion at 140°C for three hours using a hot block digester. After digestion, the samples were allowed to cool for 30 minutes before diluting with deionized water to a final volume of 40 mL.

Table 1. *Information on the dried fruits samples purchased from the sampling sites at the marketplaces in Peninsular Malaysia. Estimated sampling sites of the marketplaces are indicated in Figure 1*

No.	Sample with common names	Scientific name	Origin	Place of purchase	Date of purchase
1-1 ❶	Dried apricots 1	*Prunus armeniaca*	Saudi Arabia	Saudagar Kurma, Bukit Minyak, Penang	5th January, 2021
1-2 ❶	Dried apricots 2	*Prunus armeniaca*	Turkey	Saudagar Kurma, Bukit Minyak, Penang	6th December, 2020
1-2 ❷	Dried apricots 3	*Prunus armeniaca*	Yemen	Kurma Madinah, Kuantan, Pahang	19th January, 2021
2-1 ❸	Dried dates 2	*Phoenix dactylifera*	Saudi Arabia	Pasar Raya Ikhwan, Manjung, Perak	6th January, 2021
2-2 ❷	Dried dates 1	*Phoenix dactylifera*	Saudi Arabia	Pasar Kurma, Kampung Batu 7, Kuantan, Pahang	26th January, 2021
2-3 ❷	Dried dates 3	*Phoenix dactylifera*	Saudi Arabia	Kurma Madinah, Kuantan, Pahang	19th January, 2021
3-1 ❹	Dried figs 1	*Ficus carica*	Turkey	Manhaz, Midvalley, Kuala Lumpur	6th December, 2020
3-2 ❷	Dried figs 2	*Ficus carica*	Turkey	Pasar Kurma, Kampung Batu 7, Kuantan, Pahang	26th January, 2021
3-3 ❺	Dried figs 3	*Ficus carica*	Turkey	Baajis, IOI City Mall, Selangor	27th January, 2021
4-1 ❶	Dried kiwis 1	*Actinidia deliciosa*	Saudi Arabia	Saudagar Kurma, Bukit Minyak, Penang	5th January, 2021
4-2 ❻	Dried kiwis 2	*Actinidia deliciosa*	Saudi Arabia	Pasar Mini Mohd Salleh, Telok Mas, Melaka	25th January, 2021
4-3 ❻	Dried kiwis 2	*Actinidia deliciosa*	Saudi Arabia	Pasar Mini Mohd Salleh, Telok Mas, Melaka	25th January, 2021
5-1 ❶	Dried raisins 1	*Vitis sp.*	Saudi Arabia	Saudagar Kurma, Bukit Minyak, Penang	5th January, 2021
5-2 ❸	Dried raisins 2	*Vitis sp.*	Turkey	Pasar Raya Ikhwan, Manjung, Perak	6th January, 2021
5-3 ❷	Dried raisins 3	*Vitis sp.*	Iran	Pasar Kurma, Kampung Batu 7, Kuantan, Pahang	26th January, 2021

Note: The numbers in the black circle are those indicated in Figure 1

The diluted digests were filtered using Whatman no. 1 filter paper and stored in acid-washed plastic vials. The concentrations of Cu and Zn in the digested samples were measured using a flame atomic absorption spectrometer (FAAS, Model AAnalyst 800) with an air-acetylene flame. The detection limits for Cu and Zn were 0.004 mg/L and 0.007 mg/L, respectively. Process blanks, triplicates, and certified reference materials

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(CRMs) were analyzed alongside the samples to ensure the accuracy and precision of the measurements. The CRMs used were dogfish liver (DOLT-3, National Research Council Canada), and the measured values for Zn and Cu were consistent with certified values, confirming the method's validity.

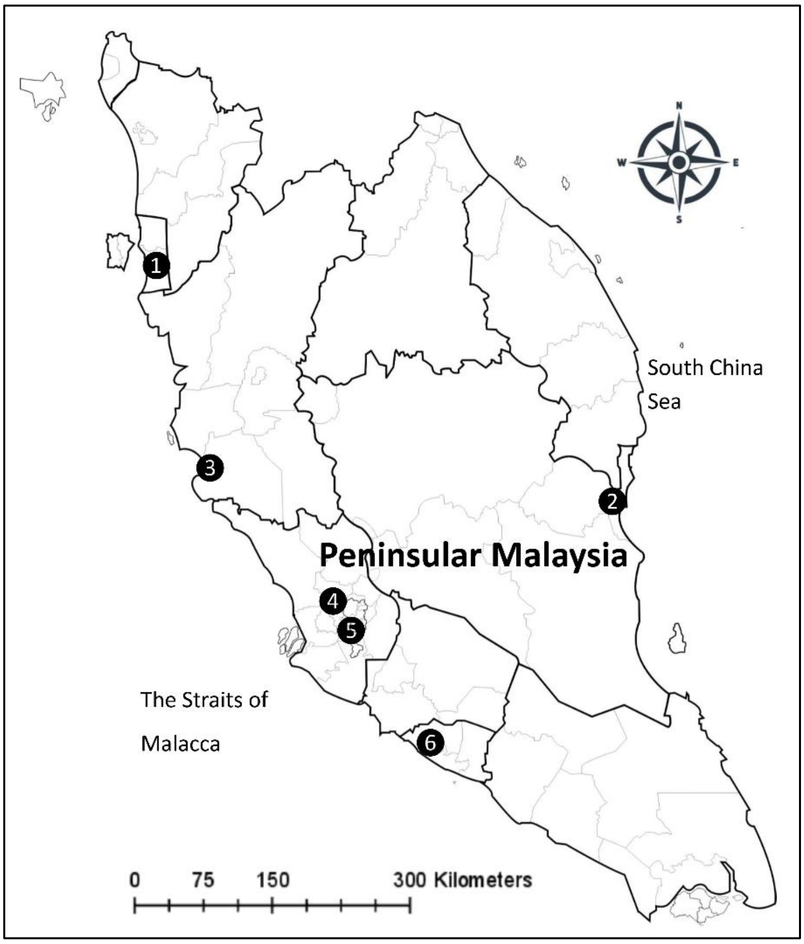

Figure 1. *Sampling sites at the marketplaces in Peninsular Malaysia. Detailed descriptions of the marketplaces are indicated in Table 1.*

Table 2. *Measurements of weights (g) and size (length (cm) x width (cm)) in the five types of dried fruits purchased from marketplaces in Peninsular Malaysia*

Sampling	Number	Parameter	Minimum	Maximum	Average
Dried apricots	10	Weight	5	10	7.5
		Size	3.0 x 2.5	4.5 x 3.5	3.75 x 3.0
Dried dates	10	Weight	7	12	9.5
		Size	3.5 x 2.5	5.0 x 3.5	4.25 x 3.0
Dried kiwis	15	Weight	4	8	6
		Size	4.0 x 3.0	6.5 x 4.5	5.25 x 3.75
Dried raisins	20	Weight	0.5	1.2	0.85
		Size	1.0 x 0.5	2.0 x 1.2	1.5 x 0.85
Dried figs	9	Weight	8	14	11
		Size	3.5 x 3.0	5.0 x 4.0	4.25 x 3.5

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Data treatment for health risk assessment

The concentrations of Cu and Zn in dry weight (DW) were converted into wet weight (WW) to align with dietary intake recommendations. The conversion factors for each dried fruit follow those in *Table 3,* which was calculated based on the water content in dried fruits.

Table 3. *Values (mean ± SE) conversion factors (CF) for all the dried fruits investigated from the present study*

Dried fruit	CF	SE
Apricots-1	0.74	0.01
Apricots-2	0.70	0.02
Apricots-3	0.75	0.05
Ajwa dates-1	0.80	0.03
Ajwa dates-2	0.79	0.02
Ajwa dates-3	0.79	0.07
Figs-1	0.80	0.08
Figs-2	0.79	0.02
Figs-3	0.79	0.09
Kiwis-1	0.85	0.05
Kiwis-2	0.82	0.07
Kiwis-3	0.84	0.01
Raisins-1	0.80	0.07
Raisins-2	0.79	0.05
Raisins-3	0.80	0.04

Note: SE= standard error

In this study, three MPLs of Cu and Zn of safety guidelines were used, namely, those proposed by the FAO (Cu: 70 mg/kg wet weight; Zn: 150 mg/kg wet weight; Naun, 1983), the Ministry of Agriculture, Fisheries and Food (Cu: 20 mg/kg wet weight; 50 mg/kg wet weight; MAFF, 2000), and Malaysian Food Regulation 1985 (Cu: 30 mg/kg wet weight; Zn= 100 mg/kg wet weight; MFR, 1985). The FAO's MPLs are based on the nations of New Zealand, the UK, and Australia, with the range of the legal limits as 20–70 mg/kg ww, and 40 to 150 mg/kg ww, for Cu and Zn, respectively.

To assess potential health risks, the estimated daily intake (EDI) of Cu and Zn from consuming these dried fruits was calculated using the *equation (1)*:

$$EDI = (Mc \times CR)/BW \qquad \text{(Eq.1)}$$

where *Mc* is the metal concentration in the fruit (mg/kg WW), *CR* is the consumption rate (100 g/person/day) based on the average intake for Malaysian adults, and *BW* is the average body weight (66 kg) for Malaysian adults (Nurul Izzah et al., 2012). Subsequently, the target hazard quotient (THQ) for each metal was calculated using the *equation (2)*:

$$THQ = EDI/ORD \qquad \text{(Eq.2)}$$

where *ORD* is the oral reference dose for each metal, which was 40 µg/kg/day for Cu and 300 µg/kg/day for Zn, as specified by the US Environmental Protection Agency (USEPA, 2024).

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A THQ value below 1 indicates no significant risk of non-carcinogenic health effects. All calculations were performed to assess the safety of Cu and Zn intake from the five types of dried fruits under typical consumption patterns.

Results

Table 4 shows the overall statistics of metal concentrations, EDI, and THQ values, in the five types of dried fruits investigated in the present study.

Table 4. *Overall statistics of Cu and Zn concentrations, estimated daily intake (EDI), and target hazard quotient (THQ), in the five types of dried fruits investigated in the present study. N= 9 = (3 x 3)*

Raisins	**Cu DW**	**Zn DW**	**Cu WW**	**Zn WW**	**Cu EDI**	**Zn EDI**	**Cu THQ**	**Zn THQ**
Minimum	5.32	4.16	4.26	3.33	11.54	9.03	0.29	0.03
Maximum	7.56	6.88	6.05	5.44	16.40	14.74	0.41	0.05
Mean	6.57	5.16	5.24	4.11	14.20	11.13	0.36	0.04
Median	6.84	4.44	5.40	3.55	14.66	9.63	0.37	0.03
SD	1.14	1.50	0.91	1.16	2.46	3.14	0.06	0.01
SE	0.66	0.86	0.52	0.67	1.42	1.81	0.04	0.01
Kiwis	**Cu DW**	**Zn DW**	**Cu WW**	**Zn WW**	**Cu EDI**	**Zn EDI**	**Cu THQ**	**Zn THQ**
Minimum	1.96	1.40	1.61	1.15	4.36	3.11	0.11	0.01
Maximum	2.00	2.56	1.70	2.18	4.61	5.90	0.12	0.02
Mean	1.98	1.98	1.66	1.67	4.49	4.51	0.12	0.02
Median	1.98	1.98	1.66	1.67	4.49	4.51	0.12	0.02
SD	0.02	0.58	0.05	0.52	0.13	1.40	0.00	0.00
SE	0.01	0.33	0.03	0.30	0.07	0.81	0.00	0.00
Dates	**Cu DW**	**Zn DW**	**Cu WW**	**Zn WW**	**Cu EDI**	**Zn EDI**	**Cu THQ**	**Zn THQ**
Minimum	4.44	7.16	3.55	5.73	9.63	15.54	0.24	0.05
Maximum	6.96	8.40	5.50	6.64	14.91	18.00	0.37	0.06
Mean	5.75	7.75	4.55	6.15	12.35	16.66	0.31	0.05
Median	5.84	7.68	4.61	6.07	12.51	16.45	0.31	0.05
SD	1.26	0.62	0.98	0.46	2.64	1.24	0.07	0.01
SE	0.73	0.36	0.56	0.27	1.53	0.72	0.04	0.00
Figs	**Cu DW**	**Zn DW**	**Cu WW**	**Zn WW**	**Cu EDI**	**Zn EDI**	**Cu THQ**	**Zn THQ**
Minimum	10.24	9.12	8.19	7.20	22.22	19.54	0.56	0.07
Maximum	12.36	12.44	9.76	9.95	26.48	26.99	0.66	0.09
Mean	11.29	10.37	8.95	8.23	24.29	22.34	0.61	0.08
Median	11.28	9.56	8.91	7.55	24.17	20.48	0.60	0.07
SD	1.06	1.80	0.79	1.50	2.13	4.06	0.05	0.01
SE	0.61	1.04	0.45	0.86	1.23	2.34	0.03	0.01
Apricot	**Cu DW**	**Zn DW**	**Cu WW**	**Zn WW**	**Cu EDI**	**Zn EDI**	**Cu THQ**	**Zn THQ**
Minimum	7.12	6.88	4.98	5.16	13.52	13.99	0.34	0.05
Maximum	8.12	12.68	6.09	9.38	16.52	25.45	0.41	0.08
Mean	7.68	10.00	5.61	7.28	15.23	19.75	0.38	0.07
Median	7.80	10.44	5.77	7.31	15.65	19.82	0.39	0.07
SD	0.51	2.92	0.57	2.11	1.54	5.73	0.04	0.02
SE	0.29	1.69	0.33	1.22	0.89	3.31	0.02	0.01

Note: DW= dry weight; WW= wet weight; SD= standard deviation; SE= standard error

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The Cu concentrations in the five types of dried fruits varied across a wide range. Figs exhibited the highest Cu concentration, ranging from 10.24 to 12.36 mg/kg DW. In contrast, kiwis had the lowest range of Cu concentrations, with values from 1.96 to 2.00 mg/kg DW. Raisins showed Cu concentrations ranging from 5.32 to 7.56 mg/kg DW, while dates displayed a Cu range from 4.44 to 6.96 mg/kg DW. Apricots had a Cu range of 7.12 to 8.12 mg/kg DW. These results indicate a significant difference in Cu concentrations across the fruits, with figs consistently showing the highest values and kiwis the lowest.

Zn concentrations also varied substantially between the fruits. Figs had the highest Zn range, ranging from 9.19 to 12.44 mg/kg DW. Zn levels in dates ranged from 7.16 to 8.40 mg/kg DW. Apricots showed a Zn range from 6.88 to 12.68 mg/kg DW. Raisins exhibited a moderate Zn concentration range from 4.16 to 6.88 mg/kg DW, while kiwis had the lowest Zn range, from 1.40 to 2.56 mg/kg DW. These findings indicate that figs were again the richest in Zn, with kiwis being the poorest source of this metal.

The EDI values reflected the metal concentrations in the fruits. Figs had the highest EDI for both Cu and Zn, with Cu ranging from 22.22 to 26.48 μg/kg bw/day and Zn from 19.54 to 26.99 μg/kg bw/day. Raisins followed, with Cu EDI ranging from 11.54 to 14.60 μg/kg bw/day and Zn EDI from 9.03 to 14.74 μg/kg bw/day. Dates showed a Cu EDI range of 9.63 to 14.91 μg/kg bw/day and Zn from 15.54 to 18.00 μg/kg bw/day. Apricots exhibited EDI values for Cu from 13.52 to 16.52 μg/kg bw/day and Zn from 13.99 to 25.45 μg/kg bw/day. Kiwis had the lowest EDI values, with Cu ranging from 4.36 to 4.49 μg/kg bw/day and Zn from 3.11 to 5.90 μg/kg bw/day.

The THQ values for Cu and Zn provide an assessment of potential health risks. Figs displayed the highest THQ range for Cu, from 0.56 to 0.66, and Zn, from 0.07 to 0.09. Raisins followed, with Cu THQ values ranging from 0.29 to 0.41 and Zn THQ from 0.03 to 0.05. Dates exhibited THQ values for Cu ranging from 0.24 to 0.37 and Zn from 0.05 to 0.06. Apricots had THQ ranges for Cu from 0.34 to 0.41 and Zn from 0.05 to 0.08. Kiwis presented the lowest THQ values, with Cu ranging from 0.11 to 0.12 and Zn from 0.01 to 0.02.

The top panel of *Figure 2* shows the Cu concentrations in the five dried fruits. Across all samples, none of the fruits exceeded the three MPLs for Cu. The highest Cu concentration was observed in figs, with a maximum value approaching around 9 mg/kg WW. Apricots followed closely, with concentrations ranging from approximately 5 to 6 mg/kg WW. Raisins and dates displayed Cu concentrations within similar ranges, between 4 and 6 mg/kg WW. Kiwis exhibited the lowest Cu concentrations, remaining below 2 mg/kg WW. The Cu levels in all fruit samples were well within the regulatory limit, suggesting no immediate concern for Cu-related toxicity.

The lower panel of *Figure 2* presents the comparison of three Zn MPLs with the present study. Like Cu, all fruits had Zn concentrations far below the three MPLs. Figs had the highest Zn concentration, with values just above 9 mg/kg WW, followed by apricots, which showed concentrations around 7 to 8 mg/kg WW. Raisins and dates exhibited Zn concentrations ranging from 4 to 6 mg/kg WW. Kiwis once again had the lowest Zn concentrations, all below 2 mg/kg WW.

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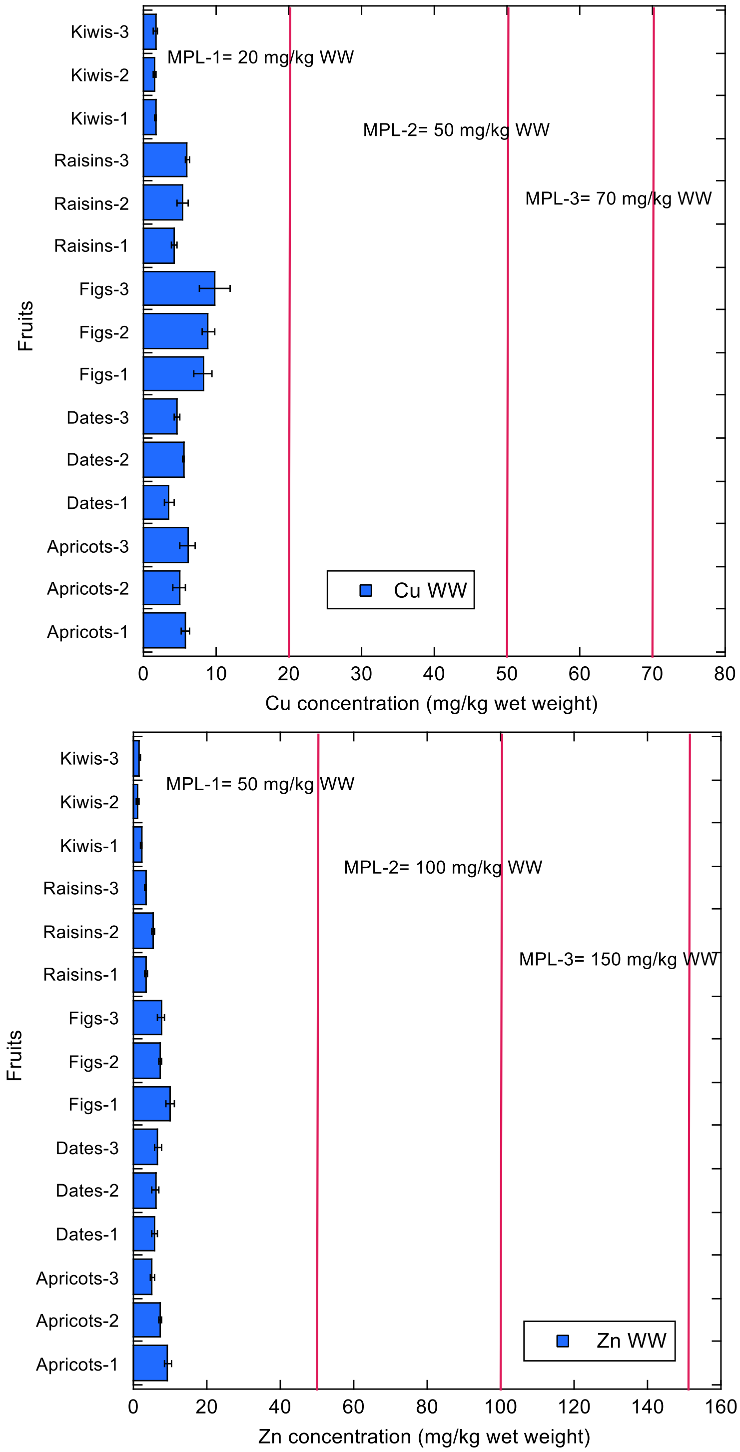

Figure 2. *Comparison of concentrations (mean ± SE; mg/kg wet weight) in the five types of dried fruits with the maximum permissible limits (MPLs) for Cu and Zn. Note: MPL-1 = MAFF (Cu: 20 mg/kg wet weight; 50 mg/kg wet weight; MAFF, 2000); MPL-2 = MFR (Cu: 30 mg/kg wet weight; Zn= 100 mg/kg wet weight; MFR, 1985); MPL-3 = FAO (Cu: 70 mg/kg wet weight; Zn: 150 mg/kg wet weight; Naun, 1983)*

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Discussion

Health risk assessment of Cu and Zn in dried fruits

The results presented in *Table 4* and *Figure 2* show that the concentrations of Cu and Zn in the five dried fruits analyzed—raisins, kiwis, dates, figs, and apricots—were well within the maximum permissible limits (MPLs) set by the Malaysian Food Regulations (MFR, 1985). The highest Cu concentration was found in figs, with figs also showing the highest Zn concentration, both of which are notably below the MPLs of 30 mg/kg WW for Cu and 100 mg/kg WW for Zn. This indicates that consuming these dried fruits is unlikely to pose immediate health risks from Cu or Zn toxicity, making them generally safe for regular dietary intake when consumed in moderation (Khairuddin et al., 2017; Aremu et al., 2022). Studies on dried fruit composition and heavy metal content further support these findings, demonstrating that dried fruits generally contain trace metal concentrations within safe limits (Morais et al., 2017; Vasilj et al., 2024).

Although the calculated THQ values for both metals were below 1, suggesting a low risk of non-carcinogenic effects, figs had the highest THQ for Cu (0.61) and Zn (0.08). This highlights the need for caution, as consistent consumption of figs with higher metal concentrations could lead to cumulative dietary exposure over time, particularly if combined with other Cu- and Zn-rich foods. This consideration is especially relevant for vulnerable groups, such as pregnant women, children, and individuals with impaired Cu metabolism, such as those with Wilson's disease (Yari et al., 2017; Burkhead and Collins, 2021). Previous studies have also emphasized the potential risks associated with heavy metal accumulation in dried fruits, particularly dates and raisins, where metal concentrations can vary significantly depending on processing and agricultural practices (Salama et al., 2019; Chamon et al., 2024).

In comparison, kiwis, with their lower Cu and Zn levels, may be a safer choice for individuals needing to control their metal intake. For those with conditions like hemochromatosis or Wilson's disease, where managing metal intake is crucial, these fruits could help lower the risk of metal accumulation from dietary sources (Asukwo et al., 2020; Sagagi et al., 2022). Prior research on heavy metals in kiwis has revealed that their metal content is generally lower than other dried fruits, making them a preferable option for those requiring dietary restrictions (Guo et al., 2016; Naghipour et al., 2024). Moreover, safety assessments of dried fruits, including those from different geographical regions, have highlighted variations in metal accumulation, suggesting that monitoring and proper selection of dried fruit sources can further mitigate health risks (Farshidi et al., 2023).

These findings align with broader research on the heavy metal content of dried fruits and nuts, emphasizing the importance of continuous monitoring to ensure consumer safety (Allah et al., 2018; Abdel-Rahman et al., 2023). Given the increasing global demand for dried fruits, future studies should explore the long-term dietary implications of heavy metal exposure and develop strategies to minimize potential risks through improved agricultural and processing techniques (Solgi and Khodadadi, 2020; Jáudenes-Marrero et al., 2024).

Implications for food security and nutrient intake

Dried fruits like figs, dates, raisins, and apricots are important sources of nutrients, particularly in regions where fresh fruit is seasonally available or limited. These fruits provide a non-perishable option for addressing micronutrient deficiencies, especially

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those related to Zn and Cu, which are essential for immune function, growth, and development (Khairuddin et al., 2017). Studies have shown that dried fruits, including figs and dates, contain higher Zn concentrations, making them valuable dietary components for populations at risk of Zn deficiencies and crucial for supporting food security and nutritional adequacy (Waheed and Siddique, 2009; Chamon et al., 2024). Furthermore, research on dried fruit quality and mineral composition has reinforced their role in nutritional interventions, particularly in arid and semi-arid regions where access to fresh produce is limited (Morais et al., 2017; Vasilj et al., 2024).

However, while the high levels of Zn and Cu in figs and dates can be beneficial, excessive consumption could become problematic, especially for those also receiving these metals from fortified foods or supplements (Demayo et al., 1982). Excessive intake of these trace metals has been linked to potential health concerns, particularly in populations with metabolic disorders or compromised renal function (Allah et al., 2018; Abdel-Rahman et al., 2023). In contrast, the lower concentrations of Zn and Cu in kiwis, raisins, and apricots offer a moderate option for regular consumption, enhancing dietary variety without risking metal overload. A recent study on heavy metals in dried fruits emphasized the variability in metal accumulation based on processing methods and geographic origin, highlighting the need for continuous monitoring to ensure safe consumption (Solgi and Khodadadi, 2020; Farshidi et al., 2023).

These findings emphasize the importance of incorporating a variety of fruits into a balanced diet, particularly in low-income or rural areas where dried fruits may play a crucial role in ensuring nutritional security (Waheed and Siddique, 2009; Alasalvar and Shahidi, 2013; Khairuddin et al., 2017; Sandhu et al., 2023). Moreover, research has suggested that dried fruits not only contribute to essential micronutrient intake but also serve as bioavailable sources of essential minerals, supporting dietary sufficiency in food-insecure populations (Guo et al., 2016; Naghipour et al., 2024). With the increasing global reliance on dried fruits as part of a sustainable and long-term nutritional strategy, continued efforts should be made to evaluate their mineral composition, health benefits, and potential risks associated with metal accumulation (Salama et al., 2019; Jáudenes-Marrero et al., 2024).

Importance of regular monitoring and quality control

The variability in metal concentrations across different batches of the same dried fruits, as shown in *Table 4* and *Figure 2*, underscores the importance of consistent monitoring of trace metal levels in food products (Basha et al., 2014; Verma and Sv, 2014; Alkarkhi et al., 2020; Aremu et al., 2022). These concentrations can be affected by soil composition, agricultural practices, and post-harvest processing. Several studies have highlighted that variations in soil metal content and irrigation water quality significantly contribute to metal accumulation in dried fruits such as figs, dates, and raisins (Morais et al., 2017; Vasilj et al., 2024). Additionally, contamination risks increase during post-harvest drying, where exposure to environmental pollutants may further elevate metal concentrations (Solgi and Khodadadi, 2020; Farshidi et al., 2023).

Given the potential health risks associated with prolonged metal exposure, particularly for vulnerable populations, robust food safety monitoring frameworks must ensure metal levels remain within permissible limits. Regulatory agencies must enforce rigorous testing protocols, especially for imported products, to ensure compliance with safety standards (Asukwo et al., 2020). Studies on dried fruits imported from different regions have revealed inconsistencies in metal concentrations, emphasizing the necessity for

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stringent regulatory oversight (Allah et al., 2018; Abdel-Rahman et al., 2023). Research on dates and other dried fruits from Middle Eastern and Asian markets has shown that metal levels can sometimes exceed safety thresholds, making periodic assessment a critical public health measure (Salama et al., 2019; Chamon et al., 2024).

Heavy metal contamination in food is a global issue, with research highlighting the presence of cadmium, Cu, mercury, Zn, and iron in various items, including cereals, seeds, fruits, and seafood. A study assessing cadmium, chromium, and Cu in fruit samples from Meerut, North India, suggests that stricter regulations should be implemented by both national and international agencies to maintain fruit safety and protect public health (Sharma et al., 2008). Similarly, recent assessments of dried fruits in European and Asian markets have revealed varying levels of metal contamination, reinforcing the need for continuous monitoring (Naghipour et al., 2024).

A case study from Pujiang County reported elevated levels of lead, cadmium, chromium, Cu, and nickel in apples, pears, peaches, and grapes (Fang and Zhu, 2013). This further reinforces the need for ongoing monitoring and regulation to protect consumer health (Verma and Sv, 2014; Aremu et al., 2022). These contaminants are often introduced through foliar fertilizers, ripening agents, fungicides, and pesticides used during fruit growth and maturation. Similar findings have been reported for dried fruits, where the application of certain agrochemicals has led to increased metal accumulation in commercial products (Jáudenes-Marrero et al., 2024).

To mitigate these risks, local governments should encourage reduced use of fertilizers and pesticides, especially in later growth stages. A quality-based remuneration system could incentivize farmers to produce low-contaminant fruits and vegetables by rewarding high-quality, contaminant-free produce. Efforts to improve drying techniques, such as solar drying, have been proposed as viable solutions for minimizing environmental contamination during the drying process (Solgi and Khodadadi, 2020; Abdel-Rahman et al., 2023). Additionally, research on alternative agricultural practices suggests that using bio-based fertilizers and controlled irrigation methods can significantly reduce heavy metal uptake by fruit-bearing plants (Li et al., 2024).

Regular monitoring is also vital to maintain consumer confidence and ensure dried fruits remain a safe and nutritious dietary choice. Since dried fruits are consumed in concentrated forms, even slight increases in metal levels can significantly elevate dietary exposure. Regular testing of dried fruits, particularly imports, for metals like Cu and Zn is crucial for public health (Allah et al., 2018; Farshidi et al., 2023). Clear labelling standards indicating potential metal content would further enhance food safety. Additionally, long-term studies on the effects of chronic exposure to low metal levels in dried fruits could provide insights into potential long-term health impacts (Salama et al., 2019; Jáudenes-Marrero et al., 2024). With the global emphasis on food safety, ensuring dried fruits meet international standards will contribute to public health and sustainable food systems.

Potential factors contributing to higher Cu and Zn levels in figs

The consistently higher levels of Cu and Zn in figs compared to other dried fruits, such as raisins, kiwis, dates, and apricots, raise important questions about the factors contributing to metal accumulation in figs (Arvaniti et al., 2019). One possible explanation is the mineral-rich soil composition and specific agricultural practices in regions where figs are cultivated. Figs are often grown in soils with high concentrations of micronutrients like Cu and Zn, which the fig tree can absorb and accumulate. This

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aligns with studies showing that plants grown in metal-rich soils tend to bioaccumulate substantial trace elements, which become more concentrated in dried products due to moisture loss during processing (Okatan et al., 2003; Morais et al., 2017; Vasilj et al., 2024). Research on dried fruit contamination further supports this, indicating that soil quality and irrigation water significantly influence metal concentrations in final products (Guo et al., 2016).

The physiology of fig trees also plays a significant role. Figs have a unique fruiting process and structure that includes a symbiotic relationship with soil microorganisms, especially mycorrhizal fungi, which may enhance metal uptake. This symbiosis increases the bioavailability of metals such as Cu and Zn, facilitating their absorption into plant tissues (Okatan et al., 2003; Kulluk et al., 2023). Additionally, the deep root systems of fig trees allow access to minerals from deeper soil layers, which can have higher metal concentrations due to geological factors or metal-containing fertilizers (Sandhu et al., 2023). Several studies have demonstrated that fruit trees with deep root structures accumulate higher levels of essential and non-essential metals, particularly in arid regions where metal-laden groundwater is a primary source of irrigation (Salama et al., 2019; Chamon et al., 2024).

Post-harvest processes, particularly drying techniques, further contribute to figs' elevated Cu and Zn levels. The drying removes water, concentrating the remaining nutrients, including trace metals. Given their relatively large and fleshy structure, figs lose significant moisture during drying, which amplifies the concentration of any metals present. In contrast, smaller or less fleshy fruits, such as kiwis, may not exhibit the same level of concentration (Okatan et al., 2003; Waheed and Siddique, 2009; Arvaniti et al., 2019; Sandhu et al., 2023). Studies on drying techniques have revealed that solar drying, sun drying, and industrial drying methods all contribute to variations in final metal concentrations, with solar drying often resulting in lower contamination due to reduced exposure to external pollutants (Solgi and Khodadadi, 2020; Abdel-Rahman et al., 2023).

Moreover, specific post-harvest handling and storage conditions may contribute to metal retention in figs. For example, if figs are stored or dried in environments with metal contamination—such as near industrial areas or in metal containers—additional sources of Cu and Zn may be introduced. Previous studies on imported dried fruits have documented significant variations in metal concentrations based on packaging and storage environments, emphasizing the role of proper food handling practices in mitigating contamination risks (Allah et al., 2018; Farshidi et al., 2023). Longitudinal assessments of dried fruit safety in global markets have reinforced the need for standardized post-harvest practices to minimize contamination and ensure consumer safety (Jáudenes-Marrero et al., 2024).

While further research is needed to understand the full interplay of factors leading to elevated metal levels in figs compared to other dried fruits, these considerations underscore the importance of managing agricultural practices, soil health, and post-harvest handling to keep metal concentrations in figs and other dried fruits within safe limits. Given the increasing demand for dried fruits in global markets, implementing best practices in soil management, sustainable irrigation, and contamination-free storage will be critical for maintaining nutritional safety and supporting food security (Li et al., 2024; Vasilj et al., 2024).

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Strategies to reduce health risks of metals in dried fruits and recommendations from present findings

Given the variations in Cu and Zn concentrations across the five types of dried fruits, particularly the higher levels in figs, several strategies can help reduce potential health risks associated with metal intake. A key approach is implementing stringent agricultural and post-harvest practices to limit metal accumulation in these fruits (Amer et al., 2019). Soil management techniques, such as regular testing and monitoring of metal levels, can significantly reduce metal uptake in plants (Asukwo et al., 2020). Studies on soil remediation have shown that applying amendments like organic matter or phytoremediation techniques can effectively mitigate metal contamination, ensuring that crops like figs and dates maintain safe metal concentrations (Morais et al., 2017).

Adjusting fertilizer use and adding soil amendments like biochar can help bind metals, reducing their bioavailability and limiting absorption by crops (Fang and Zhu, 2013). This is especially beneficial for figs, which are often grown in mineral-rich soils. Biochar and organic soil amendments have been shown to reduce heavy metal uptake in fruit-bearing plants, providing a sustainable and cost-effective approach to mitigating contamination risks (Kulluk et al., 2023). Another crucial intervention is using controlled irrigation systems to prevent metals from entering crops through contaminated water. Ensuring that irrigation water is free from industrial pollutants can greatly reduce the overall metal load in fruits (Edelstein and Ben-Hur, 2018; Tabassam et al., 2023). Research on fruit irrigation practices has demonstrated that regions with untreated wastewater irrigation exhibit significantly higher metal concentrations in produce, reinforcing the need for clean and monitored water sources (Naghipour et al., 2024; Vasilj et al., 2024). Additionally, organic farming practices that avoid metal-based pesticides and fungicides can reduce Cu and Zn accumulation in dried fruits, making them a safer alternative for consumers (Allah et al., 2018; Abdel-Rahman et al., 2023).

Post-harvest processing and storage are also vital in managing the metal content in dried fruits (Brunetto et al., 2017; Zhang et al., 2022). For example, drying methods that avoid metal contact can minimize contamination, while advanced drying techniques, such as solar or controlled low-temperature drying, help retain nutritional quality without increasing metal concentrations (Salim, 2017; Solgi and Khodadadi, 2020). Research has shown that open-sun drying methods increase exposure to environmental contaminants, whereas enclosed solar dryers provide a safer alternative for preserving fruit quality and minimizing metal accumulation (Abdel-Rahman et al., 2023; Farshidi et al., 2023). Establishing guidelines for storing dried fruits in non-metallic containers can also reduce contamination risk during storage (Fang and Zhu, 2013; Brunetto et al., 2017; Asukwo et al., 2020; Zhang et al., 2022). Several studies have indicated that improper storage conditions, including exposure to metal shelving or industrial packaging, may introduce additional Cu and Zn contamination, further emphasizing the importance of appropriate handling practices (Salama et al., 2019; Chamon et al., 2024).

Finally, public awareness campaigns highlighting the benefits of consuming various dried fruits can help reduce the risk of excessive metal intake from any single fruit. Diversifying fruit consumption allows for a balanced intake of essential nutrients and minimizes cumulative exposure to trace metals from specific sources (Waheed and Siddique, 2009; Sandhu et al., 2023). Studies on dietary diversity suggest that consumers who incorporate a variety of dried fruits experience a more balanced mineral intake, reducing the potential risks of excessive Cu and Zn accumulation from specific sources such as figs (Li et al., 2024; Vasilj et al., 2024). Based on this study’s findings, nutrient-

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rich figs should be eaten in moderation to avoid overexposure to Cu and Zn. Further research into the long-term effects of chronic metal exposure from dried fruits and continued efforts to identify optimal agricultural and processing practices are recommended to mitigate these risks (Guo et al., 2016; Jáudenes-Marrero et al., 2024).

Conclusion

The present study highlights the variability in Cu and Zn concentrations across five types of dried fruits—raisins, kiwis, dates, figs, and apricots. While all fruits remained below the MPLs set by the Malaysian Food Regulations (1985), figs consistently exhibited the highest concentrations of both metals. This elevated metal content, especially in figs, raises potential concerns regarding cumulative dietary exposure, particularly in populations regularly consuming large quantities of dried fruits. However, the THQ values remained below the threshold of 1, indicating non-carcinogenic Cu and Zn health risks. On the other hand, the dried Kiwis demonstrated the lowest metal concentrations, making them a safer option for individuals managing their Cu and Zn intake.

Several strategies have been proposed to mitigate the potential health risks associated with metal accumulation in dried fruits, including improved soil management, organic farming practices, controlled irrigation, and advanced post-harvest processing techniques. Regular monitoring of metal levels in both agricultural soils and final dried fruit products is critical to ensuring consumer safety. Additionally, clear labelling and public awareness campaigns promoting dietary diversity can help reduce the risk of overexposure to trace metals. Overall, this study emphasizes the importance of ongoing monitoring, safe agricultural practices, and informed consumer choices to ensure that dried fruits remain a nutritious and safe component of the human diet.

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