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The Contents of Heavy Metals (Cd, Cr, As, Pb, Ni, and Sn) in the Selected Commercial Yam Powder Products in South Korea

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ABSTRACT: Yam (*Dioscorea*) has long been used as foods and folk medicine with the approved positive effects for health promotion. Although consumption of yam products is increasing for health promotion, reports for the metal contamination in commercial yam powder products to protect the consumers are lacking. In this study, we aimed to assess whether the commercial yam powder products were heavy metal contaminated or not using the yam products from six commercial products from various places in South Korea. The contents of heavy metals (Cd, Cr, As, Pb, Ni, and Sn) in yam powder products were measured and compared to national and international food standard levels. Also, the metal contamination was monitored during the food manufacturing steps. The study results showed that the contents of heavy metals (Cd, Cr, As, and Pb) in yam powder products are similar to those in national 'roots and tubers' as well as in various crops. In comparison to three international standard levels (EU, Codex and Korea), Cd content in yam powder products was lower but Pb content was 5 times higher. Also, Pb, Ni, and Sn may have the potential to be contaminated during food manufacturing steps. In conclusion, the level of heavy metals (Cd, Cr, As, Ni, and Sn) except Pb is considered relatively safe on comparison to national and international food standard levels.

Keywords: *Dioscorea*, yam, heavy metals (Cd, Cr, As, Pb, Ni, and Sn), food safety

INTRODUCTION

Heavy metals, such as cadmium (Cd), chromium (Cr), arsenic (As), lead (Pb), nickel (Ni), and stannum (Sn), are a group name for metals that have been associated with contamination and potential toxicity (1). The soil, water and air are contaminated by these heavy metals, which directly effect agricultural crops through cultivation. Consumable heavy metals from contaminated agricultural crops on a long-term basis can accumulate in plant crops, and therefore in animals which consume the crops. Once accumulated in animals or crops, to decontaminate or excrete can be difficult, even though the immobilizer-assisted management skill is suggested for removing metal-contaminated agricultural soils for safer food production (2).

Toxic heavy metals are clearly harzadous to humans. Cd is well-known to cause damage to kidneys and bones (3) as well as DNA damage and mRNA transcriptional changes in the gills of *Mytilus galloprovincialis* (4). Pb poisons create physiological and morphological responses in microalgae (5). Some heavy metals also cause toxicity-related mutagenesis and carcinogenesis (6). Inconveniently, the sign and symptoms of contamination by heavy metals do not appear early or easily, especially in humans. Therefore, heavy metal contamination on the human body has been of great concern.

Yam (*Dioscorea*) has long been used as foods and folk medicine mainly in Asia for health promotion. The yam is composed of starch with small amounts of sugars, cellulose, proteins, lipids and minerals (7-9); the recognition of this tuberolous food has recently become of interest in Western society due to its implication of plant-tuber source of the healthy food. Beneficial functions of yams include antifungal (10), antioxidant (11), and anticancer activities (12,13).

Recently, the consumption of yam commercial products are increasing with increased interest for the consumption of yam health food products. Therefore, the precise assessment for the potential metal contamination of yam products is required. Also the monitoring of the metal contamination during the food manufacturing process is required with special attention. To date, no reports have analyzed the metal contamination in

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commercial yam powder products.

In the present study, we aimed to assess the level of heavy metals (Cd, Cr, As, Pb, Ni, and Sn) in commercial yam powder products from various places in South Korea to confirm whether consuming these products would be beneficial for health promotion. Hence, we analyzed the contents of heavy metals in yam products and compared them to national and international standard levels of heavy metals. We also monitored and assessed possible heavy metal contamination during the food manufacturing steps. The results of this study can shed light on the safety of metal-containing yam products.

MATERIALS AND METHODS

The collection of commercial yam powder products

Six commercial yam powder products (Andong Book-Hoo, designated as A; Bon-Chon as B; Andong Cham-Ma as C; Nock-Jon as D; Sansaem as E, and Prus as F), which were processed in South Korea, were collected for mineral analysis. To determine whether the four step process to make the yam powder product effected levels of metals, the yam powder samples from each step for product A (Andong Book-Hoo) and B (Bon-Chon) were collected and analyzed for heavy metal contamination (Product A: post-second selection, post-UV sterilization, post-heavy metal detector passing and final product step; Product B: post-bark peeling, post-second grinding, pre-packing and final product step).

Heavy metals (Cd, Cr, As, Pb, Ni, and Sn) analysis

Heavy metals (Cd, Cr, As, Pb, Ni, and Sn) in yam powders were analyzed by a two step process: dry-ashing and acid digestion. Firstly, yam powder sample (5 g) in a crucible was dry-ashed by removing moisture at 105°C for 6 h. After, the dried samples were placed in the furnace at 500～600°C for another 12～14 h until the samples turned into a white ash mineral. For the acid digestion second step, the ashed yam powder samples were dissolved in concentrated nitric acid or in HNO_3/H_2O_2 with appropriate dilution (the samples being diluted to 25 mL with deionized water). Heavy metals in the acid-resolved samples were determined using an atomic absorption spectrophotometer (AAS, Spectra 220 FS, Varian, Palo Alto, CA, USA) or inductively coupled plasma atomic emission spectrophotometer (ICP-AES, Optima 8300, PerkinElmer Inc., Waltham, MA, USA).

Confirmation for the accuracy of mineral analysis

To confirm the precision and the accuracy for the mineral analysis, a standard reference material (SRM) was obtained from the National Institute of Standards and Technology (NIST SRM 1577b, Gaithersburg, MD, USA).

Comparison of heavy metal contents in Korean yam powder products to national food standard level and national crops

The levels of heavy metals (Cd, Cr, As, Pb, and Ni) in yam powder products were compared to the national food standard level (20). The levels of heavy metals (Cd, As, Pb, and Ni) in yam powder products were also compared to various plant food resources (cereals, vegetables, pulses, and fruits) of Korea (comparing the level in yam powders to cereals for Cd, to vegetable for As, to pulses for Pb and to fruits for Ni) (19).

Comparison of heavy metal contents in Korean yam powder products to international food standard levels (EU and Codex Alimentarius Commission, Codex)

The contents of heavy metals (Cd, Cr, As, Pb, Ni, and Sn) in commercial yam powder products in South Korea were compared to the food standard levels of EU and Codex. Out of six heavy metals to be analyzed (Cd, Cr, As, Pb, Ni, and Sn), only the standard levels of Cd and Pb were available for comparison. EU food standard was used for the comparison of Cd and Pb levels (standard level of 0.1 mg/kg in peeled potatoes for both metals) (21). Codex food standard, which is a joint Food and Agricultural Organization (FAO)/World Health Organization (WHO) Codex Alimentarius Commission (CAC), was used for the comparison of Cd and Pb (standard level of 0.1 mg/kg in root and tuber vegetables for both metals) (22).

Comparison of heavy metal contents in Korean yam powder products to the standard level of drinking water

The level of heavy metals (Cd, Cr, As, and Pb) in yam powder products was also compared to the standard level of drinking water in Korea to assess heavy metal contamination in yam products (23).

Heavy metal analysis during each processing step for commercial products

The samples from each processing step (post-second selection, post-UV sterilization, post-heavy metal detector and post-passing final products for product A, etc.) were analyzed for the contents of heavy metals and possible contamination using two commercial products (A and B products).

RESULTS

Heavy metals (Cd, Cr, As, Pb, Ni and Sn) contents in commercial yam powder products

First, the acceptance for the analysis of heavy metals was confirmed by the measurement of the standard reference materials (SRM, for mineral analysis) for Cd (115.5% of the standard value), which can be considerable for metal analysis.

Heavy metals (Cd, Cr, As, Pb, Ni, and Sn) contents in Korean commercial yam powder products were presented in Table 1. While Cd, Cr, Pb, and Ni showed consistent levels through the six products, As and Sn showed various amounts among the different yam products, suggestive of different yam cultivating areas.

Comparison of heavy metal contents in Korean yam powder products to national and international standards

Comparison to heavy metal levels in national crops: The heavy metal (Cd, Cr, and As) level in yam powder products were within the range of the national crops.

Heavy metal contents in yam powder (Cd, Cr, As, Pb, and Ni) were compared to the contents in national root and tuber crops (similar crops to yam) (Table 2A) and to other various crops (cereals, vegetables, pulses, and fruits) (Table 2B).

The contents of Cd, Cr, As, and Pb of six yam products were higher than the mean value of those metals in root and tuber crops (19); the metal contents in yam products were within similar concentration ranges and did not exceed those in root and tuber crops in South Korea. However, the analyzed Ni content in yam powder products from six samples (mean 1.00 mg/kg) was higher than in national root and tuber crops (tr~0.74 mg/kg) (Table 2A).

On comparison to the level of national crops (levels for cereals, vegetables, pulses, and fruits) (19), the level of Cd, As, Pb, and Ni in yam products was within the range of the heavy metal contents in national crops (Table 2B).

Comparison to international (Korea, EU and Codex) food standard levels: Cd content in yam powder products is lower than international food standard levels, while Pb content is higher than the international Pb standard levels.

Cd and Pb contents in yam powder products were compared to the standard levels of Korea, EU and Codex

Table 1. Heavy metal (Cd, Cr, As, Pb, Ni and Sn) contents in commercial yam powder products in South Korea

Yam powder products[1)]	Heavy metals[2)]					
	Cd (μg/kg)	Cr (mg/kg)	As (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Sn (mg/kg)
A	43.1±4.1	0.70±0.25	0.17±0.16	0.74±0.27	0.82	12.42
B	44.7±5.5	4.61±0.36	0.11±0.10	0.69±0.34	2.73	43.08
C	38.7±13.4	0.62±0.38	0.05±0.01	0.45±0.04	2.68	22.04
D	46.6±3.8	0.32±0.11	0.19±0.22	0.62±0.10	1.98	16.91
E	30.5±2.3	0.76±0.09	0.06±0.02	0.08±0.06	2.87	1.89
F	41.9±18.4	0.62±0.06	0.02±0.02	0.20±0.05	0.93	1.22
Mean±SD	40.9±7.9	1.27±0.21	0.10±0.09	0.46±0.14	1.00	8.13

[1)]Yam powder products were cultivated originally from six various places in South Korea.
A, Andong Book-Hoo; B, Bon-Chon; C, Andong Cham-Ma; D, Nock-Jon; E, Sansaem; F, Prus.
[2)]Cd, cadmium; Cr, chromium; As, arsenic; Pb, lead; Ni, nickel; Sn, stannum.
Values of Cd, Cr, As, and Pb are from two separates experiments in duplicates (mean±SD) and values for Ni and Sn are single measurements.

Table 2A. Comparison of the heavy metal (Cd, Cr, As, Pb and Ni) contents in commercial yam powder products to the level of heavy metal contents in national root and tuber crops

Yam powder products[1)]	Cd[2)]		Cr		As		Pb		Ni	
	Yam (mg/kg)	Root and tuber[3)] (mg/kg)	Yam (mg/kg)	Root and tuber (mg/kg)	Yam (mg/kg)	Root and tuber (mg/kg)	Yam (mg/kg)	Root and tuber (mg/kg)	Yam (mg/kg)	Root and tuber (mg/kg)
A	0.043±0.004	tr[4)]~0.315	0.695±0.247	tr~2.756	0.174±0.158	tr~0.437	0.740±0.268	tr~1.243	0.82	tr~0.739
B	0.045±0.006	tr~0.315	4.610±0.354	tr~2.756	0.109±0.098	tr~0.437	0.687±0.343	tr~1.243	2.73	tr~0.739
C	0.039±0.013	tr~0.315	0.615±0.375	tr~2.756	0.045±0.012	tr~0.437	0.446±0.044	tr~1.243	2.68	tr~0.739
D	0.047±0.004	tr~0.315	0.318±0.110	tr~2.756	0.190±0.216	tr~0.437	0.615±0.096	tr~1.243	1.98	tr~0.739
E	0.031±0.002	tr~0.315	0.758±0.088	tr~2.756	0.060±0.018	tr~0.437	0.077±0.062	tr~1.243	2.87	tr~0.739
F	0.042±0.018	tr~0.315	0.618±0.060	tr~2.756	0.023±0.017	tr~0.437	0.198±0.046	tr~1.243	0.93	tr~0.739
Mean±SD	0.041±0.001	0.015 (mean)	1.269±0.206	0.147 (mean)	0.100±0.087	0.041 (mean)	0.460±0.143	0.204 (mean)	1.00	0.171 (mean)

[1)]The same yam powder products as in Table 1.
[2)]Cd, cadmium; Cr, chromium; As, arsenic; Pb, lead; Ni, nickel.
[3)]The values for heavy metal contents in root and tuber crops of South Korea were cited from Kim et al. (19).
[4)]tr, trace amount.
Values of Cd, Cr, As and Pb are from two separates experiments performed in duplicates (mean±SD) and values for Ni are from a single measurement.

Table 2B. Comparison of the heavy metal (Cd, As, Pb, and Ni) contents in commercial yam powder products to other agricultural products (cereals, vegetables, pulses, and fruits)

Yam powder products[1)]	Cd[2)]		As		Pb		Ni	
	Yam (mg/kg)	Cereals[3)] (mg/kg)	Yam (mg/kg)	Vegetables (mg/kg)	Yam (mg/kg)	Pulses (mg/kg)	Yam (mg/kg)	Fruits (mg/kg)
A	0.043±0.004	tr[4)]~0.460	0.174±0.158	tr~0.13	0.740±0.268	tr~1.09	0.82	tr~2.36
B	0.045±0.006	tr~0.460	0.109±0.098	tr~0.13	0.687±0.343	tr~1.09	2.73	tr~2.36
C	0.039±0.013	tr~0.460	0.045±0.012	tr~0.13	0.446±0.044	tr~1.09	2.68	tr~2.36
D	0.047±0.004	tr~0.460	0.190±0.216	tr~0.13	0.615±0.096	tr~1.09	1.98	tr~2.36
E	0.031±0.002	tr~0.460	0.060±0.018	tr~0.13	0.077±0.062	tr~1.09	2.87	tr~2.36
F	0.042±0.018	tr~0.460	0.023±0.017	tr~0.13	0.198±0.046	tr~1.09	0.93	tr~2.36
Mean±SD	0.041±0.001	0.032 (mean)	0.100±0.087	0.03 (mean)	0.460±0.143	0.70 (mean)	1.00	0.25 (mean)

1)The same yam powder products as in Table 1.
2)Cd, cadmium; As, arsenic; Pb, lead; Ni, nickel.
3)The values of heavy metal contents in agricultural products (cereals, vegetables, pulses, and fruits) of South Korea were cited from Kim et al. (19).
4)tr, trace amount.
Values of Cd, As and Pb are from two separate experiments performed in duplicates (mean±SD) and values for Ni are from a single measurement.
The level of heavy metals (As, Pb) were measured and presented in three decimal points, while the standard levels of the metal are only presented in two decimal points.

Table 2C. Comparison of the heavy metal (Cd and Pb) contents in commercial yam powder products to the international standard levels (South Korea, EU and Codex)

Yam powder products[1)]	Cd[2)3)] (mg/kg)				Pb (mg/kg)			
	Yam	Korea	EU	Codex	Yam	Korea	EU	Codex
A	0.043±0.004	0.1	0.1	0.1	0.740±0.268	0.1	0.1	0.1
B	0.045±0.006	0.1	0.1	0.1	0.687±0.343	0.1	0.1	0.1
C	0.039±0.013	0.1	0.1	0.1	0.446±0.044	0.1	0.1	0.1
D	0.047±0.004	0.1	0.1	0.1	0.615±0.096	0.1	0.1	0.1
E	0.031±0.002	0.1	0.1	0.1	0.077±0.062	0.1	0.1	0.1
F	0.042±0.018	0.1	0.1	0.1	0.198±0.046	0.1	0.1	0.1
Mean±SD	0.041±0.001	0.1	0.1	0.1	0.460±0.143	0.1	0.1	0.1

1)The same yam powder products as in Table 1.
2)Cd, cadmium; Pb, lead.
3)Heavy metal food standard level: Korea, Cd and Pb level for root and tuber crops (20); EU, Cd and Pb for root and tuber crops (21); Codex, Cd and P levels for root and tuber vegetables (22).
Values of Korea, EU and Codex standard levelsare from food contaminants division in Food Safety Evaluation Department of Korea Institute of Food and Drug Safety Evaluation.
Values are two separates experiments performed in duplicates (mean±SD).

(20-22) (Table 2C). The mean Cd levels in yam powder products (0.041 mg/kg) were lower than the international Cd standard levels for Korea, EU and Codex (0.1 mg/kg for root and tuber vegetables). However, Pb levels in yam powder products (0.46±0.1 mg/kg) were higher than Pb standard levels of Korea, EU, and Codex (0.1 mg/kg).

Comparison of heavy metal levels to the standard levels for drinking water: Heavy metal (Cd, Cr, As, and Pb) contents in yam powder was compared to the standard level in drinking water (Table 2D). The mean contents (presented in mg/kg) for Cd, Cr, As, and Pb in yam powder were higher than the standard level (mg/L) in drinking water, in comparing values.

The assessment of heavy metal contamination during product processing

During the processing steps, the contamination of Pb, Ni and Sn were observed. Heavy metal contents in yam powder products A and B during each product processing step were presented in Table 3. In product A, while the contents of Cd, Cr and As were not affected by each processing step, the contents of Pb and Sn increased (contaminated) with proceeding processing steps, appearing at high levels in the final products. In product B, Ni content increased after post-second grinding stage and proceeded up to the final products, causing contamination during the processing.

Table 2D. Comparison of the heavy metal (Cd, Cr, As, and Pb) contents in commercial yam powder products to standard level in drinking water

Yam powder products[1)]	Cd[2)]		Cr		As		Pb	
	Yam (mg/kg)	Drinking water[3)] (mg/L)	Yam (mg/kg)	Drinking water (mg/L)	Yam (mg/kg)	Drinking water (mg/L)	Yam (mg/kg)	Drinking water (mg/L)
A	0.043±0.004	<0.005	0.695±0.247	<0.05	0.174±0.158	<0.01	0.740±0.268	<0.01
B	0.045±0.006	<0.005	4.610±0.354	<0.05	0.109±0.098	<0.01	0.687±0.343	<0.01
C	0.039±0.013	<0.005	0.615±0.375	<0.05	0.045±0.012	<0.01	0.446±0.044	<0.01
D	0.047±0.004	<0.005	0.318±0.110	<0.05	0.190±0.216	<0.01	0.615±0.096	<0.01
E	0.031±0.002	<0.005	0.758±0.088	<0.05	0.060±0.018	<0.01	0.077±0.062	<0.01
F	0.042±0.018	<0.005	0.618±0.060	<0.05	0.023±0.017	<0.01	0.198±0.046	<0.01
Mean±SD	0.041±0.001	<0.005	1.269±0.206	<0.05	0.100±0.087	<0.01	0.460±0.143	<0.01

[1)]The same yam powder products as in Table 1.
[2)]Cd, cadmium; Cr, chromium; As, arsenic; Pb, lead.
[3)]The source for the values of heavy metal contents in drinking water are from the sewerage division in water supply and sewerage policy office of Korea ministry of environment, Article 2 (1) (23).
Values are from two separate experiments performed in duplicates (mean±SD).

Table 3. Heavy metal (Cd, Cr, As, Pb, Ni, and Sn) contents in each processing step of commercial yam powder products

	Yam powder products[1)] Processing step	Cd[2)] (μg/kg)	Cr (μg/g)	As (μg/g)	Pb (μg/g)	Ni (μg/g)	Sn (μg/g)
A	Post-second selection	45.4±7.6	0.74±0.47	0.16±0.18	0.45±0.05	1.92	8.7
	Post-UV sterilization	44.1±1.6	0.63±0.45	0.19±0.20	0.38±0.01	0.84	16.5
	Post-heavy metal detector	38.1±10.4	0.46±0.01	0.20±0.21	0.40±0.01	0.86	13.5
	Post-passing final product	43.1±4.1	0.70±0.25	0.17±0.16	0.74±0.27	0.82	12.4
B	Post-bark peeling	43.9±4.9	4.57±1.08	0.09±0.08	0.55±0.09	1.67	425.1
	Post-second grinding	45.5±2.2	5.35±0.09	0.05±0.03	0.46±0.10	2.80	52.6
	Pre-packing	45.5±4.6	10.76±0.02	0.12±0.11	0.52±0.16	4.87	110.2
	Final product	44.7±5.5	4.61±0.35	0.11±0.10	0.69±0.34	2.73	43.1

[1)]The same yam powder products as in Table 1.
[2)]Cd, cadmium; Cr, chromium; As, arsenic; Pb, lead; Ni, nickel; Sn, stannum.
Values of Cd, As and Pb are from two separates experiments, while other values are from a single experiment performed in duplicates (mean±SD).

DISCUSSION

The human body can be easily contaminated by heavy metal such as Cd, Cr, As, Pb, Ni, and Sn through food intake or by being exposed to heavy metal contaminated environments. Since fruits and vegetables can absorb heavy metal contents from the soil, even the same crops or vegetables can differ in mineral and metal contents depending on the soil and the region where the plants are cultivated (2). In the present study, we assessed the heavy metal contents in commercial yam powder products from six various places in South Korea and judged the safety for their intake as the health foods for improving the health condition.

The conclusions from the study results are: 1) the contents of heavy metals (Cd, Cr, As and Pb) in yam powder products are of similar levels to those in national 'roots and tubers' as well as 'various crops' (such as cereals, vegetables, pulses and fruits), which means not harmful for heavy metal contamination; 2) on the assessment of two major heavy metals (Cd and Pb) compared to international food standards (EU, Codex as well as Korea), Cd content in yam powder products is lower safety level, but mean Pb content (0.46 mg/kg) is almost 5 times higher than the international standard levels of EU, Codex and Korea (0.1 mg/kg), meaning products were highly Pb-contaminated; 3) for the assessment of the possibility of contamination during food product processing for these particular yam products, some heavy metals (Pb, Ni and Sn) contents can be contaminated during the processing steps, which imply the caution to avoid the contamination.

Several studies reported the metal contamination in agricultural products, such as the heavy metal concentration in fruits (14), vegetables (15), and mushrooms (16). The metal levels were compared to Provisional Tolerable Weekly Intakes (PTWI) established by FAO/WHO and evaluated for food safety. Lee et al. (17) analyzed the trends and contents of hazard substances in agricultural products, which were reported in the press for 5 years (2005∼2009) in South Korea, and reported that the contents of heavy metals (Pb, Cd, As, Hg, etc.)

highly increased. Because consumption of the heavy metal contaminated-agricultural products is directly contaminating the human body, we wanted to present more precise analyzed data for the agricultural products regarding food safety.

In our analysis and assessment, the contents of heavy metals (especially Cd, Cr, As, and Pb) in yam powder products are similar levels to those of roots and tubers (similar to yams) and other crops such as cereals, vegetables, pulses and fruits. Therefore, at least the six analyzed yam products in this study are reasonably safe for intake in South Korea.

Also, Cd content in six yam powder products is safe in comparison to the suggested international food standard levels, such as EU and Codex. However, for the Pb level, a special caution would need to be considered, since the Pb level in yam products in this study was much higher (5 times) than the international food standard levels. Therefore, the concentration of Pb in yam powder products might be dangerous to consume. Out of six products, Pb content in only product E was within the safe level (0.08 mg/kg in Table 2C), but the rest showed highly contaminated levels (0.2～0.7 mg/kg). Further clarification on where/how this contamination would occur needs to be investigated.

Marwa et al. (18) reported that the risk assessment of toxic elements in agricultural soils and maize tissues from selected districts in Tanzania were: Pb <0.01～0.29 mg/kg, Ni <0.52～8.14 mg/kg, As <0.01～0.08 mg/kg and Cr <0.10～1.09 mg/kg; even these heavy metal contents in their products are lower than yam powder products in our study. The study suggested to the public to stop consuming the products and to stop feeding the maize to their animals because toxic levels in these crops may increase risk to cause long-term health problems.

Another considerable issue from the current study is to avoid the heavy metal contamination during the food manufacturing process of yam products. Heavy metals can enter into agricultural food products normally by the addition of pesticides, wastewater, etc., and ideally can be removed, instead of contamination, during the processing steps. In our study, three heavy metals (Pb, Ni and Sn) were observed for contamination during the food manufacturing process.

In conclusion, commercial yam powder products would be safe as the amount of daily allowance without any harmful contamination of heavy metals; however, one should take caution in the amount of Pb content in the products. Further studies are needed for the intake of actual amounts of heavy metal concentrations from yam powder compared to PTWI for determining safe levels for heavy metals from yam powder. A standard level for each heavy metal in yam and yam products also needs to be determined to avoid heavy metal contamination from the yam product intakes.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

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