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Increasing Health Risk of Heavy Metals Accumulation from Duck Farming in Suburbs Tropical Lowlands

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Abstract

The acidic sediment of Sumatra's lowlands naturally increases the availability of micro minerals. Moreover, residential and municipal waste streams and other anthropogenic sources of pollutants commonly end up in the lowlands. As a result, waterfowl could be exposed to heavy metal contamination. This study present heavy metal concentrations (Iron, Zinc, Manganese, Copper, Cadmium, and Lead) in the muscles and liver samples of domestic mallards (*Anas platyrhynchos* f. domestica) reared in backyards around the city of Palembang, grazing mallards in rural regions, and whistling ducks (*Dendrocygna arcuata*). Zinc levels in the muscles were higher in the backyard mallards than in the grazing mallards. The muscles of whistling ducks contained higher iron than mallards. Copper, cadmium, and lead concentrations in the livers were lower in the whistling ducks than in the mallards. The metal concentrations were within the previously reported range in other mallards, however, the maximum value of Iron level (37 to 6,763 mg/kg dry weight) was higher. Manganese, Iron, Zinc, Cadmium, and Lead levels were shown to be highly correlated in the muscles and livers. Lead concentrations in 99% of samples and Cadmium concentrations in 22% of samples exceed European Commission acceptable limits. This study indicates a health risk from long-term consumption of duck meats according to the elevated Cadmium and Lead concentrations.

Keywords: Duck; Acidic water; Bioaccumulation; Heavy metals; Health risk

1. Introduction

Poultry production plays a significant part in the agricultural economy of small-scale farmers in terms of egg and meat production. The majority of poultry farming in Southeast Asia takes place in lowland areas. Duck production, in particular, is essential for the rural economy, which also supports various rice production in the region. Ducks are generally reared in extensive and intensive systems in rural areas, where the product is utilized for family use and the surplus is sold in local markets (Islam *et al.,* 2016; World Bank, 2021).

Rapid urbanization and dysfunctional waste management services and infrastructure are challenges for cities in most developing countries (Guerrero *et al.,* 2013), which may be related to increased exposure of pollutants to the environment and food chains. In the lowland areas of Sumatra where water and soil are acidic, heavy metals pollution might need more concern since their availability and uptake were higher in the acid environment (Kicińska *et al.* 2022), resulting in a larger concentration of the metals in the plant (Ali *et al.* 2019) as well as buffalo hair (Ali *et al.* 2021).

Poultry reared in extensive systems derives the majority of its nutritional requirements from free scavenging. As a consequence, extensive rearing ducks could encounter substantial risks of environmental pollutants including heavy metals (Rajkumar *et al.* 2021; Ali *et al.* 2024). For the higher tropic level of food chains, ducks might potentially be a valuable indication for environmental monitoring (Plessl *et al.* 2017; Man *et al.* 2021).This hypothesis needs to be proven in the context of the backyard, grazing, and wild ducks in the lowlands of south Sumatra.

The aim of this study was to evaluate heavy metals levels, including Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Lead (Pb), and Cadmium (Cd), in muscle and liver organs of males and females of the backyard and grazing mallards (*Anas platyrhynchos* f. domestica) and whilsting ducks (*Dendrocygna arcuata*). A secondary aim was to assess the health risk effects caused by the consumption of duck meat in the region.

2. Methodology

2.1 Sample collection

From January to September 2022, 36 backyard and grazing mallard samples (18 males and 18 females) were collected from farmers in sub-urban areas of Palembang city and Ogan Ilir region of South Sumatra, respectively. Feed samples were collected from poultry shops in the area, while water samples were collected from rivers, swamp areas, municipal drink water, and sewage effluents (Figure 1). The pH levels of the water samples were measured on the sampling sites using a portable pH meter (Hanna HI 98130) (Table 1).

The mallard ducks (674 to 1443 g of live weight) were local breeds raised by small-scale farmers throughout the year and fed mostly with household wastes, corn, and rice brain. Commercial broiler concentrates are occasionally used as supplemental feed. For the grazing ducks, the ducks are allowed to graze in paddy fields in the non-tidal swamp areas. In addition, eighteen samples (9 males and 9 females) of whistling ducks (235 to 503 g) were obtained from a seller at Sungai Lumpur, Ogan Komering Ilir district, 141 km away from Palembang city. The wild ducks are trapped with fishing nets in coastal swamp areas and sold at local markets and restaurants.

2.2 Heavy metals analysis

The pectoral muscle and liver of each individual duck were carefully removed from the carcasses, chopped with a stainless knife, and preserved in plastic bags at -20 °C. The organ samples (± 25 g) were dried in an oven at 60 °C for 3 days until no more weight loss occurred. A 0.5 g of the organ and feed samples were transferred to a digestion flask. The sample was digested for 30 minutes at 95 °C with a 5 mL solution of nitric acid, hydrochloric acid, and hydrogen peroxide (Merck, 1:1:1). After cooling, the digested sample was transferred to a volumetric flask and deionized water (Millipore purifier, Merck) was added to 50 mL. The solution was then filtered before being analyzed using microwave plasma-atomic emission spectrometry (MP-AES, MP-4100, Agilent, Santa Clara, CA, USA) (Zhao *et al.* 2015; Qudus *et al.* 2021). A sample, a spike, a blank, and a standard were done in duplicate in each run. The detection limits (mg/kg) were 1.55, 1.77, 1.25, 0.73, 1.67, and 0.51 for Fe, Zn, Mn, Cu, Pb, and Cd, respectively. Water samples were analyzed according to American public health association (APHA 2012). About 250 mL of water sample was transferred to beakers, and 5 mL of nitric acid (Merck) was added. The sample was heated (85 °C) to a final volume of about 15 - 20 ml, transferred to a 25 - mL flask, and then filtered. To assure the quality of the chemical analysis, the apparatus, chemicals and standard from known well-company were used.

2.3 Data Analysis

The Kolmogorov-Smirnov test was used to determine the data's normality. When the data fell below the detection limits, a value equal to one-third of the detection limit was entered. Afterward, the data were log-transformed to meet a normal distribution assumption. The differences in three classed ducks (backyard, grazing mallards, and whistling ducks), sex, and organs were assessed using one-way analysis of variance and followed by the Benforini test after a statistical significance ($P < 0.05$). Geometric mean, minimum and maximum values are presented and relationships between heavy metal concentrations were assessed with Spearman correlation. Data analysis was carried out with Statistical Analysis Systems (SAS institute). The level of Pb and Cd was compared to the permissible limit of European Commission threshold in meat and liver (mg/kg fresh weight) (EC 2014). The estimated daily intake (EDI) of the metals (Zn, Mn, Pb, and Cd) through duck meat consumption was estimated using the concentration of the elements (fresh weight), an average of duck meat consumption in the region (0.2 g/person/day) (Badan Pusat Statistik 2018), and body weight (61.4 and 56.2 kg, for Indonesian male and female, respectively) (Worlddata.info 2024). The EDI values were compared with the recommended levels of reference dose (RfD, EFSA, 2010; Sprong *et al.,* 2023; United States Environmental Protection Agency, 1989).

3. Results and Discussion

The means of the heavy metals concentrations in feed and water are presented in Table 1. Feed samples had detectable concentrations of Fe, Zn, Mn, Cu, and Pb, while Cd was not detectable in all feed and water samples. The geometric means and ranges of the heavy metals concentrations in pectoral muscles and livers of domestic and wild ducks are presented in Table 2. For pectoral muscle, Fe concentrations were significantly greater in whistling ducks

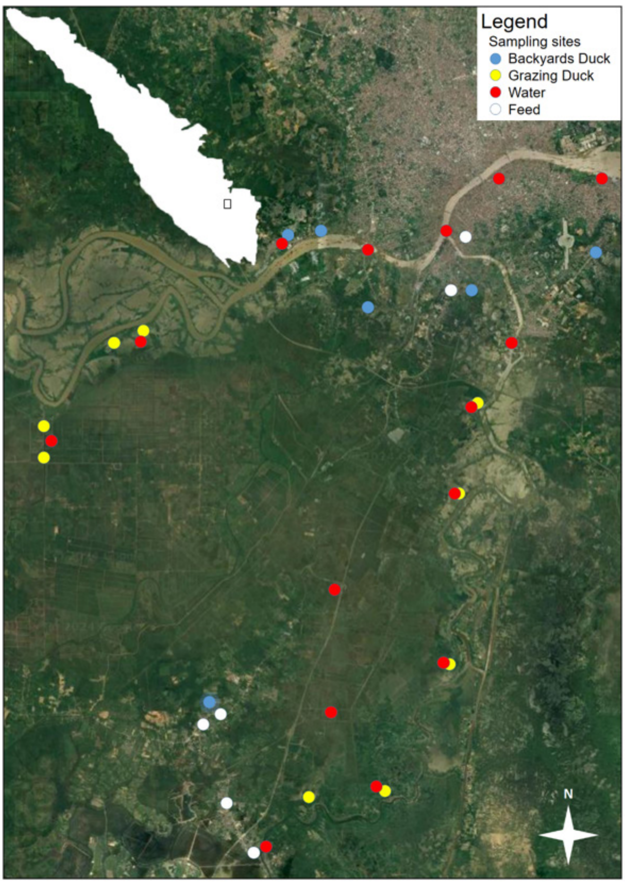

Figure 1. Sampling points and satellite image of study location on South Sumatra, Indonesia (Google maps, Google, DigitalGlobe, 2024).

than in the backyard and grazing mallards ($P < 0.01$). Zinc concentrations also varied among ducks ($P < 0.01$). Zinc concentrations in the backyard mallards were significantly higher than those in the grazing mallards but did not differ with those in the whistling ducks. Moreover, Concentrations of Mn and Cu in the muscle samples did not vary among the ducks ($P > 0.05$), but Mn concentrations differed between male and female ducks ($P < 0.05$). Concentrations of Mn, Cu, Cd, and Pb in the liver samples varied among ducks ($P < 0.05$).

In the liver samples, the backyard ducks had greater concentrations of Mn, Cu, and Pb than the whistling ducks, while the grazing ducks had the greatest Cd concentrations ($P < 0.05$). For the difference between the organs, the concentrations of Fe, Zn, Mn, and Cu were higher in the livers than in the muscles ($P < 0.01$), but the difference in Cd and Pb concentrations was not significant (Table 2). Similar to the muscle, Pb concentrations in 99% of the animals were higher than the permissible limit, whereas Cd concentrations in the whilsting and backyard ducks did not exceed the maximum standard (Table 3).

For toxic contaminants such as Cd and Pb, the concentrations in the muscle did not vary among the ducks. Meanwhile, the toxic element levels in the liver of whistling ducks were lower than in mallards (Table 2). Referring to the permissible limit in the meat and liver (EC 2014), Pb concentrations in all muscle samples exceed the threshold (Table 3).

The pectoral muscle samples that exceed the permissible limit of Cd concentration were 6, 7, and 5 for the whistling ducks, grazing, and backyard mallards, respectively (Table 3). Previous study in the region (Ali *et al.* 2021) and other tropical lowlands (Bai *et al.* 2018) also reported an excess level of Cd and Pb in water and aquatic plants, which might be linked to the higher levels of Cd and Pb.

In the muscle organ, Mn concentrations in muscle organs showed a positive correlation with Fe, Zn, and Pb concentrations ($P < 0.01$). Lead concentrations also showed a positive correlation with Zn concentrations ($P < 0.05$) and a negative correlation with Cd concentrations ($P < 0.01$) (Table 4). Moreover, in the liver, Mn concentrations positively correlated with the concentrations of Cu, Cd, and Pb ($P < 0.01$). Iron concentrations correlated with Zn while Cu correlated with Cd and Pb concentrations ($P < 0.01$) (Table 5). The positive correlations between toxic and essential metals may occur due to similar metabolism. In this study, Cd and Pb correlated with Mn and Cu concentrations in the livers, whilst in the muscle samples, Pb correlated with Zn and Mn concentrations. In the location of the present study, a positive correlation between Pb and Mn was also reported in buffalo hair (Ali *et al.* 2021).

Table 1. Heavy metal concentrations (mean ± standard error) in samples of feed (mg/kg) and water (mg/L) in a lowland sub-urban area

	Fe	Zn	Mn	Cu	Cd	Pb
Maize	24.40 ± 5.51	15.22 ± 2.47	3.15 ± 0.52	0.77 ± 0.17	ND	1.14 ± 0.19
Rice bran	40.34 ± 2.54	23.26 ± 1.81	71.46 ± 15.39	1.71 ± 0.41	ND	1.30 ± 0.06
Commercial broiler feed	75.48 ± 5.52	55.30 ± 24.28	82.93 ± 10.47	30.76 ± 23.35	ND	0.09 ± 0.02
Municipal water supply[a]	0.24 ± 0.01	0.04 ± 0.04	0.39 ± 0.39	ND	ND	ND
Residential Sewage[b]	1.60 ± 0.56	0.25 ± 0.20	0.28 ± 0.15	0.04 ± 0.036	ND	ND
Swamp area[c]	0.34 ± 0.04	0.06 ± 0.01	0.07 ± 0.01	0.02 ± 0.002	ND	0.04 ± 0.01
River[d]	1.26 ± 0.54	0.06 ± 0.02	0.09 ± 0.01	0.02 ± 0.003	ND	0.03 ± 0.01

ND = not detected; Average pH levels were 6.1[a],7.0[b], 3.9[c], and 4.2[d]

Table 2. Heavy metal concentrations in samples of whilstling ducks (*Dendrocygna arcuata*) and domestic mallards (*Anas platyrhynchos*) (mg/kg dry weight)

		Fe	Zn	Mn	Cu	Cd	Pb
Muscle							
Whilstling ducks	Geomean	345.5^{b}	68.9^{ab}	3.3	17.7	0.07	9.8
(n = 18)	Range	221.9 - 783.2	37.9 - 336.9	1.9 - 20.1	8.8 - 52.3	ND - 0.3	8.2 - 12.7
Grazing mallards	Geomean	145.8^{a}	45.2^{a}	2.1	21.8	0.07	7.5
(n = 18)	Range	37.1 - 96.3	13.9 - 120.2	0.4 - 34.0	8.2 - 170.2	ND - 0.5	2.2 - 11.7
Backyard mallards	Geomean	159.3^{a}	80.8^{b}	3.8	16.8	0.06	9.1
(n = 18)	Range	91.0 - 311.0	48.1 - 116.8	1.0 - 8.2	6.9 - 27.1	ND - 1.6	1.6 - 23.2
P value							
Duck		< .0001	0.0010	0.1453	0.2917	0.2268	0.3023
Sex		0.3684	0.3755	0.0185	0.8420	0.1349	0.0606
Liver							
Whilstling ducks	Geomean	2344.2	262.3	6.1^{a}	9.7^{a}	0.02^{a}	6.4^{a}
(n = 18)	Range	412.8 - 6040.7	57.9 - 558.3	1.9 - 11.6	2.1 - 54.7	ND - 0.02	1.2 - 8.8
Grazing mallards	Geomean	2227.2	209.9	14.7^{b}	159.0^{b}	0.44^{c}	8.8^{ab}
(n = 18)	Range	851.1 - 6763.4	105.7 - 326.6	4.9 - 23.5	41.9 - 351.1	ND - 10.0	4.9 - 14.7
Backyard mallards	Geomean	1556.3	194.7	15.3^{b}	286.7^{c}	0.08^{b}	9.8^{b}
(n = 18)	Range	959.7 - 3573.2	86.1 - 301.3	6.3 - 27.1	147.8 - 571.6	ND - 0.9	4.0 - 21.5
P value							
Duck		0.0651	0.1189	< .0001	< .0001	< .0001	0.0109
Sex		0.6620	0.8858	0.9401	0.9877	0.1569	0.5616
Organ		< .0001	< .0001	< .0001	< .0001	0.4991	0.4687

ND = not detected; Geomean sharing the same upper-case letter in each muscle or liver were not significantly different among ducks

As compared to the previous studies (Table 7), the higher Fe concentrations in the muscle and liver organs in this study may relate to the natural conditions. To the best of our knowledge, this is the first study that revealed the potential accumulation of heavy metals in food produced by animals in Sumatra's lowlands. Iron concentrations were within range of the previous study though the maximum values were much higher than the maximum values in the literatures (Table 7). Level of Zn, Mn, and Cu was also within the ranges in the previous studies. The highest concentrations of the minerals in the muscles and livers of the backyard mallards (Table 2) may relate to the human activities where the ducks reared in the sub-urban regions. In addition, Pb levels in the muscle samples were within the range of the previous studies; The maximum value was higher than in other studies but comparable to the maximum value of a study in Austria (Plessl *et al.* 2017). The maximum value of Pb in the livers was also within the range but was lower than the maximum value reported in Chesapeake Bay, USA (Di Giulio and Scanlon 1984).

Table 3. Number of whilstling ducks (*Dendrocygna arcuata*) and domestic mallards (*Anas platyrhynchos*) exceeding European Commision threshold for cadmium and lead levels in meat and liver (mg/kg fresh weight)

	Cadmium	Lead
Muscle	> 0.05	> 0.10
Whilstling ducks	6	18
Grazing mallards	7	18
Backyard mallards	5	18
Liver	> 0.50	> 0.50
Whilstling ducks	0	17
Grazing mallards	6	18
Backyard mallards	0	18

Table 4. Spearmann correlation among heavy metals in pectoral muscles of whilstling ducks (*Dendrocygna arcuata*) and domestic mallards (*Anas platyrhynchos*)

	Fe	Zn	Mn	Cu	Cd	Pb
Fe	1					
Zn	0.15	1				
Mn	0.35**	0.37**	1			
Cu	0.24	0.24	0.06	1		
Cd	0.25	- 0.22	- 0.11	0.05	1	
Pb	0.20	0.31*	0.36**	0.11	- 0.51**	1

**Correlation is significant at 0.01 level; *Correlation is significant at 0.05 level

Table 5. Spearmann correlation among heavy metals in livers of whilstling ducks (*Dendrocygna arcuata*) and domestic mallards (*Anas platyrhynchos*)

	Fe	Zn	Mn	Cu	Cd	Pb
Fe	1					
Zn	0.48**	1				
Mn	- 0.14	- 0.03	1			
Cu	- 0.01	- 0.10	0.71**	1		
Cd	- 0.08	- 0.13	0.52**	0.48**	1	
Pb	0.12	0.1	0.62**	0.44**	0.19	1

**Correlation is significant at 0.01 level; *Correlation is significant at 0.05 level

Table 6. Maximum value of estimated daily intake of heavy metals compared to the recommended reference dose (µg/kg body weight/day)

	Zn	Mn	Cd	Pb
Meat				
Male	0.267	0.025	0.001	0.017
Female	0.292	0.028	0.002	0.019
Liver				
Male	0.613	0.030	0.011	0.022
Female	0.670	0.033	0.012	0.024
Standard	300*	140*	1.0*	0.2#

The level based on United States Environmental Protection Agency (USEPA 1989) *, European Food Safety Authority (EFSA 2010; Sprong *et al*. 2023)#

The maximum EDI values of heavy metals (Zn, Mn, Cd, and Pb) through duck meat and liver consumption for male and female are presented in Table 6. The EDI of Zn, Mn, Cd, and Pb were all far below the reference dose. Based on a survey, the average daily consumption of duck meat was 0.20 g fresh weight/day. The value is lower than that used in the study of Susanti & Widiyastuti, (2022) and Susanti *et al.,* (2020) in Java Indonesia (22.5 g/day) but in range with the level used in a study in Thailand (Aendo *et al.* 2019) (0.14 to 0.54 g/day). The daily intake of the metals depends on both the concentration of the metals in meat and liver and the associated consumption data. Moreover, body weight can influence the tolerance of pollutants. Although the EDI values in the present study were lower than RfD, the health risk to the local population could not be neglected because of the higher concentration of the heavy metals in the meat and liver.

The lowlands hold a vital role in food production and sustainability since they cover more than 20% of Indonesia's agricultural land. Besides that, the lowlands have an important function in the ecology by serving as a reservoir for all streams and maintaining species diversity (World Bank, 2021). Human population growth not only increases more pressure on the area for food production, but it also causes in a greater environmental challenge due to increased waste production and the lack of waste management and infrastructure. Furthermore, the geological formation of the lowland, similar to that of other tropical lowland regions in South East Asia and Northern Australia, is characterized by pyrite sediments where natural organic acids and pollutants from pyrite oxidations cause a higher solubility of soil microminerals when pH is dropped (Fanning *et al.* 2017). By the end of the dry season, soil and water pH levels of 3.5 were detected while Mn, Fe and Pb concentration in the plants was elevated and above permissible limit for livestock (Ali *et al.* 2021, 2022). The higher levels of the micro minerals in sediment, water and aquatic biota were also reported in the other tropical wetlands (Bai *et al.* 2018; Man *et al.* 2021).

4. Conclusion

In conclusion, Fe and Zn concentrations in the muscles, as well as Mn, Cu, Cd, and Pb concentrations in the livers varied between the ducks. The male ducks showed greater Mn concentrations than female ducks, while livers had higher Fe, Zn, Mn, and Cu concentrations than muscles. Higher concentrations of Fe, Cu, Cd, and Pb in mallards in this study compared to the mallards in other locations might be attributed to the naturally acidic environment and human activities. Long-term consumption of the duck meat and liver containing high Cd and Pb concentrations may incur health risks for consumers. Therefore, duck production must be monitored, as well as waste management and disposal facilities.

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Table 7. Heavy metals concentrations (mg/kg, dry weight) in muscles and livers of mallards (*Anas platyrhynchos*) from various locations worldwide

Fe	Zn	Mn	Cu	Cd	Pb		n	Site	Source
Muscle									
152.4	60.4	2.9	19.1	0.06	8.3	[b]	32	South Sumatra	This Study
37.1 - 796.3	13.9 - 120.2	0.4 - 34.0	6.9 - 170.2	ND - 1.6	1.6 - 23.2	[c]	32	South Sumatra	This Study
296.7	36.0	4.0	18.7	0.081	2.5	[a*]	98	Poland	Kalisińska *et al*., 2004
-	35.8	1.79	17.3	0.002	0.028	[a]	14	Southern Japan	Nam *et al*., 2005
-	20.4	-	7.2	0.52	1.08	[a]	13	Western Iran	Mansouri & Majnoni, 2014
-	8.87 - 31.2	-	2.7 - 22.8	0.02 - 0.89	ND - 1.9	[c]	16	Northwestern Iran	Alipour *et al*., 2016
-	8.01 - 41.4	-	3.8 - 32.7	N.D - 0.036	ND - 23.7	[c*]	77	Eastern Austria	Plessl *et al*., 2017
31.7 - 297	13.1 - 94	ND - 2.09	8.1 - 21.6	0.02 - 0.71	0.55 - 6.37	[c]	33	Thailand	Aendo *et al*., 2020
Liver									
1871.3	202.4	15.0	211.7	0.19	9.2	[b]	32	South Sumatra	This Study
851 - 6763.4	86 - 327	5 - 27	42 - 572	ND - 10	4 - 22	[c]	32	South Sumatra	This Study
-	21 - 990	-	2.6 - 957.3	ND - 2.37	ND - 288	[c]	157	Chesapeake Bay	Di Giulio & Scanlon, 1984
2712.9	130.0	15.2	87.8	2.6	1.0	[a*]	98	Poland	Kalisińska *et al*., 2004
-	236 - 49.0	13.7 - 1.9	127 - 46	0.8 - 0.4	0.7 - 0.4	[a]	13	Southern Japan	Nam *et al*., 2005
-	89.4 - 470.7	-	32.6 - 582.2	-	ND - 8.4	[c*]	40	Donana, Spain	Taggart *et al*., 2006
917.0	95.5	9.0	40.3	0.7	3.8	[b]	20	Cheorwon, Korea	Kim and Oh, 2012
-	64.1	-	13.8	1.8	2.2	[a]	12	Western Iran	Mansouri & Majnoni, 2014
-	45.3 - 86.5	-	4.3 - 16.1	0.41 - 2.1	0.07 - 5.8	[c]	16	Northwestern Iran	Alipour *et al*., 2016
-	176.0	17.3	35.4	1.2	4.7	[a]	4	Korea	Kim *et al*., 2016
-	42.6 - 224.7	-	8.6 - 297.9	0.05 - 2.3	ND - 20.1	[c*]	77	Eastern Austria	Plessl *et al*., 2017
119 - 3329.0	91.3 - 542.0	7.98 - 55.9	93.7 - 516.4	ND -1.32	0.23 - 6.69	[c]	33	Thailand	Aendo *et al*., 2020

[a] Arithmetic mean, [b] Geometric mean, [c] Range; *Original data is fresh weight and was converted to dry weight (×3); ND: not detected

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