Received: 30 May 2023, Accepted: 26 June 2023

Review Article

Journal of Advanced Veterinary Research
(2023) Volume 13, Issue 7, 1469-1473

# An Overview on the Contamination of Poultry Meat with Heavy Metals: A Review

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## Abstract

Poultry meat and their meat products are considered as major sources of animal derived protein, essential amino acids, minerals, and vitamins. However, poultry meat might act as a vehicle for a vast array of xenobiotics such as heavy metals. The latter are specifically characterized by their bioaccumulation and biomagnification nature. Several toxic metals such as lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), chromium (Cr), and arsenic (As) have several toxicological implications if ingested. In Egypt, several avian species are consumed as meat sources including chicken, quails, ducks, and turkeys. In this review, we would like to throw the light on the current scenario of the contamination of the poultry meat with such toxic metals in Egypt and worldwide. Besides, the public health significance of such toxic metals was also discussed.

KEYWORDS
Heavy metals, Poultry meat, Egypt.

## INTRODUCTION

Poultry products, such as meat, liver, and meat products (such as burgers, luncheon meat, and frankfurters), are important sources of protein, energy, vitamins, and minerals around the world because they are nutritious, delicious, and affordable, and provide a significant portion of the recommended daily allowance (RDA) of trace minerals, proteins, and energy (Darwish *et al.*, 2018; Morshdy *et al.*, 2021). However, chicken products may offer concerns due to heavy metal pollution from the environment or the food chain. Broiler diets are frequently supplemented with microelements such as Fe, Cu, Zn, Mn, I, and As to support bird growth and health. Minerals are also required for proper metabolic activity, physical function balance, and immunity in living organisms (El Bayomi *et al.*, 2018).

Heavy metal contamination is dangerous to human health because of its biomagnification, bioaccumulation, and toxicity. It has sparked considerable worry about human health, thus scientists are focusing their research on the concentrations of these metals in food ingested by humans in order to assess the danger associated with heavy metals exposure. Metals such as copper, nickel, zinc, cobalt, and manganese are structural components of some essential compounds. These trace elements also function as cofactors in a variety of enzymes that catalyze various metabolic processes, and high amounts of these elements are poisonous (Darwish *et al.*, 2014). Metal contamination in food additives or land foodstuffs has been observed, and concerned authorities (WHO) have proposed the maximum allowable levels of metal contamination in foodstuffs. These proposed allowed values aid food manufacturers in the selection of higher-quality raw materials and the utilization of equipment. According to WHO experts, the food pattern should be thoroughly examined so that each product can be examined separately for its specific contribution of metal concentration in total metal toxicity. Natural circumstances, fertilizers, and industrial contamination are the principal causes of heavy metal accumulation in culinary items. Because climatic circumstances, such as soil texture and other environmental agents vary greatly depending on geographical location, the amount of heavy metals likewise fluctuates (Darwish and Thompson, 2023). Analysis of market products can be used to assess the population's exposure to these pollutants. Heavy metals in tiny amounts bond with proteins and become harmless; however, excessive concentrations exceeding the body's tolerance level cause serious clinical disorders. Their increased concentration reacts with essential cellular components via covalent and ionic interactions, resulting in cell membrane damage and disruption of normal cellular activities, namely the enzymatic and molecular systems of the cell. By altering the DNA structure, these metals affect the gene code (Thompson and Darwish, 2019). Heavy metals accumulate in the biological system and damage birds in a variety of ways. Poultry is commonly poisoned by heavy metals through contaminated water, poultry feed, sewage water, industrial effluents, and aerial sprays in poultry breeding regions. Another aspect that contributes significantly to meat contamination is that it is sold primarily in outdoor marketplaces and occasionally on the side of the road. Because heavy metals are highly toxic even at low concentrations, it is critical for food safety and human health to closely monitor their concentration in meat and meat products to reduce the risk of heavy metal contamination (Morshdy *et al.*, 2013; El Bayomi *et al.*, 2018). The


ISSN: 2090-6277/2090-6269/ 

processing procedure can also lead to meat product contamination due to raw materials, spices, and water utilized during the packing process.

## Cadmium

Cadmium is a poisonous metal. Since the 1960s, it has been utilized in corrosion protection, polymer electronics, and pigments. Cadmium uptake in higher animals, including humans, occurs mostly by eating, whereas skin contact exposure is insignificant. Food is a common source of cadmium exposure since many plants, particularly fish and crustaceans collect cadmium very quickly. Cadmium is a classic cumulative toxin, meaning it builds up in the kidneys over time. Acute cadmium toxicity in humans arises as a result of ingesting very high amounts of contaminated beverages and food. This causes local gastrointestinal irritating symptoms such as nausea, vomiting, stomach pain, choking sensation, and diarrhoea. Inhaling cadmium fumes can cause pulmonary edema, which can lead to mortality, as well as chemical pneumonitis. Chronic Cadmium exposure harms the lungs, heart, gonads, bones, and, most notably, the kidneys. Long-term cadmium exposure can also cause anemia (Darwish *et al*., 2019; Darwish *et al*., 2020; Aljazzar *et al*., 2021).

## Lead

Lead is a very hazardous element that is found in all tissues and organs of mammals. Lead and lead-containing compounds are widely employed in lead-acid battery storage, sheet metal, pipelines, ammunition, and paints. Lead poisoning can occur through eating, inhalation, or cutaneous contact. The most prevalent way for the general population to be exposed to lead is through the consumption of polluted water and food. Inhalation is the most common route of Pb exposure in the workplace. Cigarette smoke contains trace amounts of lead as well. Lead can be found in drinking water as a result of leaching from old pipes, faucets, and other fixtures. Lead poisoning in young children can occur as a result of ingestion of peeling and chipping lead-based paint in older dwellings (Darwish *et al*., 2015). Lead has a wide range of effects on the body's organs, physiological activities, and cellular and molecular processes. It interferes with multiple cellular signaling systems, enzyme activity, and action potentials in some nerve cells. Lead also has an effect on the thyroid and adrenal glands' activity. The primary target organs are the kidneys, blood, and neurological system. Miscarriage, male infertility, and newborn morbidity and mortality are all possible side effects. Immune system dysfunction may also emerge as a result of gouty joint symptoms, as well as heart fibrosis and myocarditis (Darwish *et al*., 2016).

## Nickel

Nickel is the $24^{th}$ element in the earth's crust in terms of natural abundance. Nickel and its derivatives are widely employed in nickel-cadmium batteries, glazes and pigments, plated coatings, and as laboratory and industrial catalysts. Nickel and nickel-containing compounds can be ingested, inhaled, or applied to the skin by humans and animals. Smoke from the combustion of coal and petroleum products, as well as emissions from some industrial goods, contribute to the release of nickel into the atmosphere. Nickel exposure can cause unpleasant effects in the gastrointestinal tract, skin, or respiratory tract, as well as systemically in the kidneys, heart, and blood. It can cause pneumonia, pulmonary edema, and even death. Nickel exposure is also linked to cancer development (Kasprzak *et al*., 2003).

## Zinc

Zinc is a trace element that is found in all cells and is widely consumed as a dietary supplement. It serves as a cofactor for a variety of enzymes. Zinc is an essential and helpful element in human development. Its shortage can impact humans, causing hair loss, decreased growth, skin eruptions, small stature, and delayed or impaired sexual maturity. Zinc deficiency has also been linked to ulcerative colitis, anemia, and chronic renal illness. Zinc exposure can occur by food or inhalation. Because most plants rapidly absorb zinc, the majority of meals are high in zinc. Zinc, in high concentrations, interferes with copper and iron metabolism; the later causes what is known as copper-deficiency anemia. Excessive zinc consumption might result in cramping, nausea, vomiting, and diarrhoea. Inhaling zinc fumes causes pulmonary edema and metal fume fever, with symptoms such as sweating, weakness, and chills alternating with fever that can last up to 24 to 48 hours. Chronic Zinc inhalation can cause liver damage, which can be fatal (Wexler and Gad, 1998).

## Copper

Copper is a trace element that is abundant in nature. It is utilized as an alloy component, as a constituent in paints and ceramic glazes, and as an electrical conductor. Copper is often ingested by humans through water or food. Copper pipes used to transport drinking water are another source of this metal. Copper accumulates in the liver as a result of excessive consumption. When large doses of copper salts are consumed, acute poisoning ensues, accompanied by nonspecific toxic symptoms such as nausea, vomiting, and a metallic taste. Ulceration of the gastrointestinal tract is another possibility. Jaundice, hypotension, coma, and death are all possible severe symptoms. Copper poisoning can sometimes cause difficulty to urinate, and liver necrosis has been documented. Excess copper inhibits amino acid transferases, resulting in lipid peroxidation. Copper is also linked to two inborn metabolic errors: Menke's illness and Menke's kinky hair disease, and Wilson's disease and hepatolenticular degeneration (Darwish *et al*., 2014).

## Quails

Quail meat is a new high-quality animal protein source. Quails are subjected to a wide spectrum of xenobiotics, including heavy metals. Donia (2015) concentrated on determining the amounts of 10 heavy metals in selected tissues and organs of migratory quails or common quail (European and East Asian populations of quail (*Coturnix coturnix*) taken from various sites in the study area (North Western Coast, Egypt). Using Inductively Coupled Plasma Mass Spectroscopy (ICP-MS), samples of liver, kidney, and muscles (chest and leg) were analyzed for the presence of aluminum (Al), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), chromium (Cr), molybdenum (Mo), nickel (Ni), lead (pb), and strontium (Sr). The findings revealed that necessary components were found in higher concentrations in the tissues of these migratory birds than non-essential elements. Meanwhile, the kidney has the highest concentration of most metals, followed by the liver and heart; the highest quantity of Cu was found in liver samples. Furthermore, liver was discovered to contain higher metal contents than muscle in the birds. Heavy element concentrations (mg/kg wet weight) in the selected examined organs are modestly diversified, such as Al (48.61-395.9), Cu (2.84-6.64), Fe (162.3-882.7), Mn

(2.18-12.2), and Zn (8.11-25.5). The levels of these trace elements obtained from the four different quail organs are as follows: Fe > Al > Zn > Mn > Cu. The concentrations (mg/kg wet weight) were as follows: Cr (2.45-14.51), Sr (1.97-8.65), Pb (1.06-6.17), Ni (0.84-5.42), and Mo (0.23-1.48). Also, the levels of these trace elements are in the following order: Cr > Sr > Pb > Ni > Mo. Aluminum, iron, manganese, and zinc were found in the highest amounts in kidney samples, followed by liver and heart samples, and in the lowest concentrations in chest muscles. Besides, Ahmed *et al*. (2017) investigated the influence of batteries and deep litter raising techniques on the concentration levels of cadmium, copper, lead, and zinc in quail meat and offal in Ismailia, Egypt. A total of 40 quail meat and offal samples were randomly taken from two main quail rearing systems: battery (Group I) and deep litter (Group II) to determine cadmium, copper, lead, and zinc content levels. In addition, 80 water and feed samples were obtained at random from both systems' water and feeders in the Food Hygiene Laboratory, Faculty of Veterinary Medicine, Suez Canal University for heavy metals analysis. Cadmium, copper, lead, and zinc concentrations were 0.010, 0.027, 1.137, and 0.516 ppm in Group I and 0.093, 0.832, 0.601, and 1.651 ppm in Group II, respectively. Cadmium, copper, lead, and zinc concentrations in quail feed were 1.114, 1.606, 5.822, and 35.11 ppm in Group I and 3.010, 2.576, 5.852, and 23.616 ppm in Group II, respectively. Cadmium, copper, lead, and zinc concentrations in quail meat were 0.058, 5.902, 10.244, and 290 ppm in Group I and 0.086, 6.092, 0.136, and 1.280 ppm in Group II, respectively. Cadmium, copper, lead, and zinc concentrations in liver samples in Group I were 0.15, 8.32, 1.05, and 3.41 ppm, respectively, and 0.13, 8.88, 0.95, and 4.21 ppm in Group II. Cadmium, copper, lead, and zinc concentrations in kidney samples were 0.24, 4.21, 1.96, and 4.03 ppm in Group I and 0.20, 5.00, 1.56, and 3.78 ppm in Group II, respectively. Heavy metal concentrations were highest in the kidney, next in the liver, and finally in the muscles. Copper concentrations in liver samples were found to be the highest. The amounts of these trace elements obtained from the four different quail organs are in the following order: Ca > Pb > Zn > Cu. Lead and cadmium concentration levels in quail meat samples surpassed Egyptian standardization guidelines, implying a health risk to quail consumers from lead and cadmium. In terms of heavy metals pollution of water and quail meals, the authors determined that the battery raising approach is more sanitary than the deep litter system. The mean concentration levels of lead in feed samples from the battery system were not substantially higher ($p>0.05$) than those in feed samples from the deep litter system. Meanwhile, water samples from the battery system exhibited considerably higher mean concentration levels of cadmium, copper, and zinc ($p>0.05$) than samples from the deep litter system. Consumers may be exposed to health concerns if they ingest quail. Moreover, Darwish *et al*. (2018) determined the residual amounts of four hazardous metals, including Cd, Pb, As, and Ni in the edible tissues of quails in this study. Furthermore, metal loads in water, feed, and litter samples collected from the same quail farms were assessed as prospective sources of quail exposure to heavy metals. The potential use of metallothionein (MT) and heat shock protein 70 (Hsp70) as molecular indicators of heavy metal exposure was examined further. Furthermore, the food intake and prospective risk assessment of the heavy metals studied were computed for children and adults. Quail edible tissues contained significant quantities of four heavy metals (contents (ppm/ww) ranging from 0.02 to 0.32 in Cd, 0.05 to 1.96 in Pb, 0.002 to 0.32 in As, and 1.17 to 3.94 in Ni), which matched to high concentrations of these metals in feeds, water, and litter. The expression of MT and Hsp70 mRNAs correlated with heavy metal concentrations in organs, suggesting that these proteins could be used as biomarkers for quail exposure to harmful metals. Dietary consumption of quail meat and risk evaluation revealed possible concerns, particularly for youngsters, after long-term exposure to the metals under consideration.

## Chicken

After nitric acid/perchloric acid digestion, the concentrations of iron (Fe), copper (Cu), zinc (Zn), , manganese (Mn),Cd, Pb, and Cr in chicken meat, chicken gizzard, and turkey meat consumed in southern Nigeria were determined using graphite furnace atomic absorption spectrophotometry. The elements in chicken meat, chicken gizzard, and turkey meat were arranged as follows: Fe>Zn>Ni>Cu>Cr>Pb>Cd>Mn. The element concentrations were as follows: 23.59-97.72 $mg.kg^{-1}$, Fe; 0.01-5.15 $mg.kg^{-1}$, Cu; 4.95-48.23 $mg.kg^{-1}$, Zn; 0.13-7.93 $mg.kg^{-1}$, Ni; 0.01-1.37 $mg.kg^{-1}$, Mn; 0.01-5.68 $mg.kg^{-1}$, Cd; 0.01-4.60 $mg.kg^{-1}$, Pb; and 0.01-3.43 $mg.kg^{-1}$, Cr. Iron, manganese, copper, and zinc concentrations were below the allowable limits, whereas cadmium, nickel, chromium, and lead concentrations in some samples were over the allowable limits. The body load with these elements is highly dependent on the concentration of the various elements in primary sources of animal protein, notably turkey meat, chicken meat, and gizzard, the frequency of ingestion of these meals, and the pace of detoxification in the human body (Iwegbue *et al*., 2008).

In Taiwan, after graphite block digestion, trace elements and heavy metals were identified in chicken and animal flesh using inductively coupled plasma mass spectrometry. Beef (20), mutton (20), hog (30), chicken (30), duck (10) and goose (10) samples were acquired from Taiwanese markets. Mn, Co, As, Se, Mo, Cd, Sb, and Pb concentrations in beef samples were 0.106-0.365 g/g, 0.002-0.033 g/g, 0.005-0.035 g/g, 0.108-0.349 g/g, 0.029-0.140 g/g, 0.002-0.003 g/g, 0.002-0.004 g/g, and 0.009-0.046 g/g, respectively. Arsenic levels were higher in pig and chicken than in other meats. Lead amounts in duck were greater. The risk assessment based on these data did not show any threat to public health (Chen *et al*., 2013).

Abduljaleel (2014) carried out a probabilistic risk analysis method to quantify trace elements bioaccumulation in chicken liver, gizzard, and lung content to assess the range of exposures for the people who consume the contaminated chicken. The concentrations of Al (aluminum), Mn (manganese), Cu (copper), Co (cobalt), and Zn (zinc) were measured using inductively coupled plasma mass spectrometry (ICP-MS), using the stock standard solution of heavy metals and blank sample. Results show the contents of elements in bird tissues samples were in the range of (18.68-62.24, 1.6-18.6, 0.12-0.61, 2.12-24.95, 35.10-93.85 µg/g for Al, Mn, Co, Cu, and Zn respectively. A risk assessment on human health beings due to consumption of chicken was performed using toxic reference benchmark, namely the reference dose (RfD). The hazard index (HI), sum of the hazard quotients calculated for all pollutants have shown that the risks of fowls' consumption were generally low and are within safe limits. Lead, Cd, Al, and Ni concentrations were determined in poultry muscle and liver using ZEEnit 700P Atomic Absorption Spectrophotometer with Graphite Furness. Mean concentrations of Pb and Cd in poultry muscle and liver exceeded the maximum tolerable limit set by the European communities. However, Al and Ni concentrations were below the guideline limits. According to the Egyptian standardization, only 33% and 66% of liver and muscle samples from Assiut exceeded the limit, respectively. The estimated weekly and daily intakes in the examined samples were below the FAO/WHO Guidelines limits. Meanwhile, Target Hazard Quotients (THQ) and

Hazard Index (HI) were calculated to estimate the human health risk of Egyptian population. In this study, THQ and HI were more than 1 for Cd when compared with their reference dose (RfD) in poultry edibles from both Assiut and Qena. The study emphasizes the potential public health risk of Cd contamination from poultry consumption to the local inhabitants in Egypt (Mahmoud and Abdel-Mohsein, 2015). Heavy metals of concern because they have negative health consequences, such as As, Cd, copper (Cu), iron (Fe), Pb, and Hg, are poisonous due to their buildup in biological tissues. To determine the residual content of chicken flesh, 400 samples (100 of each) were randomly gathered from Elkharga chicken butchers in Egypt's New Valley governorate. Arsenic levels in the breast, thigh, liver, and gizzard samples were 0.36 0.02 g/g, 0.49 0.01 g/g, 0.77 0.06 g/g, and 0.85 0.05, respectively. While the mean cadmium readings were 00.03 0.01 g/g, 0.04 0.02 g/g, 0.05 0.03 g/g, and 0.02 0.01 g/g. Copper residues had mean levels of 0.15 0.012 g/g, 0.26 0.008 g/g, 1.16 0.008 g/g, and 0.35 0.003 g/g, respectively. The mean iron readings were 6.77 0.24 g/g, 7.49 0.18 g/g, 9.36 2.96 g/g, and 5.85 1.85 g/g, respectively. Lead residues had mean levels of 0.25 0.008 g/g, 0.26 0.016 g/g, 0.31 0.017 g/g, and 0.30 0.017 g/g, while mercury residues had mean values of 0.19 0.008 g/g, 0.20 0.016 g/g, 0.34 0.017 g/g, and 0.28 0.017 g/g. All of the samples evaluated fell within the limits established by the Egyptian Organization for Standardization and Quality Control (Elsharawy and Elsharawy, 2015). The concentrations of Fe, Cu, Zn, Mn, Se, Co, Cr, Pb, Cd, and Ni in chicken meat and meat products, feed, and litter, as well as laying hens' eggs, feed, and litter, to monitor market quality and safety for human consumption as judged by recommended daily allowance (RDA) and tolerable upper levels. The most popular poultry products in Saudi Arabia were chosen as samples. From the same brand, 45 broiler samples of frozen or fresh meat, liver, burger, or frankfurter were chosen. In addition, 60 table eggs from four commercial brands were gathered, and the edible sections of these eggs were tested for mineral and hazardous element levels. In addition, 30 feed and litter samples from broiler and laying hen starter, grower and layer diets were collected. The findings revealed that the majority of trace elements and heavy metals were present in significant concentrations in the various beef sources. Furthermore, the liver had the most elements, with the exception of Cr, Co, and Ni. The highest Cr level was found in fresh beef, followed by frozen meat. Trace elements (Mn and Co) as well as heavy metals (Ni and Pb) were not detected in either frozen or fresh beef. Except for Zn and Mn, which were in higher amounts in the frankfurter, the chicken burger and frankfurter had identical trace-element and heavy-metal levels. Except for Cr, the liver had the highest heavy metal level, indicating that Pb and Cd intake was beyond the recommended daily limit (RDA) for adults. The meat items had greater Pb, Cd, and Ni levels than the grill meat and table eggs, indicating that they constituted a health risk to humans, and their Pb intake was higher than the RDA (Korish and Attia, 2020).

In Pakistan, heavy metal concentrations (Cadmium, Lead, Copper, Nickel, and Zinc) were detected in Poultry fowl *Gallus domesticus* from chosen areas in Karachi, Hyderabad, and Thatta, all in the province of Sindh. A total of 135 poultry organs (liver and flesh) and blood were obtained at random from chickens weighing 1.2 to 1.5 kg and aged 8-10 weeks. Atomic Absorption Spectroscopy was used to detect five heavy metals in the samples. Cadmium, lead, nickel, zinc, and copper were all detected in all samples. Except in Karachi, where Ni and Pb levels above the maximum allowable limits in liver, meat, and blood, the levels detected in the samples were below the WHO, FAO, and ANZFA recommended limits. The concentrations of Ni and Pb in liver and meat, but not in blood, surpassed the allowed limits in the Hyderabad samples. Ni and Pb levels in liver and beef, but not blood, exceeded the allowable limits in Thatta city samples. The current investigation found that heavy metal contamination are derived from unsanitary poultry feed material (Khan *et al*., 2015). Chicken meat and hen eggs are widely consumed around the world as curries, fast food, processed meals, and so on, implying a promising source of protein. The concentrations of Pb, Cd, Cr, As, Hg, Mn, Fe, and Zn in nationally representative samples of chicken meat and hen egg were determined to be 0.03-2.73, 0.01-0.015, 0.025-0.67, 0.04-0.06, 0.01-0.015, 0.15-0.63, 2.50-38.6, and 1.02-19.4 mg/kg-fw, respectively, in the current study. Only Pb surpassed the maximum permissible limit (MAC) for dietary food, according to the findings. Multivariate statistical studies revealed that anthropogenic activities were the primary source of heavy metals in the foods tested. The estimated daily intake (EDI), non-carcinogenic risk of individual heavy metal by target hazard quotient (THQ), total target hazard quotient (TTHQ) for combined metals, and carcinogenic risk (CR) for lifetime exposure were used to assess the human health risks associated with the dietary intake of these metals through the consumption of chicken meat and hen egg. The computed levels of EDI, THQ, TTHQ, and CR were below their respective allowed standards, indicating that the investigated foodstuffs were safe to consume in terms of heavy metal contamination (Ullah *et al*., 2022).

## Ducks

In Thailand, Aendo *et al*. (2019) determined the levels of Pb, Cd, Co, and Cr in duck eggs and meat, as well as the risk of carcinogenic and non-carcinogenic effects produced by consumption of duck products gathered in Thailand. The design of the USEPA standard focuses on Estimated Daily Intake (EDI), Incremental Lifetime Cancer Risk (ILCR), Target Hazard Quotient (THQ), and Total Target Hazard Quotient (TTHQ) is referred to as human health risk assessment. In this investigation, 98% of the duck egg samples were contaminated with Pb, with the average level generally exceeding the statutory limit. Heavy metal EDI assessment in children was the highest for all metals in eggs. Pb, Cd, and Cr ILCR levels in eggs and meat consumption were higher than 104 in children, adults, males, and females. When children consumed tainted duck eggs, their risk was 3.9 times that of adults for Pb, Cd, and Cr. This research implies that the absorption of these carcinogenic heavy metals through eggs increases the risk of cancer, particularly for youngsters, who have a larger risk than adults. The computation of THQ if consuming heavy metals contaminated duck eggs and meat in human exposure (70 years) could lead to the conclusion that THQ male was higher than female for all metals. However, the TTHQ calculations for Pb, Cd, Co, and Cr contamination in a duck egg and meat scenario for adults, males, and females were all less than one, indicating that there was no risk, however there could be unfavourable health impacts. This study advised that youngsters, specifically males, should be the focus of long-term surveillance to assess the carcinogenicity of these metals.

In China, As, Cd, Cr, Cu, Hg, Ni, and Pb levels were measured in 1066 fresh meat samples from Zhejiang province in southeast China, comprising pig, beef, mutton, chicken, and duck. As, Cd, Cr, Cu, Hg, Ni, and Pb levels were 0.018, 0.002, 0.061, 0.801, 0.0038, 0.055, and 0.029 mg/kg wet weight, respectively. There are significant positive correlations between Cd, Hg, and Pb (P 0.05) and significant negative correlations between Cu-Pb or Cu-Cd ($P<0.05$). The exposure assessment revealed that ingesting these meat products posed a comparatively low health risk to humans. However, given their intensive industrial activity, routine monitoring of heavy metals in meat products is still suggested (Han *et al*., 2022).

In Indonesia, duck flesh is a protein source for humans and can be used to detect heavy metal contamination. This study used cross-sectional analytic research to examine heavy metal contamination in duck flesh. Water, feed, and duck flesh (thigh and chest) samples were collected at random from intensive duck farming in Central Java, Indonesia. The metal content was measured and analyzed using Inductively Coupled Plasma (ICP-OES) and the manufacturer's protocol. Six acceptable heavy metals (Ag, Al, Cr, Cu, Ni, Sr) were identified in water, feed, and duck flesh, with the highest concentrations being Al and Cu, at 0.98 0.025 ppm and 0.68 0.117 ppm, respectively. Fe and Zn, two necessary heavy elements, were discovered in duck meat. Hg contamination was identified in Semarang duck meat (5.54 0.01 ppm), followed by Magelang (4.84 0.00 ppm) and Salatiga (4.56 0.00 ppm). All five water samples were contaminated with As, Hg, Cd, and Pb levels that exceeded the national threshold. The presence of Hg in meat correlates with the content of Hg in water ($p = 0.002$) and feed ($p = 0.02$) and effects both ($R2 = 0.788$; $p<0.05$). The accumulation of water and feed consumption is the best source of heavy metal contamination in duck meat. As a result, farmers must pay careful attention to duck feed in order to achieve meat safety.

## CONCLUSION

This review indicates that despite being a rich source of essential amino acids, and plenty of nutrients, poultry meat might act as a potential source for human exposure to toxic heavy metals.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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