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Metal Toxicity Found in Foodstuffs: A Review

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Annotation: Contamination of foods by heavy metals has a number of different sources. The most significant ones are: contamination of the soil from which foods are produced; residual muds; chemical fertilizers and pesticides used in agriculture; the use of other materials; etc. Since this contamination has so many different sources, there is a wide range of foods contaminated by heavy metals, including products of plant origin (cereals, rice, wheat, edible roots, mushrooms, etc.) as well as foods of animal origin (fish, crustaceans, mollusks). In particular, fish is one of the products most affected by heavy metal contamination, because heavy metals are bioaccumulative in the food chain. When heavy metals accumulate in waters, fish ingest them through their diet and accumulate them over the course of their lives. The heavy metals then reach the consumer when that fish is consumed.

Keywords: heavy metals, foods, toxicity, contamination, agriculture, fish, wide range.

Introduction

Many high-density metals are not especially toxic. Several of them are actually essential elements for human beings, though at certain concentrations they may be toxic in some of their forms. However, there is a series of elements that, regardless of their form, could represent a major environmental problem. These are commonly referred to with the generic term “heavy metals.” The danger of heavy metals is especially severe, because they are not chemically or biologically degradable. Once released into the environment, principally due to industrial or mining activities, they can remain for hundreds of years, polluting the soil and accumulating in plants and organic tissues. Moreover, their concentration in living beings increases as they move up the food chain. Among the most significant heavy metals from the point of view of health are mercury, lead, cadmium, nickel, and zinc. Some intermediate elements such as arsenic and aluminum, which are highly relevant from a toxicological point of view, are generally studied together with heavy metals.[1,2]

Mercury (Hg). Mercury is considered to be a highly toxic heavy metal. It can be present naturally in metallic form (as mercury), or in the form of mercury salts. Mercury is highly volatile; when it is present in the air, we can breathe it in through our lungs or absorb it through our skin. The most dangerous form of exposure is inhaled mercury, since it enters our body, accumulates, and remains for a long time. One thing that should be borne in mind is that mercury ought not be present in the food chain at all. It is not a natural element in foods. But it can enter our bodies through fish, because fish consume large quantities of mercury, which is one of the most prevalent heavy metals in seas and rivers. Mercury can also enter our bodies through plant and animal products, given that it travels and accumulates in the soil. Such mercury

is generated by human activities, for instance: mining, foundries, agricultural fertilizers, wastewater discharge, and the burning of solid waste.[3,4]

Lead (Pb). Lead is a metal often used in residential installations and in metal alloys or chemicals, such as pipes, the manufacturing of paints, putties, and pesticides. It is one of the heavy metals that can most easily contaminate us. Lead is extremely harmful to health. It is one of the heavy metals that has caused the most harm to the population. Lead enters the body through vegetables, meat, fruits, seafood, and wine (among many other foods contaminated with heavy metals). Tobacco smoke is another pollutant with a high concentration of lead.

Cadmium (Cd). Cadmium (in its majority) comes from zinc refining processes. It is a residual or a by-product of zinc. Cadmium is mainly present in the earth's crust and is strongly absorbed by the organic material that forms the soil. This fact itself poses the greatest danger, because such cadmium deposits, absorbed by the soil's organic material, pass into plants, and often form a part of human or animal diets in the form of hazardous heavy metals. The foods that are potentially most susceptible to cadmium contamination are mushrooms, shellfish, freshwater fish, dried algae, and potable water, among others. Smokers (those who actively smoke and those who breathe in second-hand smoke) are heavily exposed to cadmium, as are people who live near waste dumps or factories that release cadmium into the atmosphere. Workers at metal refineries can also be exposed to cadmium and other heavy metals.

Copper (Cu). Copper is a mineral of great importance for the development of human life. Care should be taken to include this element in one's diet, but in its rightful measure. In high doses, copper is considered a heavy metal and provokes severe health disorders, such as anemia, stomach problems, and harm to the kidneys and the liver. Copper is prevalent in our homes in pipes and cookware. From there, it passes into water and cooked foods. Copper is massively used in industry, which is why exposure to copper has become much higher than normal. A curious tidbit of information is that when tea is consumed in excess, if copper is not included in the diet, a person could suffer from copper deficiency, which causes extreme fatigue.[5,6]

Chromium (Cr). Chromium is a heavy metal whose principle means of absorption is contact with the skin. Overexposure to chromium can also occur through diet and breathing, though less frequently. Chromium VI can alter the genetic material of cells and cause cancer. Chromium III is an essential element for human life in small quantities. In fact, chromium deficiencies can cause metabolic disorders, heart problems, diabetes, etc. However, in concentrations that are too high, it can cause severe liver problems, kidney problems, problems in nerve tissues, and circulatory problems. Skin irritations and ulcers also occur. The greatest concentration of chromium is found in water and plant-based foods. Although Chromium III is necessary for life, the way foods are prepared or stored can alter Chromium content, increasing its concentration. This is highly dangerous for health, since heavy metals are involved.

Nickel (Ni). Nickel in its rightful measure is a metal highly necessary for life, an essential mineral for the formation of red blood cells. But when we inhale, ingest, or absorb it in excess, nickel can become extremely toxic (depending upon the quantity), affecting our lungs, larynx, and nose, and can also compromise the prostate and the heart. Nickel is a metal used in steel alloys and is also present in very low amounts in the environment and the food chain. Nickel poisoning or contamination would require a very high consumption of this element. Such poisoning tends to occur when foods are grown in highly contaminated soils, on account of which large amounts of heavy metals pass into the food chain.

Selenium (Se). Selenium is another metal that occurs naturally. It is very important for our bodies in its rightful measure. In foods, this fundamental element for life is found in meat and cereals. Natural foods usually contain the quantities that the body needs to avoid selenium deficiencies, which are associated

with several health problems, among them, erectile dysfunctions. Overexposure to selenium can be considered a form of heavy metal contamination.

We can be exposed to selenium poisoning in the same way as occurs with other metals: by ingesting food that contains selenium in excess amounts due to contaminated soils and/or waters, by inhaling selenium-contaminated air, ingesting water, or through the skin. Overexposure to selenium can occur in places where people work with paint, in the metal industry, or when selenium is released into the atmosphere through the burning of coal or oil.[7,8]

Aluminum and Arsenic. At times, when discussing heavy metal contamination, mention is also made of lighter elements, such as arsenic or aluminum. Aluminum is an element whose specific weight on the periodic table is not greater than 5 g/cm³ and whose atomic number is not greater than 20 (it does not have sufficient density to be called “heavy”). However, due to aluminum’s toxicity, it is included as one of the heavy metals on some lists of toxins. We should not lose sight of the fact that aluminum is quite abundant in nature, only surpassed by oxygen. Arsenic is the most common cause of acute heavy metal poisoning in adults. Arsenic is not a metal, but a metalloid (which basically means that it has both metallic and non-metallic properties). It is released into the environment by industrial processing of chemicals and glasses, and reaches water supplies throughout the world, creating exposure for marine life.

The **FDA** actively supervises heavy metal levels in food supplies. The FDA is taking a systematic approach to reducing risks posed by these metals, especially for vulnerable populations such as infants and children, who are the most susceptible to some of their harmful neurological and developmental effects.

Metals, like other naturally occurring elements, enter our food supply through our air, water and soil. The levels found in food depend on many factors, including:

- the levels of these elements in the air, water and soil used to grow the crops, which vary depending on factors such as natural geographical differences and past or current contamination,
- the type of the food crop and how much “uptake” there is of specific elements from the environment, and
- industrial, manufacturing, and agricultural processes.

In addition, some metals that are beneficial to health, such as iron, are intentionally added to certain foods, including breakfast cereals and infant formulas, to enhance their dietary benefits.

The properties of specific metals, the amount of intake, and a person’s age and developmental stage are all key factors that help determine how a metal affects individual health. Understanding the risk that harmful metals pose in our food supply is complicated by the fact that exposure to metals comes from many different foods. Combining all of the foods we eat, even low levels of harmful metals from individual food sources, can sometimes add up to a level of concern.

To help protect the safety of the food supply, the FDA monitors, tests, and sets standards for metals in foods, animal feed and in cosmetics. When the level of metals is determined to be unsafe, the FDA uses its authority to take action on a case-by-case basis.[9,10]

The agency’s Toxic Elements Working Group (TEWG) aims to reduce exposure to toxic elements in food, cosmetics and dietary supplements. The group is made up of senior leaders and risk managers in the Center for Food Safety and Applied Nutrition (CFSAN) with experience in microbiology, toxicology, chemistry, medicine, epidemiology, policy and law. Working with scientists across the Center, the group is tackling the issues presented by metals using the following approach:

➤ **Prioritizing metals by toxicity and prevalence** – The group is looking at the presence of metals in all products CFSAN regulates and identifying the areas where the FDA can have the greatest impact on reducing exposures. The workgroup is focusing first on: lead, arsenic, cadmium, and mercury in foods, cosmetics, and dietary supplements, because high levels of exposure to those metals are likely to have the most significant impact on public health.

Essential to prioritization is studying the large amount of data we have collected over the years. The FDA has been collecting data on contaminants and nutrients in foods for decades as part of its Total Diet Study. The study routinely samples products found in grocery stores from across the country, testing them for hundreds of contaminants, including these metals. These data are important because they can help us better understand how consumers are exposed to these contaminants.

➤ **Identifying most vulnerable populations** – People vulnerable to the harmful effects of metals in food include infants and children, the elderly, and consumers who may have chronic health conditions. As the agency works to reduce consumer exposure to metals through foods and other products, we are paying special attention to children because their smaller body sizes and metabolism may make them more susceptible to the harmful effects of these metals. Of particular concern is the effect these metals have on children's neurological development.

The FDA released Closer to Zero, the agency's action plan for reducing toxic elements (metals) in the foods eaten by babies and young children.

➤ **Determining effective ways to reduce exposure** –The FDA is committed to using the best available science to inform and support policy decisions on toxic metals. FDA will consider a wide range of policies and actions to reduce exposure, ranging from requiring or encouraging industry to take steps to reduce the presence of the metals in products to educating consumers about ways they can reduce the risks posed by these metals.

The FDA monitors levels of metals and other elements in food and food contact surfaces to inform and enforce FDA rules and guidance. The FDA tests for metals and other elements through the Total Diet Study; the FDA's Toxic Elements in Food and Foodware; and Radionuclides in Food compliance program; and through targeted sampling assignments. Sampling assignments may be conducted in response to reports of elevated levels of toxic metals or other elements in certain foods or to focus on a specific food, food additive, or specific food group (such as foods commonly eaten by infants and toddlers).[11,12]

Metals Tested for in FDA's Total Diet Study

Metals with Daily Intake Requirements	Metals that are Harmful to Health
Calcium, Chromium, Copper, Iron, Magnesium, Manganese, Molybdenum, Potassium, Sodium, Zinc	Aluminum*, Antimony*, Arsenic, Barium*, Beryllium*, Cadmium, Lead, Mercury, Silver*, Strontium, Nickel, Thallium*, Uranium, Vanadium *Tested in bottled drinking water only

The naturally occurring elements widely distributed in our environment, having high atomic mass and five times denser than water, are known as heavy metals. As a result of different human activities like industrial, agricultural, and domestic, metal toxicity is enhanced day by day. Some of these metals pose a severe threat to the human body, even if these are present in lower quantities, such as aluminum (Al), chromium (Cr), arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb). These metals are therefore referred as human carcinogens according to USEPA because they damage the organs in the human body

as a result of their non-degradable nature, capacity to accumulate, and having prolonged biological half-lives. There are many routes through which metallic pollutants can enter the human body, namely, inhalation, ingestion, dietary intake, and dermal contact. The uptake of these metals by food items including vegetables, fruits, from soil, and water depends upon many factors like species of vegetables, bioavailability and nature of soil, i.e., pH, cation exchange capacity, and carbon content. Meat like beef, fish, and goat may also be contaminated by metals by utilizing polluted water, unauthenticated feed, and fodder grown on contaminated soil and irrigated with polluted water.

Geo-accumulation index (Igeo), contamination factor (CF), and potential ecological risk index (PERI) have prime importance to evaluate the pattern of contamination and determine the potential risk due to exposure to ecological sensitivity, concentration and toxicity of metals in soil and water. Information about dietary intake of metals is also equally important for assessing their potential risk to human health, so estimated daily intake (EDI), non-carcinogenic target hazard quotient (THQ) and carcinogenic risk (THQ) coefficients are needed to demonstrate to evaluate the human health risk.

This Special Issue aims to invite original research and review articles which analyze water, food items including vegetables, fruits (dry fruits), meat (beef, fish, and goat) by advanced analytical techniques like thermally atomized atomic absorption spectrometry (AAS-TA) in solid state, inductively coupled plasma-optical emission/mass spectrometry (ICP-OES/MS). There is also the green methodology for sample preparation like ultrasound assisted extraction using probe and/or bath, microwave oven extraction, speciation of metals like Cr, and As by complexation or conversion of lower state to higher oxidation state, then assessment of human health risk by calculating Igeo, CF, PERI, EDI, THQ, and THQ.[13,14]

Discussion

Metals exist all around us. They occur naturally in the environment and can be found in a variety of food sources. Many metals pose no threat to health but certain heavy metals—ie. ones that are literally heavy, dense, and found in the Earth's crust—have been associated with a range of illnesses in children and adults.

The four main heavy metals that can cause health issues are mercury, lead, arsenic, and cadmium. The U.S. Food & Drug Administration monitors levels of these "big four" heavy metals in food and drinking water, but some sources inevitably fall through the cracks. (Take the high levels of lead in the water in Flint, Michigan, for example.) Here are four sources of heavy metals to look out for and avoid consuming in high doses.

1. Mercury in fish.

There are health benefits to eating seafood, but some fish contain high levels of the heavy metal mercury. Mercury should be of special concern for pregnant women and breastfeeding mothers, who can pass the heavy metals along to their babies.

In 2016, the Environmental Working Group performed an analysis of pregnant women who eat fish to examine their exposure to mercury. They measured mercury levels in hair samples of 254 women eating about as much fish as the U.S. government recommends for pregnant mothers. About 30 percent of women had mercury levels over the safe limit set by the EPA, considered too high for pregnant women. Using even stricter limits recommended by other experts, the researchers found that 60 percent of women had excessive mercury levels in their hair. Frequent fish eaters had 11 times more mercury than a group who rarely ate fish.

Whether you're pregnant or not, you'll want to avoid eating mercury-laden fish. Generally, smaller fish that are lower down on the food chain—such as sardines, anchovies, and mackerel—tend to be lower in

heavy metals. Larger fish such as shark, swordfish, tuna, sea bass, halibut, and marlin tend to accumulate more mercury from the ocean over time and should be avoided in high quantities.[15,16]

2. Lead in bone broth.

Bone broth is a popular ingredient thought to lower inflammation, nourish skin, and promote gastrointestinal health. However, when animals (and humans) are exposed to certain metals—particularly lead—they often store it within bone materials.

Not much research has looked into heavy metals in bone broth. There was one small (and non-peer reviewed) 2013 study measured the levels of lead in broth made from the bones of organic chickens. The broth was found to have “markedly high lead concentrations” compared to water cooked in the same cookware.

This isn't to say you should avoid bone broth altogether, but like with anything else, consume it in moderation. I am unaware of any commercially available bone broth or collagen powder that test for lead levels.

3. Cadmium and heavy metals in e-cigarettes.

Cadmium is a toxic heavy metal that has been linked to increased risk of certain cancers. Cigarette smoking, in particular, is known to expose people to high levels of cadmium.

More recently, cadmium has also been identified in e-cigarettes. A 2019 study found concentrations of other heavy metals (such as lead and copper) in certain vapors produced by e-cigarettes too. Some states like California are looking to label these products as potentially carcinogenic, similar to the labeling required in Canada.

4. Arsenic in rice.

Exposure to inorganic arsenic has been linked to heart disease, kidney disease, brain disease, and diabetes. Unfortunately, rice is really efficient at absorbing arsenic from pesticide-laden soil, irrigation water, and even cooking water.

Young children tend to be at a higher risk for arsenic exposure and the FDA cautions that rice formulas should not be the only source, or even the first source, of nutrition for an infant. Barley, multigrain, and oats are preferred nutrition sources.[17,18]

Adults buying rice can refer to this Consumer Reports resource to find grains that are less likely to contain heavy metals. One key takeaway: "White basmati rice from California, India, and Pakistan, and sushi rice from the U.S. on average has half of the inorganic-arsenic amount of most other types of rice."

The bottom line.

While not all metals are dangerous, some can harm human health. The big four to look out for are mercury, lead, arsenic, and cadmium. Eating a varied diet that isn't too high in fish, bone broth, or rice; filtering your water; and buying organic food when you can should help you steer clear of them.

Heavy metal poisoning is the accumulation of various heavy metals in your body. Environmental and industrial factors expose you to high levels of heavy metals every day, including the foods you eat and air you breathe.

Some of these metals — such as zinc, copper, and iron — are good for you in small amounts. But overexposure can lead to heavy metal poisoning, such as what occurs in Wilson's disease. This can be fatal.

Depending on your level of exposure, medications given intravenously under medical supervision can remove these toxins. These medications bind to the metals, a process called chelation. Your doctor will test your blood, urine, and hair to measure metals toxicity.

In addition to chelation, you might consider a natural complementary therapy, such as a “heavy metal detox.” However, most of these treatments aren’t backed by research. There are some dietary options which incorporate foods that electrically attract metal to help move it out of your body, though.

Results

Symptoms of heavy metal poisoning

Long-term exposure to metals can be toxic, causing harmful side effects that range from headaches to organ damage. It’s important that you seek medical treatment if you have heavy metal toxicity.

Symptoms of heavy metal toxicity vary depending on the type of metal you’re overexposed to. Mercury, lead, arsenic and cadmium are some of the more common overexposed metals.

Acute symptoms associated with these metals include:

- headaches
- abdominal pain and cramping
- nausea
- vomiting
- diarrhea
- fatigue
- difficulty breathing

In more severe cases of chronic heavy metal poisoning, you may experience symptoms including:

- burning and tingling sensations
- chronic infections
- brain fog
- visual disturbances
- insomnia
- paralysis

Good and bad foods for heavy metal exposure

Many people get a buildup of heavy metals in their system because of the foods they eat. Some studies suggest you can prevent overexposure to these toxins by avoiding certain foods. Eating other foods known for taking heavy metals out of the system may also help.

Foods to eat

Some foods can help you detoxify by getting rid of heavy metals from your body. These foods bind to the metals Trusted Source and remove them in the digestive process.

Eating foods high in vitamins and minerals can have protective effects for those exposed to heavy metals.[19,20]

Heavy metal detox foods to eat include:

- cilantro
- garlic
- wild blueberries
- lemon water
- spirulina
- chlorella
- barley grass juice powder
- Atlantic dulse
- curry
- green tea
- tomatoes
- probiotics

Also, if you aren't getting the recommended daily intake of vitamins, consider taking supplements.

Vitamin B, B-6, and C deficiencies are associated with Trusted Source poor tolerance of heavy metals and easier toxicity. Vitamin C has been reported to have chelating effects on iron. In one animal study, B-1 supplements were shown to decrease iron levels.

The U.S. Food and Drug Administration doesn't monitor the purity or quality of supplements like they do for drugs. Also talk to your doctor before trying a supplement to make sure it won't interact with any medications you're currently taking.

Foods to avoid

An effective heavy metal detox includes more than incorporating healthy fruits and vegetables. To minimize the effects of heavy metal poisoning or prevent it altogether, you need to eliminate some foods from your diet.

This is especially true for processed foods and excess fats. These foods have minimal nutritional value and slow down the detox process. This is because fats tend to soak up the harmful substances you want to remove.

Some foods to limit or avoid in your heavy metal detox diet include:

- rice (brown rice, specifically) because it often contains arsenic
- some fish, such as larger and long-living fish, as they tend to contain more mercury
- alcohol
- nonorganic foods

Outlook for this condition

Heavy metal poisoning can trigger a number of harmful side effects. If left untreated, it can be life-threatening. Follow through with any recommended medical treatment. Talk to your doctor about how dietary changes can help protect you from heavy metal overexposure.

It takes time to detox and safely remove metal toxicity from your body, but it's possible. Before participating in the heavy metal detox diet, consult with your doctor or dietician to discuss your options.[21,22]

Implications

Detecting Heavy Metals in Food and Beverages

Arsenic, Cadmium, Mercury, Lead and Other Heavy Metal Exposures

The insidious thing about heavy metal food poisoning is that toxic levels can be built up over a long time from a wide variety of sources. Whether it be from arsenic, cadmium, mercury, lead, or others, symptoms present themselves only late in the exposure. With no single geographic or species source of contamination, typically low concentrations in any given food, and people's varied diets, it is more important to avoid even minute contaminations in food sources. Because of this prolonged trace exposure, regular high-sensitivity testing for these metals is essential in key points of the food supply chain. As a result, the global trend is for increased frequency of testing.

Despite the regularity by which the major food and beverage agencies like the World Health Organization (WHO), United States Food and Drug Administration (USFDA), European Commission (EC-EFSA), China Food and Drug Administration (CFDA), and Food Safety and Standards Authority of India (FSSAI) regulate heavy metals in consumer products and feed, long-term safety remains a question of exposure levels (concentration over time).

The challenge is that "heavy" metals (usually classified as possessing a density greater than 3.7 g/cm³) are found at typically nonhazardous levels in a wide variety of food types and geographies. However, significant single, or short-time exposures have been increasingly reported and global concern for increased health risk is rising. A recent US Consumer Reports analysis (Hirsch, 2018) of 50 nationally distributed, packaged baby foods found that all 50 products had at least one of the more health damaging metals (cadmium, inorganic arsenic, or lead). Further, about 68 percent of tested products had at least one heavy metal in seriously high levels and fifteen would pose potential health risks to children if exposed with one or less servings per day. Even organic foods afforded no better protection from heavy metal exposure in the study.[23]

Heavy Metal Testing Reagents, Standards, and Water

Recent advances in analytical technologies have allowed much improved sensitivity, efficiency and availability of heavy metal testing globally. Three of the most commonly used technologies involve the use of either atomic absorption spectrophotometry (AAS), inductively coupled plasma-optical emission spectroscopy (ICP-OES), or inductively coupled plasma-mass spectrometry (ICP-MS); vast improvements over older, colorimetric techniques. These modern techniques are pushing the limits of sensitivity for heavy metal detection but can be significantly influenced by sample matrix, and require extensive operational training, high-quality reagents and purified water.

We are committed to advancing global heavy metal detection by providing Millipore[®] expertise in matrix sample preparation, Milli-Q[®] lab water solutions, and Supelco[®] analytical reagents for reliable, precise chemical analysis with modern analytical techniques, improved lab efficiency, and regulatory knowledge across the food supply chain.

Conclusions

Heavy metal toxicity is becoming increasingly prevalent in today's society. Everyday we are exposed to hundreds of toxic metals in our food, toiletries, cleaning products and in our environment. While the body requires small amounts of metal for nutritional purposes, high volumes resulting from constant exposure

make it difficult for the body to process. As a result, heavy metals accumulate in the soft tissues and slowly poison the body's systems. In the world of natural healing, a more common approach to rid the body of heavy metal toxicity or any other health issue is to go on intense short term "Detox Programs". However, I always recommend a "Detoxifying Lifestyle". The following lifestyle changes are essential to not just remove unwanted excess metal from the body but also prevent it from being consumed in the first place.

The most commonly encountered heavy metals include aluminum, arsenic, cadmium, iron, lead, mercury and nickel. These mostly come from fertilisers and insecticides, tobacco smoke, metal containers including food cans, aluminum foil, some pharmaceutical drugs, aerated drinks, margarine, refined flour and table salt often contain aluminum, cosmetics, hair products, antiperspirants containing aluminum (especially aerosol sprays), toothpaste, aluminum cookware and the list goes on and on.[24]

Lifestyle Changes

- Use a water filter: A good quality water filter will help to remove chlorine and heavy metals. Wash your fruits and vegetables with filtered water to avoid any heavy metal residues. Limit your intake of processed foods and refined foods - Refined and processed foods are a major source of metal poisoning,
- Avoid canned foods Canned foods can contain metals, especially if the cans have been damaged.
- Eat your essential fatty acids Essential fatty acids such as flaxseed oil help to lessen the effect of metal poisoning on your brain.
- Eat foods high in vitamin C and E Vitamin C and E rich foods (citrus fruit, dark leafy greens, etc) help to leach out toxic metals from your body.
- Eat foods high in selenium Selenium also helps to leach toxic metals from your body. Brazil nuts are a great source of selenium.
- Go organic! Buy organically grown produce when you can.
- Do not use aluminum cookware. Read the labels on all products you buy and if you don't understand it, look it up![25,26]

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