

Systematic Review of Quantification of the Aluminum Content Leached into Fish Processed Using Aluminum Foil

Ewangulu Ovyé Ezekiel ^{1,2}; Moses Zira Zaruwa ¹; Titilayo Oluwayemisi Bamidele ¹; Chibuzor Carole Nweze ¹; and Ogunnodi Olanrewaju Collins ¹

¹Department of Biochemistry, Faculty of Natural and Applied Sciences, Nasarawa State University, Keffi, PMB 1022 Keffi, Nasarawa State, Nigeria. ²Department of Biochemistry, College of Biological Sciences, Joseph Sarwuan Tarka University, Makurdi, PMB 2373, Makurdi, Benue State, Nigeria.

Corresponding author: ewangulu.ovye@uam.edu.ng

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Abstract

Aluminum (Al) is extensively used in many industrial sectors, including those dealing with transportation, electricity, machinery, equipment, food processing, packaging, storage, and a wide range of home appliances. Aluminium foil can leach metals into fish during processing, potentially creating health implications, particularly when aluminum foil is used during processing. Objectives include: 1) To summarize reported concentrations of aluminum in raw and processed fish, 2) To compare aluminum contents across different processing techniques, 3) To examine the influence of processing factors such as time and temperature on aluminum leaching, and 4) To identify knowledge gaps and future research needs. This review is built on seven (7) published studies on the quantification of aluminum content leached into fish under different conditions. A systematic search of Google Scholar, ScienceDirect, PubMed, and Scopus identified seven studies for use. Aluminum concentrations varied widely across studies by authors as reviewed. Techniques, which include Atomic Absorption Spectrophotometry (AAS), Inductively Coupled Plasma-Optical Emission Spectrophotometry (ICP-OES), UV-Vis Spectroscopy, and an inductively coupled plasma mass spectrometer, were employed. AAS technique reported aluminum concentration ranging from <0.001-0.130 mg/kg, ICP-MS technique reported a range of 0.54-6.0 mg/kg, whereas ICP-OES technique reported a range from below the quantification limit (BLQ) to 42 mg/kg. Most studies reviewed have Al concentrations within the Provisional Tolerable Weekly Intake of 2 mg/kg body weight, while two studies reported higher concentrations. Concentration below the limit of quantification is represented as (BLQ). Time and temperature affect Al leaching in processed fish.

Keywords: Aluminum Foil, Food Contamination, Food Processing, Concentration, AAS, ICP-OES.

Introduction

Food safety and quality can be evaluated by carrying out food chemical analysis, and this has necessitated precise information on food chemical composition (Medana, 2020). Aluminum (Al) is the third most prevalent element in the Earth's crust by weight (Sjögren *et al.*, 2015). Approximately 75% of aluminum is used for packaging food, cosmetics, chemical production and also present in daily life for instance as an ingredient in cosmetic,

drugs and creams (Deshwal & Panjagari, 2020). Consequently, the habit of wrapping meat and fish with Al foil before baking, grilling, and roasting results in leaching Al into the food due to different stimulants (Deshwal & Panjagari, 2020). When Al packages come into contact with drinks or liquids with high acidity, Al leaches into the food (Klotz *et al.*, 2017). In addition, aluminium is intrinsically present in many natural foods like vegetables, fruits, cocoa, and cereal products (Niu, 2023).

Numerous studies have explored how elements migrate from aluminum cookware into food (Mona *et al.*, 2025). The extent of this migration is influenced by several factors, such as the quality and composition of the pot, the type of food being cooked, and the cooking conditions, including temperature and duration (Alabi *et al.*, 2021).

Aluminum utensils are manufactured from waste metals and recycled aluminum-containing alloys in underdeveloped nations. A number of toxic compounds, including heavy metals like cadmium, lead, nickel, arsenic, copper, and aluminum, have been documented to leach into cooked food as a result of such impurities present in the utensils, which could accelerate the dissolving of metal. Aluminum's relatively low bio-availability made it generally recognized as safe (GRAS) for human health for a very long time.

Smoking or roasting fish using aluminum foil has become a common practice in many countries of the world due to its ability to transmit heat, easy to handle and impermeable to gases (Al Juhaiman, 2015). The use of aluminum foil with fish and meat in smoking helps protect them against direct heat effect and prevent moisture loss. But unfortunately, due to many reasons, most persons get exposed to and ingest more than what our bodies can handle. The increase rate of diseases of the kidneys, lungs and several others in and around Keffi community has made many people to suspect change in attitude especially the use of foil wrappers as one of the likely predisposers of these ailments (Izah *et al.*, 2016).

The consistent accumulation of contaminated fish above the heavy metals' acceptable limits in the human body can cause serious health issues. At levels above the permissible standard of the human body due to repetitive and consistent ingestion, these ingested metals can endanger human health over-time. Toxicologically, excessive aluminum burden is associated with oxidative stress, which involves higher levels of reactive oxygen species and related damage to lipids, proteins, and DNA. It can cause adverse effects in organs that tend to accumulate aluminum, such as bones and kidneys, especially in individuals with impaired renal excretion. Clinical summaries and mechanistic reviews document issues like anemia, bone disease, and neurological effects in cases of severe or chronic aluminum overload (Rahimzadeh *et al.*, 2022; Jackson *et al.*, 2024). Because aluminum can be released from contaminated or recycled cookware along with other toxic metals like lead and cadmium, and since lead and cadmium are known for their neurodevelopmental, cardiovascular, and renal toxicities, the presence of multiple metals raises public health concerns (Charkiewicz & Backstrand, 2023). Among these, aluminum poses the most significant health risk when ingested in large quantities, and linked to neurotoxicity and other health issues (Vlasak *et al.*, 2024; Przybysz *et al.*, 2024).

The presence of other metals, like trivalent chromium, which leaches in small concentrations, has also been taken note of, though it is less of a concern due to its low carcinogenic potential (Fermo *et al.*, 2020).

Based on toxicological research and exposure, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established a Provisional Tolerable Weekly Intake (PTWI) for (Al) of 7 mg/kg body weight (bw) in 1990. In 2008, the JECFA reexamined the safety of aluminum and reduced the PTWI to 1 mg/kg bw due to the possibility that aluminum could damage the nervous and reproductive systems of experimental animals. But in 2011, the Committee added a new modification that included a suggested PTWI of 2 mg/kg bw in response to additional bioavailability and toxicological information (EL Daouk *et al.*, 2022). PTWI is an estimate of the amount of a chemical that can be ingested over a lifetime without appreciable risk.

The most commonly used methods of aluminum measurement are Flame Atomic Absorption Spectrometry (FAAS), Graphite-Furnace Atomic Absorption Spectrometry (GFAAS), Inductively Coupled Plasma-Optical/atomic Emission Spectrometry (ICP-OES/AES) or inductively coupled plasma mass spectrometry (ICP-MS). These methods provide a high selectivity, with low detection limits (0.1 mg/kg or lower) (Khanhuathon *et al.*, 2015).

The concentrations of this metal in food and drink have been increasing over time due to the acidification of the soils that transfers the aluminum from the soil to the aquatic environment. Diet is the main exposure route to metals. Aluminum is found in different drinks and foods such as drinking water, processed foods, where it is used as additives and as a result of the packaging used and even in fresh foods as vegetables and fruits because of the aluminum contained in the soils (Hardisson, 2017). Aluminum cookware, such as drink containers, coffee pots, grill pans, pressure cookers as well as foil used as wrappers, is one of the potential sources of extra dietary Al. The intake of Al from food and drinking water is low, especially compared with that consumed by people taking Al-containing medicinal preparations (Fanni & Faa, 2015).

Al enters into human body through drinking water, food, cooking utensils, and pharmaceuticals (Yildiz *et al.*, 2017). The Council of Europe recommends a specific release limit (SRL) of 5 mg/kg food for aluminum from food contact materials on metals and alloys used in food contact materials, and could be a cause for serious concern when higher concentrations are ingested (WHO/FAO, 2014).

Statement of the Problem

Aluminum is widely used in the food sector for the production of packaging and containers that are in contact with food, and it is recognized that the release of Al from the packaging into the foodstuff represents a risk (Deshwal & Panjagari, 2020). The release of aluminum into the environment can arise from both human activities and natural processes such as weathering of rocks (Hizli *et al.*, 2023). Aluminum is known to get into the environment through the natural weathering of rocks and minerals containing aluminum (Shetty *et al.*,

2021). Igbokwe *et al.*, 2019 reported that it has been observed that natural processes may release higher volumes of aluminum into the environment when compared to anthropogenic activities.

Aluminum contamination and toxicity levels are ongoing societal concerns due to the adverse impacts on human health regardless of cooking method, e.g frying, boiling, roasting (Ertl & Goessler, 2018). Concerns about aluminum's safety in humans have been raised as a result of its cooking utensils which are made using recycled aluminum, and sold at lower prices than those made by anodized aluminum commonly used in developing countries. Due to their poor quality, research has shown their use results in elevated aluminum leaching into food (Prasad *et al.*, 2022).

Exposures to aluminum may occur to workers working in scrap metal recycling firms and in natural minerals processing plants. Study has also reported that people handling aluminum metal get exposed to poisoning during cutting, filing, sawing, and welding. Lastly, communities and animals living in areas contaminated by waste from industries can also be exposed to aluminium (Farhat *et al.*, 2020). Exposure of aluminum to human beings results in bioaccumulation in human organs such as the liver and brain with detrimental consequences. Exposure to aluminum compromises bone structure, central nervous, and hematopoietic systems (Bryliński *et al.*, 2023).

This review underlines the importance for further study to unravel safe usage guidelines for aluminum foil in food preparation.

Aim

The aim of this review was to synthesize studies on quantification of the aluminum content leached into fish processed using aluminum foil.

Specific Objectives

1. To summarize reported concentrations of aluminum in raw and processed fish
2. To compare aluminum contents across different processing techniques
3. To examine the influence of processing factors such as time, and temperatures on aluminum leaching
4. To identify knowledge gap and future research needs

Literature Search Strategy and Data Extraction

Regarding the review, a systematic literature research was conducted using Google Scholar, Scopus, ScienceDirect, and PubMed for the identification of relevant studies that report aluminum concentration in fish.

The search employed combination of keywords which include Aluminum content, Aluminum foil, Aluminum leak, PTWI, Food toxicity, fishes, Analysis, Wrapped food, Concentration. The information used in the review consists of the studies published from the gap that covers between 2015 and 2025. Only studies that reported clearly the

quantitative aluminum contents in fish, investigated raw or processed, and sufficiently provided methodological information on aluminum determination were reviewed.

The information extracted include Zaruwa *et al.*, 2020, in which catfish were processed by roasting and aluminum content was quantified using Atomic Absorption Spectrophotometry (AAS); Joseph *et al.*, 2025, also used catfish processed by grilling, and AAS analytical method was employed for the quantification of aluminum content. Fermo *et al.*, 2020, no specification of the fish type used, and oven was used as the processing technique, after which Inductively Coupled Plasma-Optical Emission Spectrophotometry (ICP-OES) was the analytical method employed for Al content quantification. Dordevic *et al.*, 2019 and Suhendan & Safak., 2020 used salmon and sea brass respectively and both used Inductively coupled plasma mass spectrometer for quantification. Yokel, (2025) used Rosefish and mackerel, and ICP-OES technique was used for quantification.

Comparison across studies were made only by having the units the same (mg/kg). Data were built descriptively and summarized in tables to show trends across analytical techniques, processing techniques, and processing factors.

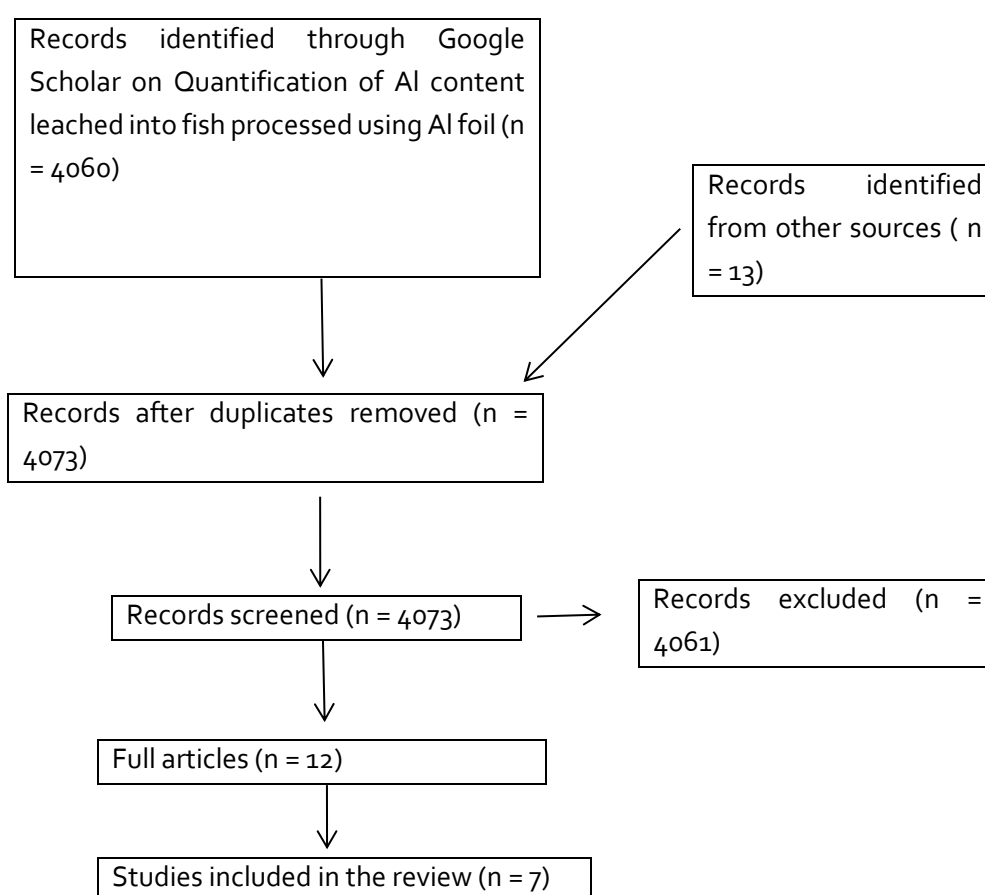


Figure 1: PRISMA flow chart of the procedure used to select the articles included in this review

The search combinations is on the quantification of the aluminum content leached into fish processed using aluminum foil.

Results and Discussion

Results

Table 1: Concentration (mg/kg) of Aluminum Content Leached into Fish Samples

Author	Fish type	Condition	Al (mg/kg)	Analytical method
Zaruwa <i>et al.</i> , 2020	Catfish	Raw	0.130	AAS
Zaruwa <i>et al.</i> , 2020	Catfish	Roasting	0.110	AAS
Joseph <i>et al.</i> , 2025	Catfish	Raw	<0.001	AAS
Joseph <i>et al.</i> , 2025	Catfish	Grilling	0.008	AAS
Fermo <i>et al.</i> , 2020	Fish	Oven without foil	BLQ	ICP-OES
Fermo <i>et al.</i> , 2020	Fish	Oven, foil, no seasoning	13	ICP-OES
Fermo <i>et al.</i> , 2020	Fish	Oven, foil, seasoning	42	ICP-OES
Hardisson <i>et al.</i> , 2017	Fish	Raw	0.40	ICP-OES
Dordevic <i>et al.</i> , 2019	Salmon	Raw	0.54	ICP-MS
Dordevic <i>et al.</i> , 2019	Salmon	Dry	1.31	ICP-MS
Suhendan & Safak., 2020	Sea brass	Raw	5.3	ICP-MS
Suhendan & Safak., 2020	Sea brass	Grilling	6.0	ICP-MS
Yokel, (2025)	Rosefish	Raw	0.947	ICP-OES
Yokel, (2025)	Mackerel	Raw	1.81	ICP-OES

BQL = Below limit of quantification

Table 2: Effect of Time on Aluminum Content Leached During Fish Processing

Author	Fish type	Analytical Method	Time (Min)	Al (mg/kg)
Al Juhaiman, 2015	Fish	UV-Vis spectroscopy	30 - 60	38.67 - 78.19
Hussein & Al-Janabi, 2021	Food	AAS	5 - 120	4 - 14
Inan-Eroglu <i>et al.</i> , 2019	Salmon	ICP-MS	40	8 - 30
Inan-Eroglu <i>et al.</i> , 2019	Haddock	ICP-MS	40	35 - 41
Inan-Eroglu <i>et al.</i> , 2019	Salmon	ICP-MS	20	18 - 20
Inan-Eroglu <i>et al.</i> , 2019	Haddock	ICP-MS	20	19 - 31
Khaled & Hala., 2007	Redmeat	AAS	20	33.60
Sadettin, (2006)	Raw beef	AAS	40	38.27

Table 3: Effect of Temperature on Aluminum Content Leached During Fish Processing

Author	Fish type	Analytical Method	T (°C)	Al (mg/kg)
Al Juhaiman, 2015	Fish	UV-Vis spectroscopy	160-220	48.35 - 154.04
Hussein & Al-Janabi, 2021	Food	AAS	60-95	4 - 12
Inan-Eroglu et al., 2019	Salmon	ICP-MS	150	8 - 30
Inan-Eroglu et al., 2019	Haddock	ICP-MS	150	35-41
Inan-Eroglu et al., 2019	Salmon	ICP-MS	200	18 - 20
Inan-Eroglu et al., 2019	Haddock	ICP-MS	200	19 - 31
Khaled & Hala., 2007	Redmeat	AAS	150	24.50
Khaled & Hala., 2007	Redmeat	AAS	200	28.67
Sadettin, (2006)	Raw beef	AAS	150	30.99

Discussion

The reviewed data in table 1 above shows difference in levels of concentration of aluminum determined from fish. In view of the scope of this review work, the following observations were made.

Across the reviewed studies, aluminum concentrations in fish varied widely depending on processing technique and analytical method employed. Reported values ranges from <0.001-42 mg/kg, with higher concentrations generally observed in processed fish as compared with raw fish. As in table 1 above, studies using AAS analytical technique reported aluminum concentration ranging from <0.001 to 0.130 mg/kg, ICP-MS technique reported a range of 0.54-6.0 mg/kg, whereas ICP-OES technique reported a range from below the quantification limit to 42 mg/kg.

Studies by Zaruwa *et al.*, 2020; Joseph *et al.*, 2025; Yokel, (2025); Hardisson *et al.*, 2017; and Dordevic *et al.*, 2019 of different conditions analyzed using different techniques have Al concentrations within Provisional Tolerable Weekly Intake (PTWI) of 2 mg/kg body weight established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), while that of Fermo *et al.*, 2020 and Suhendan & Safak., 2020 also of different conditions analyzed using different techniques have Al concentrations above PTWI of 2 mg/kg body weight except for that of Fermo *et al.*, 2020 processed without foil wrapper in which Al concentration was below the limit of quantification. The variation in leaching levels among the different samples may be attributed to differences in the alloy composition, surface finish, or manufacturing processes of the cookers (Hussein & Al-Janabi, 2021).

Highest concentration of aluminum was typically examined by authors in fish oven-dried in aluminum foil with seasoning, while that oven-dried without aluminum foil was below the limit of quantification. The consistent detection of high aluminum levels across all samples

underscores the reactivity of aluminum in acidic conditions, which is a common scenario in cooking acidic environments (Hussein & Al-Janabi, 2021). Al leaching may have occurred from the foil wrapper due to temperature as suggested by earlier report of (Tesfaye, 2015). This probably could be why the concentration of Al in fish oven-dried without wrapping in foil was below the limit of quantification compared with that oven-dried in aluminum foil with seasoning, because the heat applied would trigger a chemical reaction resulting in the breakdown of various organic compounds (Al Juhaiman, 2015; Inan-Eroglu *et al.*, 2019). The fact still remains that, if Al exceeds the acceptable limits from daily ingestion of food, cooked in utensils containing these elements, coupled with other sources from the environment, diseases such as loss of memory, damage to central nervous system, dementia, severe trembling, and several other ailments will be observed (Jabeen *et al.*, 2016).

Furthermore, difference in reported aluminum concentrations shows not only processing techniques but also specific factors such as time, temperature, and area of exposure of fish. Across the reviewed studies in table 2, processing time ranges from 20-120 min, while aluminum concentration ranges from 4-78.19 mg/kg. Highest concentration of Al was recorded in study by Al Juhaiman, 2015, using UV-Vis spectroscopy while least concentration was examined in the study by Hussein & Al-Janabi, 2021, using Atomic Absorption Spectrophotometry (AAS). Mohammad *et al.*, 2012 and Al Juhaiman, 2012 reported that longer cooking time elevates the leaching of aluminum in all food solutions used in their studies. Heating of aluminum cookware increased the rate of Al migration to cooked food (Alasfar & Isaifan, 2021; Ertl & Goessler, 2018).

Also, regarding the effect of temperature in the leaching of Al during processing, table 3 shows that across the studies, temperature ranges from 60-220°C, while aluminum concentration ranges from 4-154.04 mg/kg. Highest aluminum concentration was recorded in the study by Al Juhaiman, 2015, using UV-Vis spectroscopy while least concentration was examined in the study by Hussein & Al-Janabi, 2021, using Atomic Absorption Spectrophotometry (AAS). The increase in cooking temperature causes more leaching. As the temperature increases, the molecules move faster and therefore aluminum contaminates food more frequently (Al Zubaidy *et al.*, 2011). The leaching is also highly dependent on the pH value of the food solution, salt, and spices added to the food solutions.

Conclusion

Although based on the review, aluminum foil did not leach significant amounts of aluminum (Al) into the fish in most of the studies, which as a result recorded Al concentrations within the Provisional Tolerable Weekly Intake (PTWI) suggested in the 2011 JECFA report.

The increase in cooking temperature causes more leaching. The leaching is also highly dependent on the pH value of the food solution, salt, and spices added to the food solutions. Also, increase in cooking time resulted to increase in the Al concentration.

Aluminum foil used in cooking provides an easy channel for the metal to enter the human body. Al enters into human body through drinking water, food, cooking utensils, and

pharmaceuticals Exposure of Al from fish samples may be dangerous to vulnerable groups such as children, elderly and people with kidney disease. Consistent aluminum intake even in small quantity over a long period of time could sum up to amount considered harmful to human health.

Recommendations

The anodization process and coating of aluminium using plastic material helps minimize the leaching of metals into food. Avoiding use of aluminium cookware worn out by scratching which removes a protective layer of aluminium oxide, exposing aluminium to leaching into food.

It would be better that fish species be cooked and consumed fresh without processing with aluminum foil. Also, it is certainly worth emphasizing the need to comply with the quantity of aluminum intake as recommended by the international institutions. Furthermore, the use of earthenware while cooking is highly recommended compared to aluminum cookware. Finally, it is recommended that further research work should be carried out on the part this study did not cover such as cooking with acidic and salty dishes.

Conflicts of Interest

All authors reviewed and have no conflict of interest to declare.

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