Cooking vessels are a post-harvest contamination pathway that can add lead, cadmium, nickel, chromium, and aluminium to food independent of the raw ingredient's cleanliness

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Abstract

Five independent studies from five countries (Pakistan, Saudi Arabia, Iraq, Nigeria, and Thailand) converge on a single point that is not captured by ingredient-level heavy-metal testing: the vessel a food is cooked in can itself be a source of lead, cadmium, nickel, chromium, and aluminium, transferring those metals into the food at the cooking step regardless of how clean the raw ingredient was. Sultan et al. 2023 (Pakistan) measured lead migration from new non-anodized aluminium cookware into 4% acetic acid rising from 1.52 mg/L at 0.5 h to 5.66 mg/L at 2 h, and lead of 1.20 ppm in meat cooked for 1 h in that cookware. Alrajhi and Idriss 2021 (Saudi Arabia) detected lead of 0.099 to 0.184 mg/L and arsenic of 0.012 to 0.164 mg/L released into distilled water boiled 30 min in imported aluminium pots. Mahdi et al. 2024 (Iraq) found that the same cut of meat cooked in different vessels ended up with different metal loads, reaching cadmium of 0.4 ppm from a Teflon-coated pan and lead of 1.0 ppm from an iron pot. These three sources establish the transfer directly.

1 | Overview

The pathway is conditional rather than universal, and the evidence is honest about that conditionality. Two of the five studies act as boundary conditions. Abdulrasheed et al. 2026 (Nigeria) found that informally manufactured cookware contained very high total metal (a single sample reached 439 mg/kg lead and 578 mg/kg nickel), yet released none of it above a 0.01 mg/L detection limit when only distilled water was boiled in it, which shows that high total content does not by itself predict transfer under mild conditions. Rittirong and Saenboonruang 2018 (Thailand) cooked rice in five vessel types and four water chemistries and found no substantial increase in

metal content relative to raw grain under their tested design. Read together, the five sources support a specific, well-supported claim: acidic matrices, longer cooking times, degraded or informally manufactured vessels, and specific vessel materials are what drive metal transfer, while neutral short-contact cooking of a low-affinity matrix transfers little. The synthesis is not that all cookware contaminates all food; it is that cookware is a real and quantified contamination variable that ingredient-level testing does not observe, so a clean ingredient can still yield a contaminated meal.

2 | The Pakistan leaching signal (Sultan et al. 2023)

Sultan et al. 2023, published in Toxics (CC BY), is the most complete of the five because it measures both the vessel content and the transfer under multiple controlled conditions. The authors analyzed 30 locally purchased Pakistani cookware items (non-anodized aluminium n=8, anodized aluminium n=8, stainless steel n=7, copper n=7) by X-ray fluorescence, then ran leaching experiments in 4% acetic acid, 0.5 N sodium bicarbonate, distilled water, and cooked meat, with atomic absorption spectrophotometry on the leachates.

The vessel-content values, reported in g/kg, are high: lead was 3.20 g/kg in non-anodized aluminium cookware, 4.64 g/kg in anodized aluminium, 0.88 g/kg in stainless steel, and 2.90 g/kg in copper cookware. The transfer numbers are the load-bearing finding. In 4% acetic acid, new non-anodized aluminium cookware released lead of 1.52 mg/L at 0.5 h, 3.22 mg/L at 1 h, and 5.66 mg/L at 2 h, with cadmium rising from 0.11 to 0.30 mg/L over the same interval. The acid-and-time dependence is explicit: neutral distilled-water leaching from the same new non-anodized aluminium was far lower at 0.002, 0.003, and 0.005 mg/L over 0.5, 1, and 2 h. Cooking meat for 1 h produced lead of 1.20 ppm from new non-anodized aluminium cookware and 0.40 ppm from new anodized aluminium, establishing that the transfer occurs in a real food matrix and not only in a laboratory acid. Anodization reduced but did not eliminate release. The study reports total elemental metals; chromium is total chromium from XRF and AAS, and no Cr-VI, methylmercury, or arsenic speciation is inferred. The paper also reported blood-serum metals in local participants (lead 1.32 mg/L, cadmium 0.51 mg/L, nickel 2.17 mg/L, aluminium 13.34 mg/L), but did not isolate cookware as the sole exposure route, so those biomonitoring values are exposure context rather than attributable dose.

3 | The Saudi Arabia migration signal (Alrajhi and Idriss 2021)

Alrajhi and Idriss 2021, published in Revista Internacional de Contaminacion Ambiental, provides the largest cookware sample of the five and isolates migration into water. The authors purchased 46 imported metallic aluminium cookware items from a Riyadh market, boiled 0.9 L distilled water for 30 min at 100 degrees C in each, and analyzed the remaining water by ICP-OES for ten elements. The reported release order was Mn > Al > Pb = As > Fe > Zn > Cu = Ni = Cd > Cr.

Lead was detected in the range 0.099 to 0.184 mg/L among detected samples, and arsenic in the range 0.012 to 0.164 mg/L, both from distilled-water boiling with no added acid. Cadmium was detected in 10.86% of samples. Aluminium in the reported rows ranged from 0.010 to 1.910 mg/L, nickel from 0.002 to 0.213 mg/L, and chromium from 0.001 to 0.017 mg/L (average 0.002 mg/L). The finding that matters for the synthesis is that lead and arsenic migrated into neutral boiling water from imported low-cost cookware, which is a milder condition than the acetic-acid test in Sultan et al. and yet still produced detectable lead near or above 0.1 mg/L in a subset of items. Because the matrix was distilled water rather than food, these are migration values under a defined contact condition, not food-occurrence values; the study does not establish how much of this transfers to any particular meal. The measured element set includes total arsenic, not speciated inorganic arsenic.

4 | The Iraq utensil-comparison signal (Mahdi et al. 2024)

Mahdi et al. 2024, published in Samarra Journal of Pure and Applied Science (CC BY 4.0), is the cleanest demonstration of the core counterintuitive point because it holds the ingredient constant and varies only the vessel. The authors bought meat in Tikrit, cut it into roughly 2 cm pieces, cooked it in six vessel materials (clay, iron, copper, aluminium, Tefal/Teflon, and glass/Pyrex), and measured iron, zinc, copper, cadmium, lead, and aluminium by atomic absorption, reporting results in ppm in the cooked meat.

The same starting meat ended with materially different metal loads depending only on the pot. Cadmium in the cooked meat was 0.4 ppm from the Teflon-coated pan, 0.20 ppm from the aluminium pot, 0.06 ppm from copper, 0.03 ppm from clay, 0.02 ppm from glass, and 0.005 ppm from iron, an approximately 80-fold spread driven by vessel choice alone. Lead was highest from the iron pot at 1.0 ppm, then glass at 0.90 ppm, copper at 0.70 ppm, and aluminium at 0.60 ppm. Aluminium in the cooked meat reached 2.0 ppm from the aluminium pot versus 0.007 ppm from clay. The study did not separate vessel-derived metal from any metal already present in the source meat, and it did not report brand or meat-origin detail, so the absolute values carry that caveat; but because the design varies only the vessel, the between-vessel differences are attributable to the vessel. This is the direct evidence that vessel identity is a determinant of the metal content of the finished food.

5 | The Nigeria informal-manufacturing signal, and its null leachate (Abdulrasheed et al. 2026)

Abdulrasheed et al. 2026, published in BMC Chemistry (CC BY-NC-ND), documents the supply-chain end of the pathway and simultaneously supplies one of the study set's two boundary conditions. The authors measured Mn, Pb, Cr, Cd, and Ni in four informally manufactured cookware samples from Saki, Oyo State, along with six moulding materials and seventeen manufacturing-site soils, by flame atomic absorption after EPA 3050B digestion.

The total metal content of the informal cookware was high and variable: mean lead was 136 mg/kg (sample range 18.4 to 439 mg/kg), mean nickel 181 mg/kg (range 33.3 to 578 mg/kg), mean chromium 26.9 mg/kg, and mean cadmium 1.70 mg/kg (range 0.30 to 5.45 mg/kg). The moulding inputs point to recycled sources: a battery material contained 1004 mg/kg lead and 11.5 mg/kg cadmium, consistent with lead-acid battery scrap entering informal casting. This supports the disproportionate-risk half of the thesis, that informal and recycled-metal cookware carries a larger reservoir of transferable metal. The boundary condition is the leaching result: when 500 mL distilled water was boiled in the cookware for 1, 2, and 3 h, Mn, Cr, Cd, Ni, and Pb were all below the 0.01 mg/L detection limit, so no leachate was tabulated. High total content did not produce detectable neutral-water transfer in this study. The authors explicitly note that acidic or salty foods could increase metal mobility, which is exactly the condition (acetic acid) under which Sultan et al. did observe large lead release. The Nigeria and Pakistan results are therefore consistent rather than contradictory: they describe the same reservoir under different extraction chemistries.

6 | The Thailand null, reported honestly (Rittirong and Saenboonruang 2018)

Rittirong and Saenboonruang 2018, published in Emirates Journal of Food and Agriculture, is the study that most constrains the thesis and is included precisely because it does. The authors cooked Thai-market white rice under five vessel conditions (new aluminium cooker, used aluminium cooker, Teflon-coated aluminium, stainless steel, glass beaker) and four water conditions (tap, de-ionized, acidic, basic), then quantified aluminium and seven heavy metals by ICP-MS, comparing cooked to raw rice by t-test at $p < 0.05$.

They found no strong indication that the tested vessels substantially raised metal concentrations relative to raw grain: raw-rice aluminium was 76.50 mg/kg versus cooked-rice aluminium 76.83 mg/kg, and raw-rice zinc 22.86 mg/kg versus cooked 22.43 mg/kg, differences that are negligible. The reported element order was Al > Zn > Fe > Pb approximately Cu > Cr > As approximately Cd. This is a genuine contradiction of a naive "all cookware always contaminates" reading, and it should not be softened. The most parsimonious reconciliation is matrix-and-condition dependence: rice cooked largely in near-neutral water for a bounded time is a low-transfer scenario, matching the neutral-water null in both Abdulrasheed et al. and the neutral arm of Sultan et al., and unlike the acetic-acid and cooked-meat arms where transfer was large. The study still identified lead, arsenic, aluminium, and cadmium as the dominant contributors to its calculated hazard index of 9.18 and total cancer risk of 2.45 x 10^-2, but attributed that to the rice itself rather than to vessel transfer. The values are on a dried cooked-rice basis, not wet ready-to-eat rice, and the arsenic is total arsenic, not inorganic. Rittirong et al. sets the correct ceiling on the claim: vessel transfer is real but is not guaranteed for every food and every cooking condition.

7 | The mechanistic explanation

Metal transfer from a cooking vessel to food is a corrosion-and-dissolution process governed by the vessel's surface chemistry, the food's aggressiveness, the contact time, and the temperature. The dominant variable across these five studies is the acidity of the cooking matrix. Sultan et al. quantified this within a single vessel: new non-anodized aluminium released roughly a thousand times more lead into 4% acetic acid than into distilled water over the same 2 h. Organic acids in food (acetic acid in vinegar and tomato, citric acid in citrus, lactic acid in fermented foods) solubilize surface metal oxides and expose fresh metal, so acidic and long-cooked dishes extract the most. Time compounds this, as the monotonic 0.5 to 2 h rise in Sultan et al. shows. Temperature and boiling accelerate it, which is why even the neutral-water migration in Alrajhi and Idriss was detectable after 30 min at 100 degrees C.

Vessel identity and integrity are the second axis. Mahdi et al. showed that vessel material selects which metal enters the food: copper vessels raised copper, aluminium vessels raised aluminium, iron vessels raised lead, and Teflon and aluminium vessels raised cadmium. Sultan et al. showed that anodization of aluminium roughly halved lead release relative to non-anodized, and that old degraded cookware released more than new under neutral water (an old non-anodized aluminium pot released lead of 0.22 mg/L in neutral water at 1 h against 0.003 mg/L from new), because a worn or damaged protective layer exposes more reactive surface. The informal-manufacturing reservoir documented by Abdulrasheed et al. sits upstream of all of this: cookware cast from mixed recycled scrap, including lead-acid battery material, carries a far larger pool of leachable lead and cadmium than food-grade alloy, so when an aggressive matrix does extract metal, there is more of it to extract. The mechanism therefore predicts exactly the split the five studies show, with high transfer for acidic, long-cooked, or degraded-informal combinations and low transfer for neutral, short, food-grade combinations.

8 | Why ingredient-level testing does not observe this

Heavy-metal surveillance is built around the ingredient and the packaged product as sold. A sample of raw rice, raw meat, or a bottled ingredient is digested and analyzed, and the result is treated as the consumer's exposure from that food. That measurement is taken before the food ever meets a cooking vessel, so any metal contributed by the vessel at the cooking step is invisible to it by construction. The Mahdi et al. design exposes the gap most sharply: one batch of meat, tested as an ingredient, would return one lead and cadmium value, yet the same meat produced cadmium spanning 0.005 to 0.4 ppm and lead spanning roughly 0.6 to 1.0 ppm depending only on

the pot it was cooked in. An ingredient-level result cannot bound that, because the contamination is introduced downstream of the tested article.

The blind spot is widened by where this cookware is used and sold. The transfer-positive studies are concentrated in imported low-cost and informally manufactured cookware in Saudi Arabia, Pakistan, Iraq, and Nigeria, which are exactly the vessels least likely to carry food-contact-material compliance testing. A brand can source a genuinely clean ingredient, and a consumer can still receive an elevated dose because the vessel in their kitchen, or in an informal food-service kitchen, is the contamination source. This is the same structural point made in organic-certification-not-protective, where a certification that addresses agricultural inputs does not touch a contamination mechanism that operates through a different route, and it compounds with the additive-exposure logic in combined-exposure-underprotection, since vessel-derived lead and cadmium add to whatever the ingredient already carries rather than replacing it.

9 | What the evidence implies for testing, regulation, and consumption

For testing and surveillance, the load-bearing implication is that an ingredient-level or as-sold heavy-metal result does not bound the metal content of the food as eaten when the food is cooked in an aggressive matrix in a non-food-grade vessel. Where a product category's normal preparation is acidic and long-cooked (tomato-based dishes, citrus or vinegar braises, fermented preparations), the cooking step is a distinct exposure node that ingredient testing does not cover, and the appropriate position is to treat vessel-transfer as an uncharacterized variable rather than to assume it is zero. The five sources here are migration and cooked-food studies under specific conditions, not a market-representative occurrence survey of finished restaurant or home meals, so they establish that the pathway exists and is sometimes large; they do not yet establish a population-level distribution of vessel-attributable dose. That distribution is the missing piece and a candidate for a Journal of Food Metallomics synthesis.

For regulation, the pathway falls under food-contact-material controls rather than food-occurrence limits, and the transfer-positive evidence is concentrated in imported and informally manufactured cookware that sits outside effective food-contact-material enforcement in the studied markets. The evidence supports migration-limit testing of low-cost imported metal cookware for lead and cadmium under acidic conditions (the condition under which release was largest), and supports treating informally cast cookware made from recycled scrap as a lead source in its own right, consistent with the battery-derived lead documented by Abdulrasheed et al. Chromium in every source is total chromium, and no source speciated Cr-VI or inorganic arsenic, so any Cr-VI or iAs framing would be an overreach on this evidence.

For consumers, the specific and quantified guidance is as follows. Cooking acidic foods (vinegar, tomato, citrus, fermented dishes) for extended times in non-anodized aluminium, worn, or informally manufactured metal cookware can transfer lead and cadmium into the food, with Sultan et al. measuring lead rising to 5.66 mg/L in 4% acetic acid over 2 h in new non-anodized aluminium and 1.20 ppm lead in meat after 1 h. The mitigations the evidence supports are choosing anodized rather than non-anodized aluminium (roughly halved lead release in Sultan et al.), replacing visibly degraded or informally cast metal cookware (old cookware released more than new under identical neutral conditions), and avoiding prolonged cooking of acidic foods in reactive metal vessels. The evidence does not support alarm about all cooking in all vessels: neutral, short-contact cooking of a low-affinity food such as plain rice showed no substantial vessel-derived increase in Rittirong et al., and neutral-water boiling in high-content Nigerian cookware released nothing above 0.01 mg/L in Abdulrasheed et al. The risk is specific to the combination of an aggressive matrix, a long time, and a reactive or degraded vessel, and it is that combination consumers can act on.

10 | Uncertainty and what this synthesis does not yet rest on

The finding's own uncertainty is substantial and is stated here rather than hidden. First, four of the five studies are small (sample_n of 4, 6, 20, and 30 for Abdulrasheed, Mahdi, Rittirong, and Sultan respectively; only Alrajhi at 46 is larger), and none is a market-representative survey of finished meals, so no population percentile of vessel-attributable dose can be computed from them. Second, the two food-matrix studies (Mahdi in meat, Rittirong in rice) did not separate vessel-derived metal from metal already present in the source food, so their absolute cooked-food values carry that confound even though Mahdi's between-vessel differences are attributable to the vessel. Third, the studies are geographically clustered in the Middle East, South Asia, and West Africa, where low-cost and informal cookware is prevalent; they do not characterize food-grade cookware in tightly regulated markets, and the pathway's magnitude there is unquantified by this set. Fourth, the migration studies (Sultan's acid arm, Alrajhi's water arm) report leachate concentrations in mg/L against a defined volume,

not doses delivered to a specific serving, so converting them to per-meal exposure requires assumptions this synthesis does not make. Fifth, the direct contradiction in Rittirong et al. is real and is the reason the claim is scoped to conditions rather than asserted universally.

The synthesis rests on three independent A-tier sources that directly document vessel-to-food or vessel-to-water transfer (Sultan, Alrajhi, Mahdi), a fourth that documents the informal-manufacturing reservoir and the neutral-water boundary (Abdulrasheed), and a fifth that sets the low-transfer boundary for neutral cooking of a low-affinity matrix (Rittirong). Resynthesis triggers fire on the next independent source that either quantifies a population-level distribution of finished-meal vessel-attributable dose, characterizes food-grade cookware in a regulated market, or provides Cr-VI or inorganic-arsenic speciation for cookware leachate, any of which would materially extend or bound the claim.

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STATUS AND LICENCE

COMPETING INTERESTS

The Heavy Metal Index reports what the peer-reviewed and regulatory literature supports. It is operated separately from any certification program, does not evaluate or endorse brands, and does not use certification thresholds as evidence for the statements made here.

DATA AVAILABILITY

Every source behind this finding is listed with its own extraction record at https://heavymetalindex.com/synthesis/-cookware-utensil-metal-leaching-pathway#sources, each linking to the ingest receipt, the extracted values, and the file hash of the document it was built from.

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