



Research Article

Safety evaluation of potential toxic metals exposure from street-vended foods consumed in Davao City, Philippines

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Abstract Street-vended foods are a vital source of affordable nutrition in the Philippines. However, their safety is compromised by environmental contaminants. This study quantified lead (Pb), cadmium (Cd), and mercury (Hg) in popular street-vended foods, grilled chicken intestines (*isaw*), deep-fried breaded chicken eggs (*kwek-kwek*), and steamed dumplings (*siomai*), from two high-traffic markets in Davao City using atomic absorption spectroscopy. Cd was below the detection limit in all the samples. Pb and Hg exceeded the Codex Alimentarius maximum levels (Pb: 0.025 mg/kg; Hg: 0.0001 mg/kg) in up to 30% and 90% of the samples, respectively, with Hg contamination being the most prominent, particularly in steamed dumplings. Estimated daily intake calculations showed higher exposure per body weight in children, as reflected in chronic hazard indices above safety thresholds (HI >1) for children consuming grilled intestines and steamed dumplings, primarily driven by Hg exposure. The carcinogenic risks from Pb were below the acceptable limits. These findings highlight significant pediatric health risks associated with Hg exposure in street-vended foods and suggest the need for targeted vendor training, regulatory monitoring, and public health interventions. These results provide crucial evidence for food safety policies that address contamination in informal food markets without disrupting their economic role.

Keywords food safety, street-vended foods, heavy metals contamination, health risk assessment



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1. Introduction

Street-vended foods sustain over 2.5 billion people worldwide, particularly in low- and middle-income countries, where they provide affordable nutrition amid urbanization pressures (Adaku et al., 2024; Salamandane et al., 2023). However, a recent systematic review of 37 cities documented widespread heavy metal contamination in street-vended foods. Lead (Pb), cadmium (Cd), and mercury (Hg) levels in Asian and African samples frequently exceeded the Codex Alimentarius limits by 5-10 times. Traffic-related emissions, industrial dust particulates, and unsafe food handling and cooking practices are widely recognized contributors to heavy metal contamination in street-vended foods, particularly in open-air markets, where food is directly exposed to atmospheric particulates (Kabir et al., 2025). These contaminants pose chronic risks, including neurotoxicity, renal damage, and carcinogenicity, disproportionately affecting vulnerable groups such as children, whose smaller body weights amplify exposure (Balali-Mood et al., 2025; Mititelu et al., 2025; Satarug et al., 2020). Despite global recognition, regulatory gaps persist, with informal vendors operating in high-pollution zones lacking routine monitoring.

In the Philippines, street-vended foods such as *isaw* (grilled chicken intestines), *kwek-kwek* (deep-fried eggs), and *siomai* (steamed dumplings) are dietary staples for low-income urban populations. However, prior studies in Manila have largely focused on Pb contamination in grilled meats and selected staple foods, reflecting concerns regarding vehicular and environmental Pb exposure (Abdulmajid et al., 2014; Solidum, 2014). These investigations provided important baseline data, but were limited in geographic scope, typically assessed a single or limited set of metals, and did not consistently apply integrated human health risk assessment models that estimate cumulative exposure effects, particularly for children.

To date, no published studies have comprehensively evaluated multi-metal contamination and associated non-carcinogenic and carcinogenic risks of commonly consumed street-vended foods in Mindanao. Davao City, a major urban center in Mindanao with dense street markets and significant vehicular traffic, lacks local data on multi-metal contamination risks in street-vended foods (Balingit et al., 2024). This evidence gap hinders targeted food safety interventions. Therefore, this study aimed to determine the concentrations of Pb, Cd, and Hg in selected street-vended foods in Davao City and assess the associated non-carcinogenic and carcinogenic health risks among adults and children. Metal concentrations were measured using Atomic Absorption Spectroscopy (AAS), and health risks were evaluated using United States Environmental Protection Agency (USEPA) models, including Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and carcinogenic risk estimates for adults and children. The findings address this deficiency by informing policies to mitigate pediatric vulnerability while preserving the economic value of street vending.

2. Materials and methods

2.1. Study area

The study was conducted in Davao City, the regional center of the Davao Region in Mindanao, Philippines. Davao City is a highly urbanized city with a land area of approximately 2,443.61 km² and a population of approximately 1.77 million. It serves as a major commercial and food distribution hub in the Southern Philippines. The city encompasses mixed residential, commercial, and industrial

zones, with multiple administrative districts that support a dense network of formal and informal food outlets, including street-vended food markets (Develos et al., 2024).

Street-vended food samples were collected from two large high-traffic street-vended food markets in Davao City. These markets, characterized by numerous clustered stalls offering a wide variety of ready-to-eat foods in the evening, are among the primary locations where residents and visitors regularly purchase street-vended food. Targeting these markets has enabled assessment of heavy metal residues in commonly consumed street-vended items representative of local dietary exposure.

2.2. Study design and sampling

A cross-sectional quantitative descriptive-comparative design with purposive quota sampling targeted representative high-exposure consumer settings in Davao City, rather than generating city-wide prevalence estimates. Two large, high-traffic street-vended food markets were selected because of their dense vendor clustering, proximity to major roads, and high customer turnover, making the samples representative of typical worst-case exposure scenarios for frequent urban consumers (Callano, 2012). Although this approach limits the statistical representativeness of all street-vended foods in Davao City, it accurately reflects realistic exposure scenarios.

Duplicate street-vended food samples were collected from two high-traffic markets in Davao City. Three widely consumed food types, *isaw* (n=20), *kwek-kwek* (n=20), and *siomai* (n=20), were selected based on their popularity and frequent consumption patterns.

Sampling was conducted on two consecutive Fridays at 19:00 h to coincide with peak customer traffic and vendor activity, thereby capturing the typical operational conditions. Food portions were aseptically collected using sterile, labeled containers, avoiding direct hand contact, and immediately placed in insulated coolers containing ice packs to maintain a temperature of 0–4°C during transportation. The cold chain was maintained from collection to laboratory delivery to minimize microbial proliferation and prevent compositional changes that might affect heavy-metal determination.

2.3. Sample preparation and digestion

Upon arrival at the laboratory, all samples were stored at -20°C overnight prior to processing. The following day, the

samples were thawed at room temperature and sequentially rinsed with tap water and distilled water to remove any visible surface debris and extraneous particulates. This step was performed to minimize external dust contamination and better reflect the intrinsic metal content of the food matrix; however, this may underestimate actual consumer exposure because street-vended foods are typically consumed without washing. This limitation is acknowledged in the interpretation of the exposure estimates.

Each 5 g portion was then cut into smaller pieces and oven-dried at 75°C for 5 days until a constant weight was achieved, reducing the moisture content. The moisture content was calculated as the difference between the fresh and dry weights, and metal concentrations obtained on a dry-weight basis were converted to wet-weight equivalents using the corresponding moisture correction factors prior to risk assessment.

The dried material was pulverized using a clean mortar and pestle to obtain a homogeneous powder. The powdered samples were then subjected to dry ash. Initial pre-ashing was performed on a hot plate, and the temperature gradually increased to approximately 300°C under an infrared lamp until the visible smoke diminished. The residue was then transferred to a muffle furnace and ashed at 450°C for at least 8 h or until a white to grey ash was obtained, indicating near-complete removal of organic matter. The resulting ash was dissolved in 5 mL of 6 M hydrochloric acid (HCl), evaporated to near dryness in a water bath, and subsequently re-dissolved in 10-30 mL of 0.1 M nitric acid (HNO₃). The solution was stirred, covered with a watch glass, and allowed to stand for 1-2 h to ensure complete dissolution before being transferred to acid-washed plastic bottles for further instrumental analysis.

Because Hg is volatile at elevated temperatures, dry ashing at 450°C may result in a partial loss of Hg through volatilization. Consequently, the Hg concentrations reported in this study represent conservative estimates and may underestimate the minimum levels of Hg contamination in the analyzed samples.

2.4. Heavy metal determination and quality control

The concentrations of Pb, Cd, and Hg were determined using AAS with element-specific wavelengths, lamp currents, and optimized gas mixtures, according to the instrument

manual (Callano, 2012). Background correction has been applied to flameless AAS and low-concentration flame applications. Pb and Cd were analyzed using flame AAS (FAAS), while Hg was determined using graphite furnace AAS (GFAAS). For Hg analysis, the dry-ashed residue (450°C) was dissolved in 6 M HCl followed by 0.1 M HNO₃, and aliquots of this digested solution were injected directly into the GFAAS graphite tube for atomization and quantification at the Hg-specific wavelength (253.7 nm) with palladium chemical modification and Zeeman background correction. Analytical quality assurance and quality control were performed by running reagent blanks (below the limit of detection [LOD] for all metals) calibration verification standards, and duplicate digests with relative standard deviation (RSD) less than 10% for each sample batch. Method accuracy was confirmed by analyzing spiked samples with acceptable recoveries, and precision was assessed using relative standard deviation ($RSD \leq 10\%$ across triplicates). The limits of detection (LOD) and quantitation (LOQ) were as follows: Pb (0.000234 ppm), Cd (0.0003 ppm), Hg (0.000068 ppm), LOQ=(0.00078 ppm), Cd (0.001 ppm), and Hg (0.00004 ppm). All glassware and plasticware were soaked in dilute HNO₃ and rinsed with deionized water before use to minimize contamination.

2.5. Human health risk assessment

The human health risks associated with the ingestion of heavy metals (Pb, Cd, and Hg) through street-vended foods were assessed using the U.S. Environmental Protection Agency (U.S. EPA) risk assessment framework, which is widely adopted globally to evaluate carcinogenic and non-carcinogenic risks (Ekhtor et al., 2017). Standardized exposure assumptions and toxicological reference values were applied uniformly for adults and children to allow comparative risk estimation. The reference doses (RfD) used were 0.025 mg/kg/day for Pb and 0.0001 mg/kg/day for Hg, based on US EPA Integrated Risk Information System (IRIS) values. Cadmium risk indices were not computed because the measured concentrations were below the detection limits for all the samples.

2.5.1. Estimated daily intake (EDI)

The EDI of each heavy metal was calculated to account for its concentration in food, average daily consumption, and body weight using the following formula:

$$EDI = \frac{C_{\text{metal}} \times FIR}{BW_{\text{average}}}$$

where C_{metal} is the metal concentration (mg/kg), food ingestion rate (FIR) is the average daily food ingestion (kg/person), and average body weight (BW_{average}) is the average body weight (70 and 24 kg for adults and children, respectively). Because no official data exist on the daily intake of grilled *isaw*, *kwek-kwek*, *siomai* by Filipino consumers, we assumed 1 serving per day for typical consumers: (1) *isaw* (~1 stick $\approx$ 0.09 kg/day); (2) *kwek-kwek* (~1 order/1 quail egg $\approx$ 0.015 kg/day); and (3) *siomai* (~1 serving/4 pcs $\approx$ 0.1 kg/day). This conservative, locally relevant approach aligns with previous street-vended food exposure assessments (Abdulmajid et al., 2014; Ekhatior et al., 2017).

2.5.2. Non-carcinogenic risk

2.5.2.1. Target hazard quotient (THQ)

The non-carcinogenic risk of heavy metal consumption was estimated using THQ values. THQ is the ratio of the determined dose of a pollutant to the reference level that is considered harmful. THQ values were determined using the following formula:

$$THQ = \frac{Efr \times ED \times FIR \times C}{RfDo \times B_{\text{average wt}} \times ATn \times 10^{-3}}$$

where Efr is exposure frequency assumed to be 365 days year⁻¹, ED is exposure duration in 56 years equivalent to an average lifetime, FIR is average daily consumption in kg person⁻¹ day⁻¹, C is concentration of metal in food sample in mg/kg, RfDo is reference dose in mg/kg day⁻¹, and ATn is average exposure time for noncarcinogens in days.

2.5.2.2. Chronic hazard index (HI)

The HI is the sum of more than one hazard quotient for multiple toxicants or multiple exposure pathways; it was calculated using the following equation:

$$HI = \sum THQ$$

An HI greater than 1 indicates a potential health concern due to non-carcinogenic effects.

2.5.3 Carcinogenic risk

For carcinogenic risk estimation, only Pb was evaluated because an oral cancer slope factor (SF) has not been established for Hg. The oral slope factor for Pb was 0.0085 (mg/kg/day)⁻¹, based on EPA risk assessment guidance. Cumulative cancer risk represents the sum of individual food-specific risks for each population group. Cancer risk can be evaluated using

$$\text{Cancer risk} = CDI \times SF$$

where CDI is the chronic daily intake (mg/kg/day) of the carcinogenic metal, and SF is the corresponding slope factor. The cumulative cancer risk was calculated as the sum of the risks for all the carcinogenic metals assessed. Acceptable risk levels were considered within the range of 10⁻⁶ to 10⁻⁴, in accordance with EPA guidelines.

This approach enabled a quantitative assessment of both carcinogenic and non-carcinogenic risks associated with the consumption of street-vended foods contaminated with heavy metals in Davao City, thereby providing critical data to inform food safety and public health interventions.

2.6. Statistical analysis

Heavy metal concentrations are reported as the mean $\pm$ SD (mg/kg wet weight; n=20 per food type). A one-way ANOVA with Tukey's HSD post hoc test was used to assess differences in Pb and Hg levels among foods (p<0.05). Normality was verified using the Shapiro-Wilk test. Analyses were performed using IBM SPSS Statistics (version 25.0, IBM Corp., Armonk, NY, USA). The risk metrics (EDI, THQ, HI, and cancer risk) used deterministic calculations with mean concentrations and standard EPA parameters. Identical exposure frequency and ingestion assumptions were applied across age groups, with body weight and exposure duration as the only age-specific variables, ensuring consistency in the comparative risk estimation.

3. Results and discussion

3.1. Heavy metal concentrations in street-vended foods

Heavy metal analysis revealed distinct contamination patterns among the three street-vended foods commonly sold

in Davao City: *isaw*, *kwek-kwek*, *siomai*, as shown in Table 1, Cd concentrations were below the detection limit in all samples, consistent with previous findings in Philippine street-vended foods, which reported that Cd rarely exceeded residue thresholds (Abdulmajid et al., 2014; Solidum, 2014). In contrast, Pb and Hg were present in varying concentrations, with multiple samples exceeding the maximum residue limit (MRLs). The MRLs applied in this study were derived primarily from the Codex Alimentarius (CXS 193-1995) and WHO/FAO guidelines (2015). As these street-vended foods are composite/processed items without specific category limits, proxy MRLs from analogous food categories were used: for Cd (0.001 mg/kg), the stringent limit for low-Cd foods (cereals and vegetables); for Pb (0.025 mg/kg), the general limit for offal/meat products (*isaw*) and miscellaneous foods (*kwek-kwek*, *siomai*); and for Hg (0.0001 mg/kg), the methylmercury proxy for vulnerable populations and low-mercury foods. This conservative proxy approach aligns with previous Philippine street-vended food studies (Abdulmajid et al., 2014; Callano, 2012) and is consistent with international street-vended food risk assessments lacking category-specific standards. However, this standard approach to street-food risk assessments inherently introduces uncertainty that should be acknowledged when interpreting exceedance frequencies and comparative contamination levels. Pb exceeded MRLs in up to 30% of samples. In contrast, Hg exceedance rates were notably higher (80% in grilled chicken intestines and deep-fried eggs and 90% in steamed dumplings), indicating that Hg contamination was the dominant concern across all food types. Notably, *siomai* exhibited the highest proportion of samples exceeding the MRL for Hg. In contrast, the highest mean Hg concentration was observed in *kwek-kwek*. This distinction indicates that *siomai* had more frequent regulatory

exceedances, whereas *kwek-kwek* showed a higher average contamination among positive samples, highlighting the differences between exceedance frequency and mean concentration as indicators of exposure risk.

One-way ANOVA showed no statistically significant differences in Pb ($p=0.059$) or Hg ($p=0.677$) between food types, indicating common contamination sources across the two high-traffic vending environments. This uniformity suggests shared environmental exposure pathways, primarily atmospheric deposition from heavy vehicular traffic and industrial emissions near both markets, supplemented by potential cross-contamination from common raw ingredient suppliers and food contact materials (e.g., reused cooking utensils). These findings align with the contamination patterns reported in other urban street-vended food studies conducted in high-pollution zones (Ankar-Brewoo et al., 2020; Kabir et al., 2025). Additionally, the high Hg content in steamed dumplings may be derived from the sources of the ingredients, processing environments, or accumulation of contaminated raw materials. Food displayed under open-air conditions, typical of street-vended food markets in Davao, further increases the likelihood of particulate deposition.

3.2. EDI of lead and mercury

The EDI calculations presented in Table 2 show that children experienced substantially higher exposure to Pb and Hg than adults, reflecting their lower body weight and food intake. Among all food types, steamed dumplings had the highest estimated mercury exposure (0.0000886 and 0.000258 mg/kg/day for adults and children, respectively). Grilled chicken intestines also exhibited elevated EDI values, which is consistent with the accumulation of metals in animal viscera and tissues.

Table 1. The level of cadmium, lead, and mercury in specific street-vended foods sold in Davao City, Philippines

	MRL ¹⁾	Grilled chicken intestines (n=20)		deep-fried breaded chicken eggs (n=20)		Steamed dumplings (n=20)		<i>p</i>
	mg/kg	+ve ²⁾ (%)	mg/kg	+ve (%)	mg/kg	+ve (%)	mg/kg	
Cadmium	0.001	0	<d ³⁾	0	<d	0	<d	-
Lead	0.025	5 (25)	0.089±0.369 ^{ns4)}	6 (30)	0.090±0.236 ^{ns}	4 (20)	0.019±0.064 ^{ns}	0.059
Mercury	0.0001	16 (80)	0.044±0.034 ^{ns}	16 (80)	0.069±0.046 ^{ns}	18 (90)	0.062±0.053 ^{ns}	0.677

¹⁾MRL is the Maximum Residue Limit.

²⁾A positive sample that exceeded the MRL.

³⁾<d means below the limit of detection (LOD) = 0.0003 mg/kg.

⁴⁾ns, not significant.

Table 2. Estimated daily intake (EDI) of heavy metals (mg/kg/day) for adults (70 kg) and children (24 kg)

Heavy Metal	Lead		Mercury	
	Adult	Children	Adult	Children
Grilled chicken intestines	0.000114	0.000334	0.0000566	0.00017
Deep-fried breaded chicken eggs	0.0000193	0.0000563	0.0000148	0.0000431
Steamed dumplings	0.000027	0.000079	0.0000886	0.000258

These results are consistent with those of prior studies in Manila, where Pb contamination in grilled meats is widespread (Abdulmajid et al., 2014; Solidum, 2014). Higher exposure in children emphasizes their greater physiological susceptibility to pollutants, as even modest concentrations can lead to neurodevelopmental and renal impairments over chronic periods (Balali-Mood et al., 2025; O'Connor et al., 2025). Therefore, although the average EDI values appear modest, the cumulative effect of daily consumption among children is a significant health concern.

3.3. Non-carcinogenic risk assessment (THQ and HI)

The non-carcinogenic risk assessment summarized in Table 3 provides further insights into the health implications of Pb and Hg exposure through street-vended foods. The THQ values for Pb were below 1 for both adults and children across all food types, indicating a low non-carcinogenic risk from Pb exposure. In contrast, mercury THQ values exceeded the safety threshold (THQ>1) for children consuming *isaw* and *siomai*, but remained below 1 for adults, suggesting that mercury alone may pose a potential non-carcinogenic risk among pediatric consumers. Consequently, the chronic HI exceeded the safety threshold (HI>1) for children consuming *isaw* (HI=1.66) and *siomai* (HI=2.59), primarily driven by mercury exposure.

Mercury primarily drove these elevated risks, reaffirming its role as a principal toxicological concern in this study. Adults exhibited significantly lower HI values (0.15-0.89), which remained within the acceptable limits. The high HI values observed in children mirror the international evidence linking chronic mercury ingestion to subtle cognitive and developmental deficits (Kang et al., 2024; Nkwunonwo et al., 2020).

Cooking practices may intensify contamination; grilling over charcoal or using reused metal skewers can introduce metals, whereas reused deep-frying oils accumulate particulates that absorb atmospheric contaminants (Bereda, 2025; Callano, 2012).

3.4. Carcinogenic risk assessment of lead

The carcinogenic risk from Pb exposure is shown in Table 4. All estimated cancer risks fell within the U.S. EPA's acceptable range (10^{-6} - 10^{-4}), indicating that Pb in these street-vended foods does not present imminent carcinogenic hazards for adults or children under the exposure assumptions applied. When cancer risks from all assessed food types were summed to estimate cumulative dietary exposure, the total Pb-related cancer risk was 1.37×10^{-6} for adults and 3.99×10^{-6} for children, values that likewise remain well below regulatory concern thresholds. Thus, these totals reflect the combined

Table 3. Target hazard quotients (THQs) and chronic hazard index (HI) for Lead and Mercury in selected street-vended foods

Street-food	Adult (70 kg)			Children (24 kg)		
	THQs ¹⁾		HI ²⁾	THQs		HI
	Lead	Mercury		Lead	Mercury	
Grilled chicken intestines	0.004577	0.565714	0.57	0.013350	1.650000	1.66
Deep-fried breaded chicken eggs	0.000771	0.147857	0.15	0.002250	0.431250	0.43
Steamed dumplings	0.001086	0.885714	0.89	0.003167	2.583333	2.59

¹⁾THQs, target hazard quotients.

²⁾HI, chronic hazard index.

Table 4. Chronic daily intake and carcinogenic risk for Pb in selected street-vended foods

Streetfood	Adult		Children	
	Cancer risk	Total cancer risk	Cancer risk	Total cancer risk
Grilled chicken intestines	9.73×10^{-7}	1.37×10^{-6}	2.84×10^{-6}	3.99×10^{-6}
Deep-fried breaded chicken eggs	1.64×10^{-7}		4.78×10^{-7}	
Steamed dumplings	2.31×10^{-7}		6.73×10^{-7}	

exposure from multiple foods rather than the risk attributable to a single item.

Mercury was excluded from this assessment because of the absence of an established carcinogenic slope factor. However, its neurotoxic effects persisted even at doses below the carcinogenic risk. This underscores the need for preventive measures targeting chronic low-dose Hg exposure, especially among children whose dietary habits and metabolism increase their vulnerability.

The combined risk evaluations identified a consistent contamination hierarchy: steamed dumplings and grilled chicken intestines were the highest-risk items, whereas deep-fried breaded chicken eggs posed the lowest risk. These patterns revealed that exposure risk correlates with both food type and preparation method.

Several methodological limitations should be considered when interpreting these findings. Sample washing prior to analysis likely underestimates actual consumer exposure, as street-vended foods (*isaw*, *kwek-kwek*, *siomai*) are typically consumed unwashed directly from vendors, excluding significant surface-adhered traffic-related Pb and Hg particulates. Additionally, purposive sampling from two high-traffic markets limits generalizability to all Davao street-vended foods, and the lack of Hg speciation analysis prevents distinguishing more toxic inorganic forms from organic mercury. Despite these limitations, this study provides the first comprehensive multi-metal health risk assessment of street-vended foods in Davao City, establishing critical baseline data to guide targeted food safety interventions and immediate public health actions in vulnerable pediatric populations.

4. Conclusions

This study revealed that mercury is the dominant contaminant in selected street-vended foods in Davao City, with concentrations exceeding the maximum residue limits in

approximately 80-90% of grilled chicken intestines and steamed dumplings. At the same time, while Cd remained undetectable, and Pb posed comparatively lower concern. Although the individual non-carcinogenic and carcinogenic risks for adults remained within acceptable limits, children faced elevated cumulative non-carcinogenic hazards ($HI > 1$), indicating a potential public health concern associated with the regular consumption of certain street-vended foods. These contamination patterns are plausibly influenced by environmental deposition and open-air food-handling and cooking practices typical of street-vending environments. However, specific exposure sources were not directly measured and therefore cannot be confirmed. These findings highlight the urgency of vendor training, market zoning from pollution sources, and routine monitoring to guide evidence-based food safety policies, without undermining the economic role of street vending. Within this context, this study provides the first city-level, multi-metal exposure and health risk assessment of street-vended foods in Davao City and, to our knowledge, in Mindanao, contributing baseline evidence to inform local food safety surveillance and targeted public health actions.

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Conflict of interests

The authors declare no potential conflicts of interest.

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Ethics approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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