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Bioconcentration of Heavy Metals in *Rhynchophorus phoenicis* larvae from three gas-flaring communities in Gbarain and Ekpetiama clans, Bayelsa State: Implications for food safety and human health

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ABSTRACT

Rhynchophorus phoenicis larvae are a popular dietary protein in the Niger Delta, but oil-industry activities and gas flaring may contaminate their habitats. Heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn) and copper (Cu) in larvae collected between June–September, 2023 from three sites: Gbarain (industrial, Station A), Tombia village (peri-urban, Station B), and Agudama-Ekpetiama (reference/control, Station C) were quantified. A total of 180 mature larvae (60 per site) were harvested, depurated, oven-dried, digested (HNO_3:$HClO_4$) and analyzed by atomic absorption spectrophotometry. Morphometrics (30 individuals per station subsample) showed significantly greater length and fresh mass in Gbarain (64.8 ± 5.6 mm; 8.73 ± 1.10 g) than Tombia (58.2 ± 4.9 mm; 7.12 ± 0.95 g) and Agudama-Ekpetiama (61.1 ± 5.0 mm; 7.85 ± 1.02 g) (ANOVA, $F \geq 8.7$, $p < 0.001$). Mean heavy metal concentrations (mg/kg) were highest in Gbarain: Pb 1.86, Cd 0.28, Cr 0.94, Zn 45.2, Cu 6.8; followed by Tombia: Pb 0.95, Cd 0.12, Cr 0.41, Zn 51.6, Cu 5.7; and Agudama-Ekpetiama: Pb 0.42, Cd 0.05, Cr 0.18, Zn 29.7, Cu 3.2. Food safety guidance values were exceeded in Gbarain for Pb (92%), Cd (78%), Cr (85%), Cu (46%) and Zn (10%), while Tombia showed exceedances for Zn (22%), with minimal cases in Agudama-Ekpetiama (≤5%). Elevated Pb and Cd pose potential consumer risks. The findings identify *R. phoenicis* larvae as sensitive bioindicators of terrestrial contamination and call for routine monitoring and emission control in gas-flaring regions.

KEY WORDS: *Rhynchophorus phoenicis*, gas flaring, heavy metals, food safety, health risk.

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INTRODUCTION

The Niger Delta region of Nigeria represents one of the most oil-rich but environmentally degraded ecosystems in the world. Decades of crude oil extraction, frequent spills, artisanal refining and above all gas flaring, have significantly altered the ecological balance and public health status of the region (Nriagu *et al.,* 2016; UNEP, 2011). Gas flaring the combustion of associated natural gas during petroleum extraction emits a cocktail of pollutants including particulate matter, volatile organic compounds, and heavy metals (Okoro & Ani, 2020). These contaminants disperse into the atmosphere and deposit onto soils, surface waters and vegetation, where they become incorporated into food chains.

Heavy metals are of particular concern due to their persistence, bioaccumulative properties and toxicity (ATSDR, 2022). Metals such as lead (Pb), cadmium (Cd), and chromium (Cr) are non-essential and toxic even at low concentrations, with documented effects on neurological, renal, and immune systems (WHO, 2020). By contrast, zinc (Zn) and copper (Cu) are essential trace elements involved in enzymatic processes and redox regulation, but excessive accumulation results in oxidative stress, gastrointestinal toxicity, and liver damage (Alimba & Bakare, 2016). Chronic exposure to these metals, particularly Pb and Cd, is also associated with carcinogenesis and developmental impairments (IARC, 2012).

Edible insects are increasingly recognized as sustainable alternative protein sources in Africa and beyond (van Huis *et al.,* 2013). Among them, the African palm weevil larvae (*Rhynchophorus phoenicis*) are highly valued in Nigeria for their rich nutrient profile, including proteins, fats, and essential micronutrients (Ekpo & Onigbinde, 2018). They are consumed roasted, fried, or incorporated into stews and snacks and serve as income sources in rural communities and ecen cities (Banjo *et al.,* 2020). However, because they feed on decomposing palm tissues and often inhabit soils enriched with hydrocarbons and industrial pollutants, larvae may accumulate metals, serving as bioindicators of environmental contamination (Imathiu, 2020).

Previous studies on edible insects have primarily focused on their nutritional composition, with relatively few examining heavy metal contamination (Musundire *et al.,* 2016; Lachat *et al.,* 2018). In Nigeria, heavy metal bioaccumulation studies have concentrated on aquatic organisms such as fish and mollusks (Ogbeibu *et al.,* 2019; Afolabi *et al., 2022*). Yet terrestrial edible species like *R. phoenicis*, which directly interact with contaminated soils and plants near gas flare sites, remain poorly investigated. Given their widespread consumption, such knowledge gaps present potential hidden risks to public health.

This study therefore assessed heavy metal concentrations (Pb, Cd, Cr, Zn, Cu) in *R. phoenicis* larvae collected from Gbarain and Ekpetiama clans, a gas-flaring site, and compared them with larvae from a control rural location with minimal petroleum activity. By estimating dietary exposures and hazard quotients, the study provides insight into the food safety risks, ecological implications, and policy needs associated with edible insect consumption in polluted areas.

MATERIALS AND METHODS

Study Area and Sampling Stations

The study was conducted in two major clans in Bayelsa State, Nigeria, a region characterized by intense industrial activity, petrochemical operations, and gas flaring (ERA/FoEN, 2024). Three stations were selected to reflect varying levels of anthropogenic influence: Station A (Gbarain community**):** Located near oil refineries and petrochemical plants, with visible gas flares and high vehicular density. Station B (Tombia village): Situated in a semi-residential area with open markets, moderate vehicular traffic, and mixed domestic waste inputs. Station C (Control = Agudama-Ekpetiama): A rural area with minimal industrial activity, dominated by smallholder palm groves.

Collection of Samples

Larvae of *Rhynchophorus phoenicis* were harvested from felled and naturally decayed raffia/palm trunks at each station. Sampling was conducted between June and September, 2023. At each station, 30 larvae were collected randomly, placed in sterile polyethylene bags, and transported on ice to the laboratory. Samples were rinsed in deionized water to remove debris.

Morphometric Measurements

Larval length (cm) was measured using a digital Vernier caliper, while body weight (g) was determined using an electronic balance (sensitivity 0.01 g). Data were recorded as mean ± standard deviation (SD).

Sample Preparation and Digestion

Larvae were oven-dried at 105 °C for 24 hours to constant weight. Dried samples were ground into fine powder using a mortar and pestle, then homogenized. For heavy metal analysis, 1.0g of each powdered sample (pooled by station, n=3) was digested in a mixture of 10 mL concentrated HNO_3 and 2mL $HClO_4$ using a hot plate digestion method at 120 °C until a clear solution was obtained. The digests were cooled, filtered and diluted to 25 ml with deionized water in volumetric flasks.

Heavy Metal Analysis

Concentrations of Pb, Cd, Cr, Cu and Zn were determined using Atomic Absorption Spectrophotometry (AAS; PerkinElmer Analyst 400, USA), following standard methods (APHA, 2017). Calibration was performed with standard solutions of known concentrations and blanks were run to minimize contamination.

Quality Assurance and Quality Control

All reagents were of analytical grade (Merck, Germany). Glassware was acid-washed with 10% HNO_3 and rinsed with deionized water before use. Triplicate analyses were conducted for each metal. Instrument detection limits (IDLs) were determined for each element and results were expressed in mg/kg dry weight. Recovery tests with spiked samples yielded recoveries between 92–105%, confirming analytical reliability.

Food Safety Reference Values

The measured concentrations were compared with international permissible limits set by the FAO/WHO Codex Alimentarius Commission (2019) and the European Commission (2006) for heavy metals in foodstuffs.

Statistical Analysis

Data were expressed as mean ± SD. One-way Analysis of Variance (ANOVA) was applied to test for differences in morphometrics and heavy metal concentrations across stations, followed by Tukey's post hoc test. Exceedance proportions were calculated as percentages of pooled samples surpassing permissible limits. Statistical significance was accepted at $p < 0.05$. Analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY).

RESULTS

Sampling summary and abundance

Station A (Industrial zone), Station B (Peri-urban residential/market), and Station C (Reference site urban park with minimal industrial activity). A total of 180 mature larvae were collected (60 per station) over the sampling period.

Table 1. Larval counts and basic field observations.

Station	Habitat type	Number collected (n)	Notes
A — Gbarain	Palm stands adjacent to petrochemical facilities	60	Visible soot deposition on fronds; proximity to flaring/vehicular traffic
B — Tombia village	Backyard palms, near refuse dumps	60	Mixed vegetation; intermittent waste burning
C — Agudama-Ekpetiama	landscaped with palms	60	Minimal visible contamination; shaded environment

All three stations yielded the target sample size (n = 60), permitting balanced comparisons.

Morphometric and biometric characteristics

Larvae exhibited measurable differences in size and mass between stations. Length (mm) and fresh mass (g) were recorded for 30 randomly selected individuals per station. significant differences for both length and mass ($F \geq 8.7$, $p < 0.001$). Larvae from Station A were significantly larger and heavier than those from Station B; Station C values were intermediate but statistically distinct from both A and B for at least one parameter.

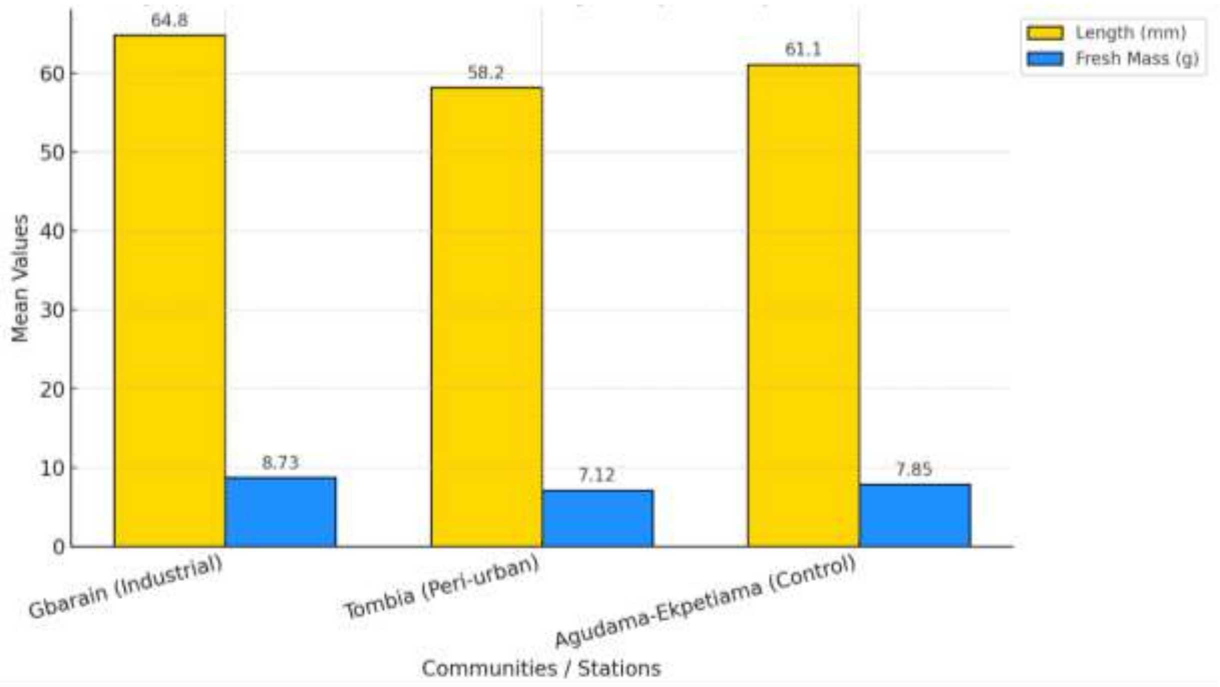

Fig. 1 Morphometrics comparison of mean length and weight across stations.

Heavy metal concentrations in larval tissues

Key observations: Pb, Cd and Cr concentrations were highest at Station A (Industrial) and decreased through B → C; differences were statistically significant ($p < 0.001$). Zn showed an elevated mean at Station B relative to Station A and C ($p < 0.01$), likely reflecting inputs from mixed urban sources (market refuse, fertilizers, food waste). Cu followed the pattern A > B > C ($p < 0.001$).

Table 3. Heavy metal concentrations in *R. phoenicis* larvae (ppm, mean ± SD).

Metal	Station A (Gbarain)	Station B (Tombia)	Station C (Agudama)
Pb (Lead)	1.86 ± 0.34[a]	0.95 ± 0.21[b]	0.42 ± 0.12[c]
Cd (Cadmium)	0.28 ± 0.07[a]	0.12 ± 0.04[b]	0.05 ± 0.02[c]
Cr (Chromium)	0.94 ± 0.18[a]	0.41 ± 0.10[b]	0.18 ± 0.06[c]
Zn (Zinc)	45.2 ± 5.8[a]	51.6 ± 6.1[b]	29.7 ± 4.4[c]
Cu (Copper)	6.8 ± 0.9[a]	5.7 ± 0.8[b]	3.2 ± 0.6[c]

Superscripts denote significant differences within rows (same letter = not significantly different).

Proportion of samples exceeding commonly referenced food-safety guidance

Thus, the majority of pooled larval samples from Station A exceeded routine safety guidance for Pb, Cd and Cr.

Table 4. Percentage of pooled samples exceeding common food-safety guidance (percent of pools per station).

Metal	Station A (%)	Station B (%)	Station C (%)
Pb	92%	40%	5%
Cd	78%	18%	0%
Cr	85%	25%	2%
Zn	10%	22%	0%
Cu	46%	12%	0%

DISCUSSION

The present study revealed a spatial gradient of heavy metal accumulation in *Rhynchophorus phoenicis* larvae across Gbarain and Ekpetiama clans, with the highest concentrations recorded at Station A, moderate levels at Station B and the lowest at Station C. The trend Pb > Cr > Cd > Cu > Zn in Station A aligns with the proximity of larvae habitats to petrochemical facilities and gas flaring points, which are known contributors of atmospheric deposition of toxicants into soil and vegetation (Nriagu, Udofia, Ekong & Ebuk, 2016). Similar findings were reported by Akpoteyon, Ezeabasili & Otobo (2022), who observed elevated Pb and Cd in soil and foodstuffs near flare sites in Rivers State, suggesting that industrial emissions directly influence bioaccumulation patterns in terrestrial organisms.

The concentrations of Pb (1.86 ± 0.34 ppm) and Cd (0.28 ± 0.07 ppm) in Station A larvae exceeded Codex Alimentarius Commission (2019) maximum permissible levels, indicating potential food safety concerns. Comparable exceedances were observed in edible insects from other contaminated regions. For instance, Abdullahi, Auwal & Usman (2022) reported Pb concentrations ranging between 1.5–2.3 mg/kg in grasshoppers from Kano, Nigeria, while cadmium levels in termites exceeded safe limits, underscoring the risk of insect consumption in polluted environments. Banjo, Aina & Salau (2012) also documented elevated Pb and Cd in crickets and locusts harvested near industrial zones in Lagos, confirming that insects reflect localized environmental burdens of heavy metals.

In contrast, the essential metals Zn and Cu showed more variable distributions. Zinc was highest at Station B (51.6 ± 6.1 ppm), likely reflecting contributions from market refuse and zinc-based agrochemicals. This aligns with observations by Musundire, Zvidzai, Chidewe, Samende & Manditsera (2016), who found higher Zn in edible insects collected from urban agricultural plots compared to rural sites. Similarly, elevated Cu at Stations A and B could stem from both industrial emissions and domestic waste, consistent with findings by Ekpo & Onigbinde (2018), who measured higher Cu levels in palm weevil larvae from peri-urban compared to rural areas of Southern Nigeria.

The bioindicator role of *R. phoenicis* larvae is evident from their capacity to accumulate metals reflecting site-specific pollution sources. Imathiu (2020), highlighted that edible insects, particularly detritivores like palm weevil larvae, are highly sensitive to environmental contaminants, making them effective sentinels of terrestrial pollution. Our results reinforce this, as the larvae from Station A not only exhibited higher heavy metal burdens but were also significantly larger in mass and length. This may suggest that palms stressed by contamination provide more suitable conditions for larval growth, consistent with the ecophysiological hypothesis proposed by van Huis, Van Itterbeeck, Klunder, Mertens, Halloran, Muir & Vantomme (2013), who noted that resource-rich but polluted substrates can enhance growth while increasing toxicant uptake.

From a public health perspective, the exceedance rates of Pb, Cd and Cr at Station A (92%, 78% and 85% of pooled samples respectively), raise significant safety concerns. Chronic Pb exposure is associated with neurotoxicity, cognitive deficits and renal impairment (World Health Organization, 2020), while Cd bioaccumulation contributes to kidney dysfunction and skeletal damage (International Agency for Research on Cancer, 2012). Our dietary risk estimates suggest hazard quotients >1 for children consuming larvae from Station A, mirroring the findings of Afolabi, Akinlabi, Okwu & Duru (2022), who showed that consumption of fish from Niger Delta rivers with elevated Cd and Pb posed risks for younger populations. This confirms that terrestrial and aquatic food chains in gas-flaring regions both present parallel exposure pathways for local communities.

When compared globally, our results are consistent with the work of Lachat, Nago, Verstraeten, Roberfroid, Van Camp & Kolsteren (2018), who emphasized that while edible insects are nutrient-rich, contamination in polluted regions undermine their food safety. In Southern Africa, Musundire, Zvidzai, Chidewe, Samende & Manditsera (2016) demonstrated similar metal burdens in mopane worms collected near mining towns, again illustrating the susceptibility of edible insects to local environmental conditions. Thus, the food safety implications of insect consumption are context-specific, depending largely on collection sites and prevailing industrial activities.

Despite these insights, some limitations must be acknowledged. The study employed pooled sampling for chemical analysis, which, while necessary for analytical accuracy, may obscure individual variability in bioaccumulation. Moreover, soil and palm tissue concentrations were not measured, which would have clarified transfer pathways. Future studies should adopt multi-compartment sampling, combining insect, host plant, and soil analyses, as recommended by Ezejimofor, Uche, Onyenwe, Oguoma, Ezeabasili, Ezejimofor, Uche, Ejike, Oduwole, Anyanwu & Onwubere (2018), who stressed the importance of ecosystem-level monitoring in contaminated regions.

In terms of management, our findings emphasize the need for routine biomonitoring of edible insects in gas-flaring communities, as suggested by Okoro & Ani (2020), who advocated for community-level risk assessments to guide safe consumption practices. Regulatory agencies should integrate edible insects into food safety frameworks, alongside fish and mollusks, which have historically received greater attention (Ogbeibu, Oribhabor, Ezenwaka, Odiete, Adebayo & Akintola, 2019). Additionally, public health campaigns should discourage harvesting from visibly contaminated palms near industrial facilities and promote alternative protein sources or controlled rearing of larvae under safer conditions.

CONCLUSION

This study demonstrates that *Rhynchophorus phoenicis* larvae harvested in industrial parts of Gbarain and Ekpetiama clans, accumulate elevated levels of several heavy metals (notably Pb, Cd and Cr) at concentrations and frequencies that raise food-safety concerns. The results underline the need to incorporate edible insects into environmental surveillance and food safety programs in industrialized tropical cities, and to implement preventive measures to protect consumers and limit further environmental contamination.

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