

Globalized Food Chains, Localized Risk: A Dietary Exposure and Hazard Quotient Assessment of Residual Cyanogenic Glycosides in Imported Cassava

Emediong U. Ndedu^{1*}, Moses Friday Anthony², Ikemesit Bassey Awak³

¹Department of Agriculture, Federal University of Technology, Ikot Abasi, PMB 1055, Ikot Abasi, Akwa Ibom State, Nigeria

²Department of Plant Science, Akwa Ibom State University, Ikot Akpaden, PMB 1167, Nigeria

³Department of Public Health, University of Calabar, Calabar, PMB 1115, Cross River State, Nigeria

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ABSTRACT

Cassava (*Manihot esculenta*) is a staple for approximately 800 million people worldwide, and its principal cyanogenic glycoside, linamarin, represents a geographically uneven food-safety risk. Regulatory limits and surveillance data are based on production-region contexts, leaving limited understanding of dietary exposure among diaspora populations consuming imported cassava products in non-endemic markets, often without inherited knowledge of safe preparation. This study reanalyzes validated indirect competitive ELISA data quantifying linamarin in seventeen fresh and processed cassava-derived products sold in the United Kingdom and sourced from Costa Rica, Cameroon, Ghana, India, Thailand, China, and Jamaica. Concentrations were converted to cyanide equivalents to estimate daily intake, hazard quotients, and margins of exposure for child and adult consumer subgroups using the European Food Safety Authority acute reference dose of 20 µg cyanide/kg body weight.

A serving-size sensitivity analysis and margin-of-exposure reframing extended the original point-estimate assessment. Fresh and minimally processed products, particularly fresh root (hazard quotient 1.57 in children) and leaves (1.12), exceeded the reference dose under single-serving exposure, whereas fully processed dry products — flours, tapioca, chips, and garri — remained more than two orders of magnitude below it. Cassava cortex and peel, initially below the acute threshold at 100g, exceeded it at realistic serving sizes of 185–208g. Overall, processing degree, rather than geographic origin, was the principal determinant of residual risk. Children consuming fresh or minimally processed cassava parts represent the primary population of concern in non-endemic markets. Targeted labelling, import monitoring, and margin-of-exposure assessment could strengthen risk management across diaspora food supply chains.

Keywords: linamarin; cyanogenic glycosides; dietary exposure assessment; hazard quotient; margin of exposure; diaspora food safety

INTRODUCTION

Globalization of food trade routinely separates a staple crop from the region-specific knowledge that historically made it safe to eat. Cheeses, fermented soy products, raw-milk products, and numerous other traditionally processed foods carry safety profiles that depend on preparation practices developed, refined, and transmitted within the producing culture over generations; when such products are exported into markets where that transmission chain is absent, attenuated, or several generations removed from direct practice, the product's intrinsic hazard is unchanged but the consumer's capacity to manage it may not be. Cassava is an unusually clear illustration of this general problem, because the gap between a raw and a safely prepared product is large, quantifiable, and directly measurable using existing analytical chemistry, and because

global trade in cassava-derived products has expanded substantially alongside the growth of diaspora communities whose diets sustain demand for them in markets where cassava itself is not a traditional staple crop.

Cassava is cultivated and consumed by hundreds of millions of people across sub-Saharan Africa, Latin America, and Southeast Asia, where it accounts for a substantial share of dietary energy intake; per-capita consumption in African producing countries has been estimated at roughly 0.4 kg per person per day, a level exceeding that of most other staple crops on any continent. Generations of processing knowledge — soaking, fermentation, grating, sun-drying have evolved specifically to reduce cassava's cyanogenic glycoside content to safe levels before consumption. Linamarin, the principal cyanogenic glycoside in cassava, releases hydrogen cyanide upon enzymatic hydrolysis (Cressey and Reeve 2019) and is responsible for documented outbreaks of acute cyanide poisoning and the chronic, irreversible upper motor neuron disease known as konzo.

Historical work in the Democratic Republic of Congo (then Zaire) demonstrated that konzo outbreaks track closely with shortcuts in traditional processing: communities that reduced cassava soaking from four nights to a single night, typically under economic pressure to bring produce to market faster, showed markedly higher disease rates than neighbouring communities that retained the longer soaking period (Banea, Poulter, and Rosling 1992). More recent surveillance across the Democratic Republic of Congo and Mozambique continues to find urinary thiocyanate concentrations, a biomarker of cyanide exposure, well above the World Health Organization's 350 $\mu\text{mol/L}$ safety threshold in konzo-affected populations, with reported values reaching as high as 1,730 $\mu\text{mol/L}$; a 2025 systematic review synthesizing 45 epidemiological studies confirms that inadequate processing, compounded by conflict, drought, and protein-poor diets, remains the central mechanism linking cassava consumption to cyanide-related disease in endemic regions (Osman et al. 2025). This body of evidence establishes processing adequacy, rather than cassava consumption per se, as the operative safety variable — a framing this study extends to a very different consumption context.

International food-safety frameworks reflect a production-region orientation that this literature has shaped. The Codex Alimentarius Commission sets a maximum level of 10 mg/kg hydrogen cyanide for edible cassava flour (Codex Alimentarius Commission 1989), and comparable national limits exist for ready-to-eat cassava chips. These thresholds, and the surveillance systems built to enforce them, were developed primarily with endemic consumption patterns in mind: large-volume, high-frequency, culturally embedded intake, typically of processed staple forms, by populations with generations of inherited preparation knowledge. Far less is known about a parallel and growing exposure pathway — the trade of fresh, frozen, and processed cassava products into markets where cassava is not a dietary staple, consumed largely by diaspora communities who may lack access to, or awareness of, the preparation practices that render high-risk products safe. This pathway is not a marginal one.

A 2026 survey of 1,507 African diaspora consumers across the United Kingdom found that 97% regularly include African food in their diets, with 35% consuming it daily, and identified cassava-derived products among the staple imported categories sold through a growing network of importers, wholesalers, and retailers concentrated in London, Birmingham, Manchester, and Leeds (The Food Bridge and GFAiR 2026). UK customs data on fresh, chilled, frozen, and dried cassava (Harmonized System code 071410) show Costa Rica as the single largest source of UK cassava imports by value, followed by India, Sri Lanka, the Netherlands, and Indonesia — a provenance profile that maps closely onto the country-of-origin spread of the product set analyzed here. Unlike the endemic-region exposure pathway, this diaspora import pathway is governed by generic food-handling labelling rather than cyanogenic-glycoside-specific guidance, and by consumers who may be one or more generations removed from direct exposure to traditional processing practice.

Existing analytical work addressing this pathway has been oriented toward method development rather than exposure characterization. Azmi (2019) developed and validated a polyclonal antibody-based indirect competitive ELISA capable of quantifying linamarin specifically, rather than total cyanogenic potential, and applied it to seventeen cassava-derived products available in the United Kingdom retail market. That work

established, for the first time, immunoassay-based linamarin concentrations across a range of commercially traded products spanning fresh roots to fully processed flours and snack foods. However, the resulting concentrations were reported descriptively, compared against generic safety limits, and were not converted into a formal exposure or risk-characterization framework specific to the consuming population.

This is the gap the present study addresses. Rather than generate new analytical data, we reanalyze the existing linamarin concentration dataset as a dietary exposure problem: combining measured concentrations with consumption-scenario assumptions and an internationally recognized toxicological reference dose to compute hazard quotients for defined consumer subgroups. This reframes a method-validation dataset as an environmental and public-health exposure assessment, consistent with recent work applying similar deterministic exposure modelling to cyanogenic glycoside intake among Asian populations (Park et al. 2024), and with dose-reconstruction work quantifying cyanide intake from cassava-based diets in the Democratic Republic of Congo, where daily intake at the 95th percentile has been estimated at 26–271 mg/kg body weight/day among heavy consumers of insufficiently processed staple forms (Miderho et al. 2023), but applied here to the distinct and under-examined context of a non-endemic, import-dependent consumer population, at a single-serving rather than habitual-staple exposure frequency.

We further extend the original hazard-quotient framework in three respects that, to our knowledge, have not previously been applied to this dataset or this exposure pathway:

- a margin-of-exposure reframing of the hazard-quotient results, following the interpretive logic EFSA's Scientific Committee has developed for communicating risk-manager-relevant safety margins;
- a serving-size sensitivity analysis testing whether the two-product exceedance boundary reported in prior descriptive work is robust to realistic variation in portion size; and
- an explicit processing-category comparison quantifying the risk-reduction magnitude in exposure rather than concentration terms. Together, these extensions are intended to strengthen the evidentiary basis for the labelling and import-monitoring recommendations this reanalysis supports.

MATERIALS AND METHODS

Secondary Data Source

Linamarin concentration data (mg/kg fresh weight for wet products, mg/kg dry weight for dry products; mean of six replicate determinations per sample) and product provenance (country of origin, retail source, processing category) were drawn from the published results of Azmi (2019), covering seventeen products: four fresh or minimally processed cassava parts (root, leaves, cortex, peel) and thirteen processed products (frozen chunks and slices, fermented dough, tapioca products, cassava flour, chips, and three garri variants), purchased from UK retailers between June 2017 and December 2018. No new laboratory analysis was performed for this study.

Conversion to Cyanide Equivalents

Linamarin concentrations were converted to theoretical maximum cyanide-equivalent concentrations using the stoichiometric mass ratio of hydrogen cyanide to linamarin (molecular weights 27.03 g/mol and 247.25 g/mol, respectively), giving a conversion factor of 0.109. This represents an upper-bound estimate assuming complete enzymatic hydrolysis and release of bound cyanide, consistent with conservative dietary risk-assessment practice.

Exposure Scenario and Hazard Quotient Calculation

A deterministic, single-serving exposure scenario was modelled using a 100g portion for each product

category. Estimated daily intake (EDI, μg cyanide/kg body weight) was calculated as: $\text{EDI} = (\text{cyanide-equivalent concentration} \times \text{serving mass} \times 1000) \div \text{body weight}$, using reference body weights of 15 kg for a young child and 60 kg for an adult. Hazard quotients (HQ) were calculated as EDI divided by the acute reference dose (ARfD) of 20 μg cyanide/kg body weight established by the European Food Safety Authority Panel on Contaminants in the Food Chain for cyanide from cyanogenic glycosides, applicable regardless of dietary source (EFSA CONTAM Panel 2019). An HQ at or above 1 indicates that a single serving of the product, under the stated assumptions, would meet or exceed the acute reference dose for that subgroup.

Comparative Analysis by Processing Category

Products were grouped into four processing categories — fresh, minimally processed, partially processed, and fully processed based on the descriptions in the source dataset, to test descriptively whether residual cyanide-equivalent load tracked more closely with processing degree or with country of origin. Category-level summary statistics (arithmetic mean cyanide-equivalent concentration) were computed to quantify the magnitude of risk reduction associated with each processing step, in addition to the pairwise single-product comparisons reported in the original descriptive analysis.

Margin of Exposure Reframing

To complement the hazard-quotient results with a metric more directly interpretable by risk managers, we additionally computed a margin of exposure (MOE) for each product and consumer subgroup, defined as $\text{MOE} = \text{ARfD} \div \text{EDI}$ (equivalently, $\text{MOE} = 1 \div \text{HQ}$). This follows the interpretive convention EFSA's Scientific Committee has established for genotoxic and non-threshold contaminants (EFSA Scientific Committee 2005), in which a larger MOE indicates a larger safety buffer between estimated exposure and the reference point of concern, and an MOE below 1 indicates that the reference point has been met or exceeded. Although the ARfD used here is a threshold rather than a non-threshold reference point, the MOE transform provides a complementary, ratio-scale expression of the same underlying comparison that is often more readily communicated to non-specialist audiences — including importers, retailers, and labelling regulators than a hazard quotient expressed on a sub-1 decimal scale.

Serving-Size Sensitivity Analysis

Because the 100g reference serving is an illustrative point estimate rather than an empirically observed portion size for any specific product or population, we conducted a sensitivity analysis recomputing the child hazard quotient across a range of serving sizes (25–250 g, in 25 g increments) for the four products with the highest HQ at the reference serving size (fresh root, leaves, cortex, and peel). Because EDI and HQ scale linearly with serving mass at fixed concentration and body weight, this analysis identifies the serving size at which each product's hazard quotient crosses the acute reference dose threshold, providing a more complete picture of risk than a single point estimate permits.

Visualization Methods

Hazard quotients, category-level concentration means, and the serving-size sensitivity analysis were visualized using grouped and logarithmic-scale bar charts and line plots (Figures 1–3) to support comparison across the four to five orders of magnitude spanned by the raw concentration data. All figures were generated directly from the reanalyzed dataset described above; no additional data sources were used in their construction.

Assumptions and Limitations of the Modelling Approach

This is a deterministic, illustrative exposure model, not a probabilistic or population-representative assessment. Serving size, body weight, and the assumption of complete hydrolysis are fixed point estimates rather than distributions drawn from consumption-survey data specific to diaspora populations, which do not currently exist for this exposure pathway. The small per-product sample size ($n = 6$ replicate determinations per product, one product per category) in the source dataset limits statistical inference to descriptive

comparison rather than formal hypothesis testing. These limitations are addressed further in the Limitations subsection below.

RESULTS

Table 1 presents linamarin concentrations, derived cyanide-equivalent concentrations, and hazard quotients for both consumer subgroups across all seventeen products.

Table 1. Reanalysis of linamarin concentration data (Azmi 2019) as cyanide-equivalent dietary exposure and hazard quotients (HQ) for child (15 kg) and adult (60 kg) consumers under a 100 g single-serving scenario. HQ ≥ 1 indicates the acute reference dose (20 μg CN/kg bw; EFSA CONTAM Panel 2019) is met or exceeded.

No.	Product	Origin	Processing category	Linamarin (mg/kg)	CN-eq (mg/kg)	HQ child	HQ adult
1	Fresh cassava root	Costa Rica	Fresh	43.08	4.71	1.57	0.39
2	Cassava leaves (ground/frozen)	Cameroon	Fresh	30.78	3.36	1.12	0.28
3	Cassava cortex	Costa Rica	Fresh	14.89	1.63	0.54	0.14
4	Cassava peel	Costa Rica	Fresh/by-product	13.17	1.44	0.48	0.12
5	Cassava chunks (frozen)	India	Minimally processed	14.51	1.59	0.53	0.13
6	Cassava slices/diced (frozen)	India	Minimally processed	9.22	1.01	0.34	0.08
7	Cassava dough (fermented)	Ghana	Partially processed	2.03	0.22	0.07	0.02
8	Pure tapioca flour	Thailand	Fully processed	0.003	<0.01	<0.01	<0.01
9	Black tapioca pearls	China	Fully processed	0.036	<0.01	<0.01	<0.01
10	Green tapioca pearls	Thailand	Fully processed	0.008	<0.01	<0.01	<0.01
11	White tapioca pearls	Thailand	Fully processed	0.023	<0.01	<0.01	<0.01
12	Cassava flour	Jamaica	Fully processed	0.033	<0.01	<0.01	<0.01
13	Cassava chips (barbeque)	Jamaica	Fully processed	0.455	0.05	0.02	<0.01
14	Cassava chips (lightly salted)	Jamaica	Fully processed	0.449	0.05	0.02	<0.01
15	Garri Ijebu	Jamaica	Fully processed	0.270	0.03	0.01	<0.01
16	Garri white	Jamaica	Fully	0.425	0.05	0.02	<0.01

			processed				
17	Garri yellow	Jamaica	Fully processed	0.282	0.03	0.01	<0.01

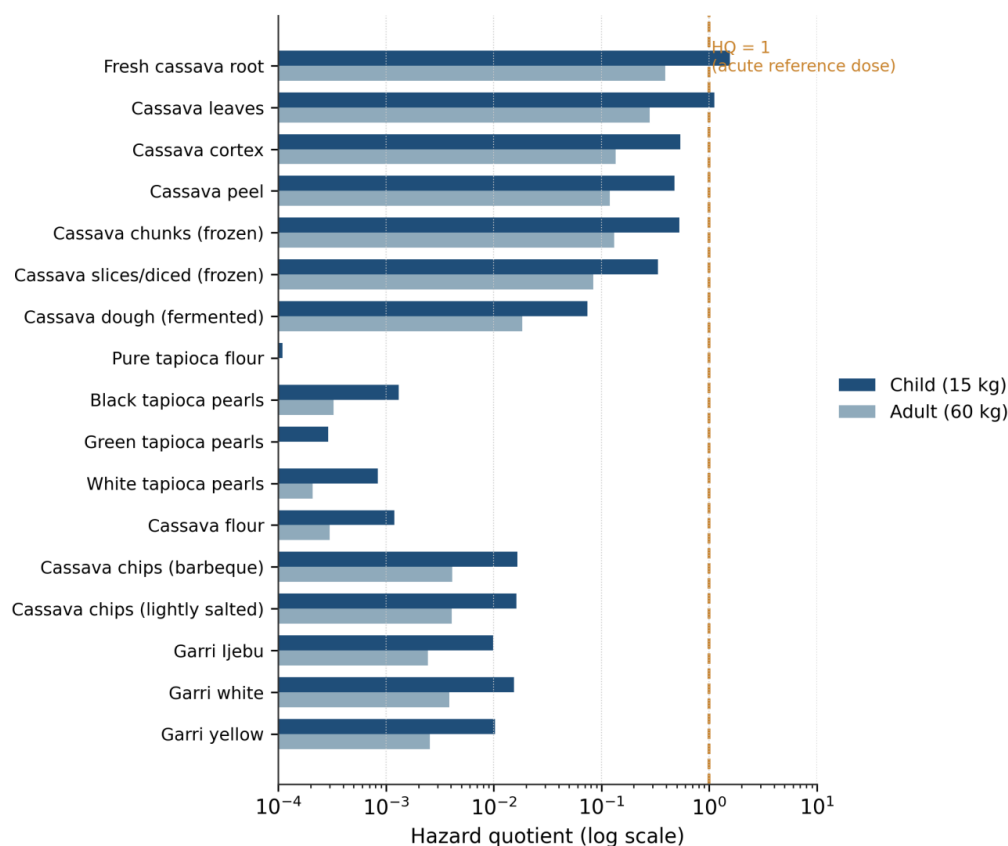


Figure 1. Hazard quotients (log scale) for all 17 products, child and adult consumer subgroups. Dashed line marks HQ = 1 (the acute reference dose).

Two products exceeded a hazard quotient of 1 for the child subgroup under this scenario: fresh cassava root (HQ 1.57) and cassava leaves (HQ 1.12). No product exceeded an HQ of 1 for the adult subgroup, though fresh root, leaves, cortex, peel, and frozen chunks/slices all fell in an elevated range (HQ 0.08–0.39) that would leave little margin under a larger serving size or repeated exposure. Cassava cortex, peel, and frozen chunks and slices, though below the acute threshold at the reference serving, retained hazard quotients between 0.34 and 0.54 in children — an order of magnitude above the fully processed product group.

Figure 1 displays the full hazard-quotient ranking for both consumer subgroups on a logarithmic scale, making clear both the roughly four-order-of-magnitude spread across the product set and the consistent step-change at the fresh/minimally processed to fully processed boundary.

Every fully processed product — pure tapioca flour, black/green/white tapioca pearls, cassava flour, cassava chips, and all three garri variants produced hazard quotients below 0.02 for children and below 0.004 for adults, more than fifty-fold lower than fresh root at the level of individual product comparison. Fermented cassava dough, classed as partially processed, occupied an intermediate position (HQ 0.07 in children), consistent with fermentation providing substantial but incomplete linamarin reduction relative to full drying and milling.

Table 2 restates the same product-level results in margin-of-exposure terms. Fresh cassava root carries a child MOE of 0.64 and cassava leaves a child MOE of 0.89 — both below 1, indicating the acute reference dose is met or exceeded before the full modelled serving is consumed. Cortex, peel, and frozen chunks/slices carry child MOEs between 1.85 and 2.94, a narrow buffer that, as the serving-size sensitivity analysis below

shows, is readily eroded by realistic increases in serving size. Fully processed products carry child MOEs ranging from roughly 60 (chips) to in excess of 9,000 (pure tapioca flour), a range spanning more than four orders of magnitude and illustrating quantitatively how completely conventional processing removes residual risk once carried to completion.

Table 2. Margin of exposure (MOE = ARfD ÷ EDI = 1 ÷ HQ) by product and consumer subgroup. Larger values indicate a larger safety buffer; MOE < 1 indicates the acute reference dose is met or exceeded.

No.	Product	MOE child	MOE adult
1	Fresh cassava root	0.64	2.56
2	Cassava leaves	0.89	3.57
3	Cassava cortex	1.85	7.14
4	Cassava peel	2.08	8.33
5	Cassava chunks (frozen)	1.89	7.69
6	Cassava slices/diced (frozen)	2.94	12.5
7	Cassava dough (fermented)	14.3	50.0
8	Pure tapioca flour	~9,100	~36,600
9	Black tapioca pearls	~765	~3,058
10	Green tapioca pearls	~3,440	~13,760
11	White tapioca pearls	~1,197	~4,787
12	Cassava flour	~834	~3,335
13	Cassava chips (barbeque)	60.5	242
14	Cassava chips (lightly salted)	61.3	245
15	Garri Ijebu	102	408
16	Garri white	64.8	259
17	Garri yellow	97.6	390

Category-level comparison (Table 3, Figure 2) shows a monotonic decline in mean cyanide-equivalent concentration with increasing processing intensity: fresh products averaged 2.79 mg/kg CN-equivalent, minimally processed products 1.30 mg/kg,

The single partially processed product 0.22 mg/kg, and fully processed products 0.0221 mg/kg — a 126-fold difference between the fresh and fully processed category means, somewhat larger than the fifty-fold figure obtained from the single highest-risk pairwise product comparison, because the category mean is not driven solely by the single highest-concentration fresh product.

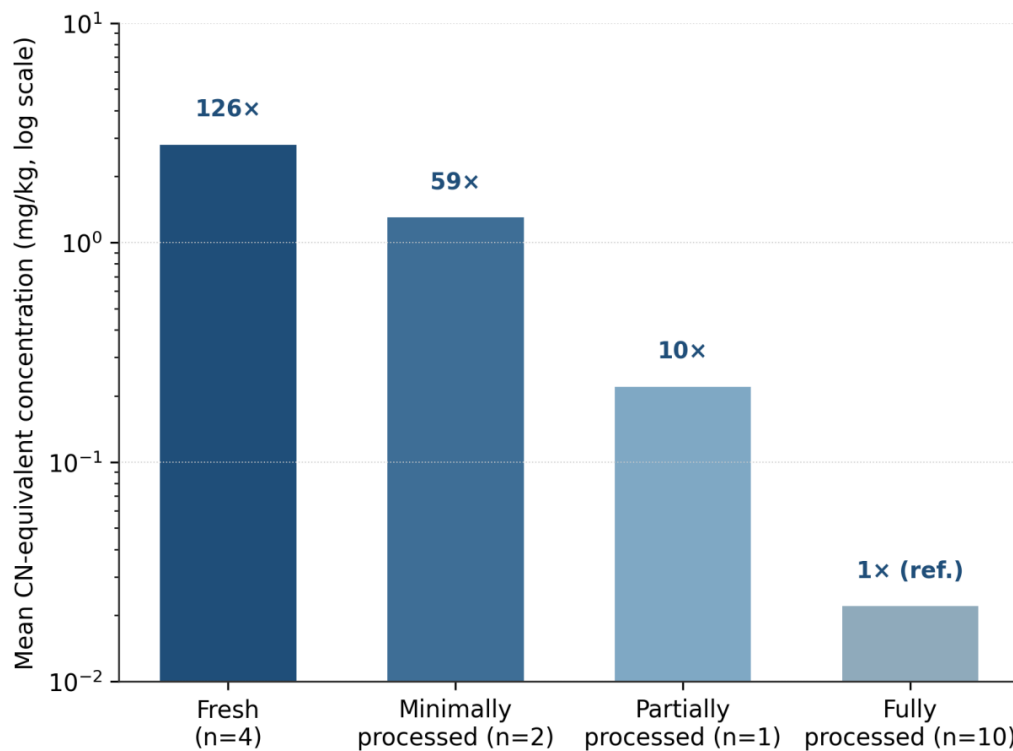


Figure 2. Mean cyanide-equivalent concentration (mg/kg, log scale) by processing category, with fold-reduction relative to the fully processed category.

Table 3. Mean cyanide-equivalent concentration by processing category, with ratio relative to the fully processed category mean.

Processing category	n	Mean CN-eq (mg/kg)	Ratio vs. fully processed
Fresh	4	2.79	126×
Minimally processed	2	1.30	59×
Partially processed	1	0.22	10×
Fully processed	10	0.0221	1× (reference)

Country of origin did not track with hazard quotient independently of processing category: high-hazard-quotient products originated from Costa Rica and Cameroon, while low-hazard-quotient products spanned origins including Jamaica, Thailand, China, and India — a spread that, notably, includes Costa Rica appearing at both the highest-risk (fresh root) and negligible-risk ends of the distribution depending on processing status rather than provenance. Processing degree, not geographic origin, was the dominant determinant of residual dietary risk in this dataset.

The serving-size sensitivity analysis (Figure 3) shows that the two-product exceedance boundary reported at the 100 g reference serving is not robust to realistic variation in portion size. Cassava cortex, with a child HQ of 0.54 at 100 g, crosses HQ = 1 at a serving size of approximately 185 g; cassava peel, with a child HQ of 0.48 at 100 g, crosses HQ = 1 at approximately 208 g. Both serving sizes are well within the plausible range for a fresh-vegetable side portion, particularly for cassava leaves prepared as a cooked green or root/cortex prepared as a starchy side, rather than an extreme or unrealistic consumption assumption.

Fresh cassava root and cassava leaves, already above threshold at 100 g, reach hazard quotients of approximately 3.9 and 2.8, respectively, at a 250 g serving — a portion size broadly consistent with a single meal-sized helping of a starchy staple for an older child or a shared household portion. This sensitivity analysis indicates that the population of products carrying meaningful acute risk for child consumers under

plausible, rather than only point-estimate, consumption assumptions is larger than the two products identified at the single reference serving size, extending rather than overturning the paper's central risk-ranking finding.

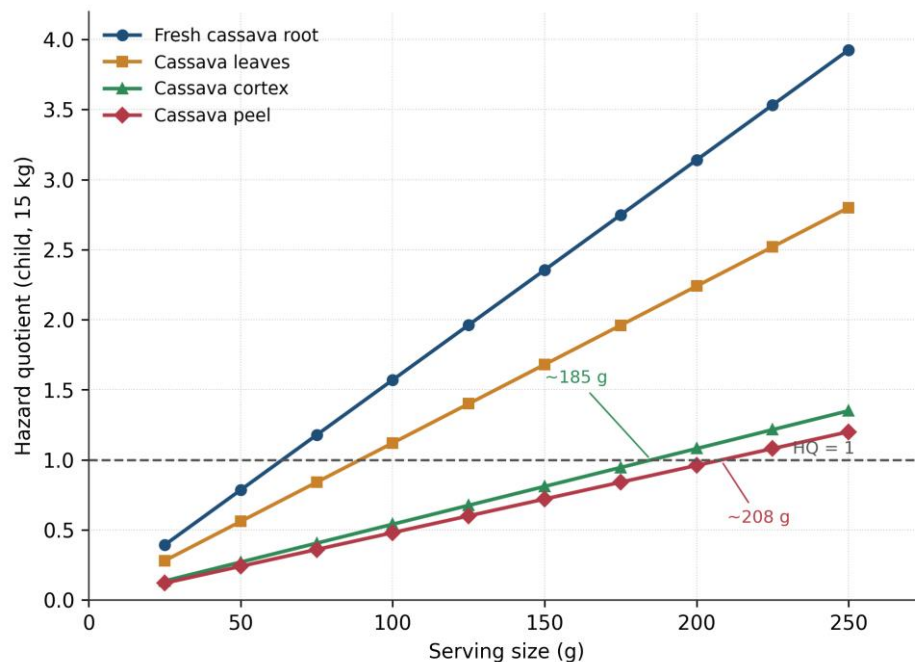


Figure 3. Sensitivity of child hazard quotient to serving size (25–250 g) for the four highest-risk fresh/minimally processed products. Cortex and peel cross HQ = 1 at approximately 185 g and 208 g, respectively.

DISCUSSION

Chronic Endemic-Region Evidence as Context For An Acute, Non-Endemic Risk

The health consequences of inadequate cassava processing are not confined to the acute cyanide poisoning captured by the ARfD-based hazard quotient framework used here. Neurological and cognitive follow-up work in konzo-affected regions of the Democratic Republic of Congo has found that serum concentrations of 8,12-iso-iPF₂ α -VI isoprostane, a marker of oxidative damage, are significantly associated with reduced cognitive performance in affected children, explaining over 85% of variance in a standardized cognitive battery in one cohort, with mechanistic work implicating cyanide-driven oxidative stress compounded by micronutrient deficiencies including selenium, copper, and zinc (Makila-Mabe et al. 2014). This chronic-exposure literature is not directly comparable to the acute, single-serving exposure scenario modelled in the present study — the populations, exposure frequencies, and toxicological endpoints differ substantially but it establishes that the underlying hazard, incompletely hydrolyzed or degraded linamarin reaching systemic circulation, carries health consequences beyond the acute poisoning endpoint the EFSA ARfD is designed to guard against. This context strengthens, rather than substitutes for, the case for the acute exposure-assessment approach adopted here: it indicates that residual risk in the fresh and minimally processed product categories identified above should not be dismissed merely because chronic konzo-type outcomes are implausible at the single-serving, non-staple exposure frequencies typical of diaspora consumption.

Processing Degree as the Dominant Risk Determinant

The more than fifty-fold reduction in hazard quotient between fresh cassava root and fully processed products such as garri or cassava flour, and the 126-fold reduction observed at the level of category means, confirms, in exposure-assessment terms rather than descriptive concentration terms, that conventional cassava processing methods are highly effective at reducing cyanide-equivalent dietary risk when properly applied. This is consistent with the wider literature on cyanogenic glycoside retention during cassava

processing, and specifically with historical field evidence from the Democratic Republic of Congo showing that konzo incidence tracks not with cassava consumption itself but with departures from full traditional processing (Banea, Poulter, and Rosling 1992), and more recent dose-reconstruction work in the same region continues to find cyanide intake orders of magnitude above the reference dose among populations consuming incompletely processed cassava as a dietary staple (Miderho et al. 2023). The present analysis extends this processing-adequacy literature by expressing the risk reduction directly in terms of a recognized toxicological benchmark — the hazard quotient and its margin-of-exposure complement — rather than concentration alone, and by doing so for a consumption context that differs materially from the chronic, high-frequency staple-consumption exposure that dominates the existing konzo literature. That the same underlying mechanism (incomplete linamarin breakdown) produces materially different absolute risk profiles depending on consumption frequency and portion size is itself a finding relevant to how this risk pathway should be communicated.

Distinguishing Acute Exposure Risk from Chronic Staple-Consumption Risk

It is worth being explicit about a distinction the hazard-quotient framework used here can obscure if read out of context. The ARfD of 20 µg cyanide/kg body weight is, by design, an acute reference point: it describes the exposure level below which a single event of intake is not expected to produce acute adverse effects, not a chronic tolerable intake calibrated to repeated, staple-frequency consumption. The chronic dose-reconstruction literature from the Democratic Republic of Congo, by contrast, reports habitual daily cyanide intakes at the 95th percentile of 26–271 mg per kilogram of body weight per day among populations consuming cassava as a dietary staple multiple times daily (Miderho et al. 2023) — intake magnitudes and frequencies not comparable to, and considerably exceeding, the single 100 g serving modelled in the present analysis. The present study's exceedance findings for fresh root and leaves in children should therefore be read as identifying products that meet or exceed an acute single-event threshold under a plausible one-off consumption scenario, not as evidence that diaspora consumers face konzo-scale chronic exposure; the two exposure regimes are toxicologically distinct, arise from different consumption frequencies, and warrant different regulatory responses: acute exceedance supports point-of-sale labelling and preparation guidance, whereas the chronic staple-consumption risk documented in endemic regions has historically been addressed through agricultural intervention (promotion of low-cyanogenic cultivars) and community-level processing-practice programmes not directly transferable to a diaspora retail context where consumption is occasional rather than staple.

Vulnerable Subgroup and Non-Endemic Market Framing

The concentration of hazard-quotient exceedance in the child subgroup, and its absence in adults under the same scenario, mirrors findings from EFSA's own population-level assessment, which found the acute reference dose exceeded primarily in children and adolescent age groups (EFSA CONTAM Panel 2019). The present analysis suggests this pattern may be amplified, rather than mitigated, in diaspora consumer contexts, where fresh or minimally processed cassava parts — cortex, peel, leaves, frozen chunks — are sold without the accompanying preparation guidance that is often informally transmitted within endemic-region communities across generations. This transmission gap is plausibly widened by the diaspora food market's own growth trajectory: survey evidence indicates that African-diaspora food consumption in the United Kingdom is now a routine, near-universal dietary pattern, with more than a third of surveyed consumers reporting daily consumption of African food categories that include cassava-derived products, and with retail availability concentrated in urban centres that may draw in second- and third-generation diaspora consumers with progressively less direct exposure to source-region preparation practice (The Food Bridge and GFAiR 2026). A market of this scale and growth trajectory is not a marginal edge case for food-safety policy; it is a substantial and apparently expanding exposure pathway that current labelling frameworks do not specifically address.

Regulatory and Labelling Implications

Current import labelling for cassava products entering non-endemic markets typically addresses general

food-safety handling rather than cyanogenic-glycoside-specific preparation instructions. The clear separation in hazard quotient between fresh/minimally processed and fully processed categories observed here, reinforced by the margin-of-exposure results in Table 2, which show more than four orders of magnitude of safety buffer separating the two groups, suggests that risk-based labelling distinguishing products requiring further processing before consumption from those already safe to eat could meaningfully reduce exposure without requiring changes to underlying trade volumes or product formulations. UK import data show fresh and dried cassava arriving predominantly from Costa Rica, India, Sri Lanka, and Indonesia (by import value under Harmonized System code 071410), a provenance pattern that corresponds closely to the fresh- and minimally-processed products identified here as carrying the highest residual risk, and suggests that origin-based inspection regimes would be a poor substitute for processing-status-based labelling: a Costa Rican fresh root and a Costa Rican processed product occupy opposite ends of the risk distribution in this dataset despite sharing a country of origin. A labelling intervention targeted at processing status, rather than country of origin, would align regulatory attention with the variable this analysis identifies as the actual driver of residual risk.

Practical Shape of A Processing-Status Labelling Scheme

A processing-status labelling scheme consistent with the findings reported here would not require new analytical infrastructure beyond what already exists: the same ELISA methodology validated by Azmi (2019) and reanalyzed in the present study is capable of screening incoming shipments or retail samples at a cost and turnaround compatible with routine import surveillance, rather than requiring bespoke method development. A minimal version of such a scheme would (i) classify cassava-derived products at the point of import or retail listing into the same four processing categories used in section 2.4 (fresh, minimally processed, partially processed, fully processed); (ii) attach a short, plain-language preparation instruction — for example, a minimum soaking or cooking duration derived from the existing traditional-processing literature — to any product falling in the fresh or minimally processed categories; and (iii) exempt fully processed, negligible-risk products such as garri, cassava flour, and tapioca from additional labelling burden, consistent with the more than four-orders-of-magnitude margin-of-exposure separation observed between the two groups in Table 2. Such a scheme would concentrate regulatory and labelling effort precisely where the present analysis locates residual risk, without imposing uniform new requirements across a product category most of which the data show to be already effectively safe.

A Margin-of-Exposure Framework as A Communication Tool

The margin-of-exposure reframing introduced in section 2.5 is not merely a rescaling of the hazard quotient; it changes what the numbers communicate to a non-specialist audience. A hazard quotient of 0.02 for a garri product is easily misread as a “small but present” risk in a way that a margin of exposure of fifty — fifty-fold below the point at which the acute reference dose would be met is not. Risk communication research underlying EFSA's own adoption of the MOE approach for genotoxic and non-threshold contaminants was motivated by exactly this concern: that risk managers and downstream audiences find a larger-is-safer ratio more intuitively interpretable than a smaller-is-safer fraction, particularly when comparing across products spanning several orders of magnitude, as the present dataset does (EFSA Scientific Committee 2005). We suggest that any future labelling or import-monitoring scheme building on the present findings adopt an explicitly stated margin-of-exposure or equivalent ratio framing, rather than a raw hazard quotient or concentration figure, precisely because the audience for such labelling — food importers, retailers, and ultimately consumers making real-time purchasing and preparation decisions is not a specialist risk-assessment audience.

Serving Size and the Limits of the Single-Point Exposure Scenario

The serving-size sensitivity analysis presented in section 3 qualifies, without overturning, the paper's central finding. At the illustrative 100 g reference serving, only two of seventeen products exceed the acute threshold for children; at a 200g serving — still well within a plausible single-meal portion for a starchy staple or leafy vegetable side dish — four products do, and cassava peel approaches the threshold. This

matters directly for the labelling recommendation advanced in section 4.5: any regulatory threshold or labelling trigger built on a single fixed serving-size assumption risks under-identifying products that pose meaningful risk at realistic, rather than minimal, portion sizes. A labelling or monitoring scheme informed by this analysis should therefore be built around a defensible range of plausible serving sizes for each product category, rather than a single point estimate, and should treat cortex, peel, and frozen chunks/slices — the products that cross threshold within the plausible serving range examined here — as meriting the same category of preparation guidance as fresh root and leaves, rather than being classed with the fully processed, negligible-risk group on the strength of their sub-threshold status at 100 g alone.

LIMITATIONS

This reanalysis inherits the sampling limitations of the source dataset: a single sample per product category, purchased at one UK location over an eighteen-month window, cannot represent the full variability of cassava products entering non-endemic markets, nor variation across importing countries. The exposure model is deterministic and point-estimate (or, in the sensitivity analysis, deterministic across a fixed grid) rather than probabilistic, and assumes complete cyanide release, a conservative but not necessarily realistic assumption depending on food preparation immediately prior to consumption. Serving sizes and body weights are illustrative reference values rather than measurements from an actual diaspora consumption survey, which does not currently exist for this population; the serving-size sensitivity analysis presented above partially addresses this gap by testing a range of plausible portions, but it cannot substitute for empirical portion-size data specific to diaspora UK consumers of these products. The margin-of-exposure calculation introduced in section 2.5 is a direct algebraic transform of the hazard quotient and therefore inherits every assumption underlying that quotient; it improves communicability, not the underlying evidentiary base. These limitations mean the specific hazard quotient and margin-of-exposure values reported here should be read as indicative of relative risk ranking across product categories rather than as precise estimates of population risk, pending validation with consumption-survey data and, ideally, an independent replicate dataset with a larger per-product sample size. The deterministic, conservative-bound design was adopted deliberately given these data constraints: with a single analytical sample per product and no consumption-frequency distribution for this population, a probabilistic (e.g., Monte Carlo) exposure simulation would convey a false sense of statistical precision that the underlying dataset cannot support. The present analysis is accordingly framed as a first-pass, screening-level risk characterization intended to identify which products and subgroups warrant the consumption-survey and expanded-sampling work proposed below, rather than as a definitive population risk estimate.

Directions for Future Research

Three extensions would most directly strengthen the evidentiary basis for the labelling and monitoring recommendations advanced here. First, a diaspora-specific consumption survey, recording actual serving sizes, preparation practices, and consumption frequency for fresh and minimally processed cassava parts among UK-resident consumer populations, would replace the illustrative serving-size and body-weight assumptions used here with empirically grounded distributions, enabling a full probabilistic exposure assessment in place of the deterministic point-and-sensitivity approach adopted in this reanalysis. Second, an expanded product sampling scheme — multiple retail lots per product category, across multiple UK regions and import seasons would allow the per-product variance that the current $n = 6$ replicate, single-lot design cannot address, and would support formal statistical comparison between processing categories rather than the descriptive comparison presented here. Third, replicate application of this exposure-assessment framework to other non-endemic import markets outside the UK — continental Europe, North America would test whether the processing-degree-dominant risk pattern identified here generalizes across import contexts with different retail compositions and diaspora population profiles, or whether it is specific to the particular product mix available in the UK retail market during the 2017–2018 sampling window.

Globalized Food Chains and Localized Risk: A General Framing

The pattern identified in this dataset is a specific instance of a more general feature of globalized food

systems: a food-safety control calibrated for one consumption context can leave a residual, uncalibrated risk when the same product is traded into a different consumption context, even when the product itself, and the hazard it carries, are unchanged. Cassava's cyanogenic glycoside content is identical whether the product is sold in a market adjacent to the farm where it was grown or in a diaspora grocery several thousand kilometres away; what differs is the density of inherited preparation knowledge available to the consumer at the point of purchase, and the regulatory attention directed at the specific hazard as opposed to generic food-handling concerns. Globalized trade in staple crops with region-specific safe-preparation requirements — cassava is one example, but not a unique one routinely separates a product from the knowledge context that historically made it safe to consume, without a corresponding transfer of that knowledge alongside the product itself. The present analysis suggests that this separation, rather than any change in the product's intrinsic hazard, is the mechanism generating the localized risk identified here. A labelling and monitoring response targeted at processing status rather than product origin, as argued in section 4.5, is therefore best understood not as a narrow fix specific to cassava, but as one instance of a more general principle for regulating globalized trade in traditionally processed staple foods: food-safety information needs to travel with the product across the same distance the product itself travels.

CONCLUSION

Reframing an existing linamarin quantification dataset as a dietary exposure assessment reveals that fresh and minimally processed cassava products entering non-endemic markets can meet or exceed an internationally recognized acute cyanide reference dose for child consumers under plausible single-serving scenarios, while fully processed products present negligible comparative risk — a separation of more than two orders of magnitude that is robust across both hazard-quotient and margin-of-exposure framings. Extending the original point-estimate analysis with a serving-size sensitivity check shows that this risk boundary is broader than a single reference serving size suggests: cassava cortex and peel, sub-threshold at 100 g, cross the acute reference dose at realistic serving sizes below 210 g, indicating that the population of imported cassava products meriting processing-specific consumer guidance is larger than a single fixed-serving analysis would identify. Processing degree, rather than country of origin, is the primary determinant of this risk gradient — a finding consistent with, and here extended in exposure-assessment terms to a novel, non-endemic consumption context relative to, the long-established literature linking incomplete cassava processing to cyanide-related disease in production-region settings. These findings support the development of processing-status-specific guidance and labelling, expressed where possible in margin-of-exposure rather than raw hazard-quotient terms for clearer risk communication to non-specialist audiences, for cyanogenic cassava products in import-dependent, non-endemic markets, and illustrate the value of applying formal exposure-assessment methodology, including sensitivity analysis around key scenario assumptions, to existing analytical datasets originally generated for method-validation purposes.

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Ethical approval

Not applicable. This study is a secondary reanalysis of previously published, publicly available analytical data (Azmi 2019) and did not involve new data collection from human participants or animals.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

The linamarin concentration data underlying this reanalysis are available in the cited source (Azmi 2019).

Derived cyanide-equivalent concentrations, hazard quotients, and margin-of-exposure calculations generated for this study are available from the corresponding author on reasonable request.

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