Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Aflatoxin contamination of commercial food products in Malawi: an eleven-year regulatory surveillance study (2016–2026)

Daniel S. Mwalwayo
Malawi Bureau of Standards
Limbikani Matumba
Lilongwe University of Agriculture and Natural Resources (LUANAR)
Jonas Mwatseteza
University of Malawi
Teddie Mollande
Malawi Bureau of Standards
Benjamin Kanyenda
Malawi Bureau of Standards
Stephen Kuyeli
Malawi Bureau of Standards
Bernard Thole
Malawi University of Business and Applied Sciences (MUBAS)
Maurice Monjerezi
mmonjerezi@unima.ac.mw

University of Malawi

Article

Keywords: aflatoxin, food safety, Malawi, dietary exposure, margin of exposure, groundnut value chain

Posted Date: October 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10932129/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Aflatoxins are potent natural carcinogens contaminating staple foods across sub-Saharan Africa, yet long-term food-chain data for Malawi are scarce. We analysed 1,264 regulatory samples of 10 commercial products (beans, corn-soy blend, macadamia, maize flour, maize grain, peanut butter, peanut flour, peanuts, porridge flour, and rice) that were tested for total aflatoxin by the Malawi Bureau of Standards between 2016 and 2026. Overall, 41.2% of ready-to-eat samples exceeded the European Union limit, and 37.6% of all samples exceeded the Malawian limit (maximum 222.8 µg/kg). Among 247 infant and weaning-food samples, 44.5% exceeded the Codex limit of 5 µg/kg, and all exceeded the Malawian infant limit of 0.1 µg/kg, which lies below the reporting limit of the lateral-flow assay used. Peanut flour was the most contaminated product (median 83.8 µg/kg). Processed products were more contaminated than raw commodities (Mann–Whitney U test, $P < 0.001$), driven by the groundnut chain, in which the median increased 31-fold from raw peanuts to peanut flour. Illustrative exposure modelling yielded margins of exposure of 4–19 and 0.7–3.2 excess liver cancer cases per 100,000 people per year from maize alone. Contamination showed no consistent temporal trend. Processing and post-harvest handling are critical control points, and infant foods require more sensitive testing.

Introduction

Mycotoxins, a diverse group of secondary metabolites produced by fungi, have attracted considerable attention because of their impact on human and animal health, food safety, and agricultural economies. They contaminate a large fraction of the global food supply, with recent estimates suggesting that 60–80% of food crops carry detectable levels, far above the long-held assumption of 25%[1].

Among the diverse mycotoxins, aflatoxins are the most prominent owing to their potent toxicity and wide distribution across agricultural commodities. Aflatoxins are produced primarily by *Aspergillus* species, notably *Aspergillus flavus* and *Aspergillus parasiticus*, under favourable conditions of temperature, humidity and substrate availability. They comprise a group of structurally related compounds, aflatoxin B1 (AFB1), B2 (AFB2), G1 (AFG1), and G2 (AFG2), of which AFB1 is the most toxic and prevalent[2–7]. AFB1 is classified as a Group 1 human carcinogen and is a principal cause of hepatocellular carcinoma, acting synergistically with chronic hepatitis B infection, a combination of relevance in sub-Saharan Africa, where both exposures are common. In response to growing health concerns, many countries have set regulations limiting mycotoxin levels in food. These regulations are based on risk assessment (hazard and exposure) and reflect agriculturally achievable levels in different foodstuffs[8–10]. Regulatory limits for aflatoxin in selected food products across selected countries are presented in Supplementary Table S1.

Malawi's food system is heavily dependent on maize and groundnuts, both highly susceptible to aflatoxin contamination, as well as on processed derivatives of these crops (maize flour, peanut butter, peanut flour, and corn-soy blend), which are widely traded and consumed. Despite this, systematic data on contamination across a range of commercial products and on the resulting consumer exposure are

limited. This study reports total aflatoxin levels in 10 commercial food products collected for regulatory purposes by the Malawi Bureau of Standards over 11 years (2016–2026). The study aimed at (i) quantifying contamination and regulatory non-compliance by product, (ii) testing whether processed products are more contaminated than raw commodities, (iii) examining temporal trends, and (iv) translating the measured concentrations into an illustrative dietary-exposure and liver-cancer-risk assessment for Malawian consumers.

Results and discussion

This eleven-year analysis of 1,264 commercial food samples provides one of the most comprehensive pictures to date of aflatoxin contamination in Malawi's commercial food supply. Three findings stand out: contamination is widespread and often exceeds regulatory limits; risk is concentrated at specific points along value chains rather than being uniformly distributed; and current regulatory testing is insufficiently sensitive to protect the most vulnerable consumers. Each has direct implications for food-safety policy.

Overall contamination and product differences

Across the 1,264 samples, aflatoxin concentrations ranged from 0.8 to 222.8 µg/kg (the maximum in maize flour), with an overall median of 3.6 µg/kg. Contamination was high overall: of the 1,017 ready-to-eat samples subject to a European Union (EU) total aflatoxin limit[11], 41.2% (419/1,017) exceeded it, and 37.6% (475/1,264) of all samples exceeded their applicable Malawian limit[12,13]. Under a uniform assessment against the general 4 and 10 µg/kg limits, 44.5% and 21.2% of samples exceeded the respective thresholds. The distribution was strongly right-skewed, with most products clustered around low values and a long tail of heavily contaminated samples (Fig. 1).

Contamination differed significantly among the ten products (Kruskal–Wallis H = 163.7, df = 9, $P < 0.001$; $\varepsilon^2 = 0.13$, a moderate effect; with a sample of 1,264, the test is highly powered, so the effect size rather than the *P* value conveys the practical magnitude). Peanut flour was by far the most contaminated product (median 83.8 µg/kg), followed at a considerable distance by peanut butter (7.1 µg/kg), porridge flour (5.2 µg/kg) and corn-soy blend (4.6 µg/kg); rice (2.3 µg/kg), beans (2.5 µg/kg) and peanuts (2.7 µg/kg) were the least contaminated (Supplementary Table S2, Fig. 1). Notably, maize grain (median 3.5 µg/kg) sat in the middle of the distribution rather than near the top. Dunn's post hoc test with Benjamini–Hochberg correction identified 33 of 45 pairwise comparisons as significant (adjusted $P < 0.05$); the resulting significance groups are shown as letters in Fig. 1, confirming that these product differences were robust rather than driven by a few extreme values.

The proportion of samples exceeding regulatory limits varied markedly among products (Supplementary Table S3, Fig. 2). Among the ready-to-eat products, peanut flour showed the highest non-compliance (77.4% > EU; 67.7% > MS 302), followed by peanut butter (60.3% > EU; 45.9% > MS 302), maize flour (50.4%) and maize grain (44.1%). Even the least contaminated products were not negligible: 18.4–27.0%

of beans, rice, peanuts and macadamia samples exceeded the EU limit. Against MS 302, maize grain (34.9%), peanut butter (45.9%) and peanut flour (67.7%) were the most frequent violators. The two infant foods were non-compliant with the Codex limit[14] in 44.0% (corn-soy blend) and 53.8% (porridge flour) of samples, and with the Malawian infant limit[13] in 100% of samples for both.

The scale of this contamination is consistent with earlier Malawian studies reporting frequent, often severe, aflatoxin contamination of maize and groundnut products[7,15,16]. Malawi's warm climate, reliance on aflatoxin-susceptible crops, smallholder production and limited post-harvest infrastructure together create conditions highly favourable to *Aspergillus* growth and toxin accumulation. Mann–Kendall trend tests on annual medians were conducted for the nine products with at least four sampled years. One product, maize flour, reached nominal significance before correction ($P = 0.048$), but no product remained significant after Benjamini–Hochberg correction across the parallel per-product tests (adjusted $P = 0.30$ for maize flour). Annual non-compliance remained high throughout (Fig. 3): among ready-to-eat products it fluctuated between 25.0% (2022) and 55.0% (2017) against the EU limit, and among infant foods between 13.6% (2024) and 87.5% (2017, n = 8) against the Codex limit, with no downward trajectory in either series. The persistence of high contamination across the full 2016–2026 period, with no significant decline in any product (all adjusted $P > 0.05$), indicates that awareness campaigns and existing controls have not yet translated into measurable improvement.

The corn-soy blend (CSB) and porridge flour results warrant scrutiny because both are fortified weaning foods formulated for infants and young children, who ingest the most food per unit of body weight and are the most susceptible to aflatoxin's effects on growth and its role in hepatocellular carcinoma. Every one of the 234 CSB samples and all 13 porridge-flour samples exceeded the Malawian infant-food limit of 0.1 µg/kg (MS 90:2018); 44.0% of CSB and 53.8% of porridge-flour samples also exceeded the less stringent Codex limit of 5 µg/kg, and 16.7% of CSB samples exceeded even the general Malawian limit of 10 µg/kg. The apparent complete non-compliance with MS 90:2018 is, however, a statement about the stringency of that standard relative to the method rather than a measurement of how far above it the samples lay: routine lateral-flow monitoring did not report concentrations below 2 µg/kg, twenty times the 0.1 µg/kg standard, so compliance with the national infant limit could not be verified for any sample in the series, even in principle. The monitoring regime is therefore structurally weak precisely where the standard is strictest, a regulatory blind spot with serious public-health implications; closing it will require adopting more sensitive quantitative methods, such as HPLC or LC–MS/MS confirmation, for infant foods, together with dedicated surveillance of the weaning-food supply chain. This limitation does not diminish the public-health concern; rather, it underscores that current routine testing is insufficient to verify that weaning foods meet the applicable limit.

Contamination along the value chain: raw versus processed products

Processed and value-added products carried significantly higher aflatoxin concentrations than raw commodities overall (median 4.7 versus 2.9 µg/kg; Mann–Whitney U test, $P < 0.001$; rank-biserial

correlation = 0.30, a moderate effect; the composition of each category is detailed in Supplementary Table S4), but this single contrast masked a strongly commodity-specific pattern along the country's major value chains (Fig. 4). In the groundnut chain, contamination rose sharply across successively more processed products: the median climbed from 2.7 µg/kg in raw peanuts to 7.1 µg/kg in peanut butter and 83.8 µg/kg in peanut flour, an approximately 31-fold difference between the raw commodity and the most processed product (Fig. 4).

Because samples were not linked at the lot level, this gradient is an association across products rather than a tracked transformation of the same material; it is nonetheless consistent with the concentration of contaminated and cull kernels into ground products[7] and, possibly, with mould proliferation under the warm, humid, informal conditions of small-scale storage and processing. In the maize chain, by contrast, grain (median 3.5 µg/kg) and flour (4.1 µg/kg) showed comparable contamination, with no evidence that milling systematically reduced or increased aflatoxin levels. The association between processing and contamination was therefore driven overwhelmingly by the groundnut chain rather than being a universal feature of processing. This pattern points to the handling, sorting, storage and grinding steps of the groundnut chain, rather than the peanut itself, as candidate critical control points for aflatoxin. Interventions could therefore be targeted at the specific steps at which the toxin appears to concentrate, focusing on the groundnut sector, rather than applied uniformly across processed foods.

Unsupervised multivariate analysis was consistent with this reading. Each product was profiled using four features (log median, log interquartile range, log maximum, and percentage of samples exceeding the applicable limit) and subjected to principal component analysis (PCA) and Ward hierarchical clustering (Fig. 5). The first principal component captured 72.5% of the variance (first two components, 94.5%); all four features loaded in the same direction, identifying PC1 as a single axis of contamination severity along which the products ranged from rice, beans, macadamia and peanuts at the low end to peanut flour at the high end. The second component (22.0% of variance) separated products with an extreme upper tail of a few very high samples from those with more uniformly elevated prevalence. Unsupervised clustering did not separate raw from processed foods. Instead, the high-severity cluster mixed both categories, with raw maize grain grouped with processed maize flour, peanut butter, and corn-soy blend, while the low-contamination raw commodities (rice, beans, macadamia, peanuts), together with porridge flour, formed a separate cluster, and peanut flour separated from every other product. Contamination severity therefore tracks the specific commodity and its value chain rather than a simple raw-versus-processed distinction.

Two mechanisms may explain this pattern. First, numerous pre- and post-harvest interventions at farm level in Malawi have substantially reduced aflatoxin contamination in raw produce, yet comparatively little is done at the aggregator and processor level, where negligent handling and storage can allow contamination to develop. Second, much of the raw produce submitted for testing is destined for export and undergoes rigorous sorting, leaving shrivelled, damaged, and highly contaminated grain for local processing[7,16–18]. Both scenarios result in highly contaminated processed products reaching the market, as seen here for peanut flour, peanut butter and corn-soy blend. Our product-resolved, eleven-year series

extends this earlier export-concentration observation by localising it to specific steps in the value chain. The effect is concentrated in the most-processed groundnut products (peanut flour and butter) and persists throughout the monitoring period rather than being a transient feature. Contamination of food crops with aflatoxins is among the major factors compromising product quality during storage[19].

Public-health significance of exposure

Translating the measured maize concentrations into consumer exposure indicates a substantial potential health burden. Using the pooled maize median of 3.8 µg/kg (grain and flour combined, reflecting maize as consumed), a central adult maize intake of 337 g/day and a body weight of 60 kg, the estimated margin of exposure (MOE) was 18.7 at the median maize concentration and 4.2 at the mean, both far below the value of 10,000 that signals a public-health concern and indicating exposures more than two orders of magnitude into the range of concern (Table 1). Across the plausible intake range (300–383 g/day), the MOE remained below 22 in all cases.

Table 1
Illustrative dietary exposure and liver cancer risk scenarios for adults (maize) and infants (corn-soy blend). EDI, estimated daily intake; MOE, margin of exposure (concern if < 10,000). Parameters are literature-derived; see Methods and Supplementary Information.

Group	Level	Conc. (µg/kg)	Intake (g/day)	BW (kg)	EDI (ng/kg bw/day)	MOE	Risk, population*	Risk, HBsAg+*
Adult	median	3.8	337	60	21.3	18.7	0.7	6.4
Adult	mean	17.0	337	60	95.2	4.2	3.2	28.6
Infant	median	4.6	100	9	51.1	7.8	1.7	15.3
Infant	mean	9.3	100	9	102.9	3.9	3.4	30.9

**Excess liver-cancer cases per 100,000 per year, for the population average (~ 8% HBsAg prevalence) and for HBsAg-positive individuals.*

Expressed as cancer risk, these exposures correspond to an estimated 0.7 (median) to 3.2 (mean) excess cases of liver cancer per 100,000 people per year from maize consumption alone, using a population-average potency and weighting by an assumed 8% HBsAg prevalence. In hepatitis-B-positive individuals, for whom aflatoxin potency is roughly 30-fold higher, the corresponding estimates rise to 6.4 (median) to 29 (mean) excess cases per 100,000 per year. For the infant corn-soy blend scenario (9 kg body weight, 50–100 g/day), MOEs were similarly low (7.8 at the median and 3.9 at the mean), underscoring the disproportionate exposure of young children on a body-weight basis.

When interpreted against regulatory benchmarks, these exposures fall within the range that EFSA and JECFA consider a public health concern, and the corresponding excess liver cancer estimates are consistent with aflatoxin's established role in the region's high hepatocellular carcinoma burden[20,21]. The

interaction with endemic hepatitis B is particularly important because it multiplies the per-unit potency of aflatoxin and concentrates risk in an identifiable group that would benefit from both aflatoxin control and hepatitis B vaccination. These figures are illustrative; intake and HBsAg-prevalence parameters were drawn from the literature rather than measured in this population, and the calculation assumes the sampled commercial products are representative of food as consumed and are intended to convey the order of magnitude of the potential impact rather than a precise population risk. Their consistency across scenarios nonetheless indicates that aflatoxin exposure from these commodities is very likely to be of public health significance in Malawi.

Having outlined the illustrative, order-of-magnitude exposure estimates and their attendant uncertainties, we now turn to consider their broader implications for food-safety governance and the strengthening of Malawi's national aflatoxin monitoring system. Being regulatory samples, these results also speak to the effectiveness of the national food-safety monitoring system. They suggest that the way food-safety measures are implemented and enforced could be strengthened to improve their effectiveness. Emphasis within the food chain should be placed on the quality of raw materials and on the systems processors put in place during handling and storage to minimise aflatoxin contamination; monitoring and testing of final products should serve to verify that these systems are working. Persistent non-compliance among producers points to accountability within the processing sector as a further target for strengthening. These observations are consistent with earlier reports[7,15]. African countries generally have limited capacity to manage aflatoxin contamination, resulting in high contamination levels and missed export opportunities[22]. The pattern is also consistent with increased *Aspergillus flavus* infection during storage, likely reflecting suboptimal postharvest handling by value chain actors[23].

Conclusion

This study is among a few studies reporting on a large sample size of 1,264, over a long period (11-year span), focusing on a large number (10) of commercial products, including processed and infant foods that are often neglected in surveillance. It shows that aflatoxin contamination in Malawi's commercial foods is widespread, frequently exceeds regulatory limits, and showed no consistent change from 2016 to 2026. The greatest risk lies along the groundnut value chain, where contamination was up to 31-fold higher in the most processed product than in the raw commodity, and in infant corn-soy blends and porridge flour, which were uniformly non-compliant with the 0.1 µg/kg Malawian infant standard (MS 90:2018) and which current lateral-flow testing cannot monitor at that level at all. Contamination tracked the specific commodity and its value chain rather than a simple raw-versus-processed distinction, underscoring handling, storage and processing by aggregators and processors as the critical control points. As noted above, these are regulatory samples and may not fully represent the wider food supply, and the exposure estimates are illustrative. To improve safety, efforts should focus on: (i) the high-risk processing and storage stages, especially in the groundnut sector; (ii) adopting more sensitive, quantitative testing methods for infant foods, with reporting limits below the 0.1 µg/kg standard; and (iii) strengthening enforcement and traceability for processed foods.

Methods

Sample collection and aflatoxin determination

Samples of ten commonly consumed commercial food products (beans, corn-soy blend (CSB), macadamia, maize flour, maize grain, peanut butter, peanut flour, peanuts, porridge flour and rice) were submitted to the Malawi Bureau of Standards (MBS) for aflatoxin testing between 2016 and 2026. These products were selected because they are staple, widely traded commodities in Malawi and are routinely monitored for regulatory compliance. A total of 1,264 samples with valid product identity, collection year and analytical result were included in the analysis.

Total aflatoxin (AFB1 + AFB2 + AFG1 + AFG2) was determined using Reveal Q + for Aflatoxin lateral-flow immunoassay kits according to the manufacturer's directions (Neogen Corporation, Lansing, MI, USA). Reveal Q + is a single-step lateral-flow immunochromatographic assay in a competitive format intended for quantitative testing of aflatoxin in grain and grain products. The kits are validated methods with a good cross-reactivity profile and recovery rate[24] and are approved by the Federal Grain Inspection Service of the US Department of Agriculture for official testing[25,26]. The analytical procedure followed was that described by Ng'ambi et al.[27]. Developed test strips were read in a Reveal AccuScan Gold Reader (AccuScan Gold Reader 9595, Neogen Corporation), which was calibrated with manufacturer-supplied standards before each reading. The kit has a quantification range of 2–150 µg/kg total aflatoxin; samples above 100 µg/kg were diluted and re-analysed. Each sample was analysed in duplicate using separate portions. Concentrations are expressed as µg/kg (equivalent to ppb) of total aflatoxin and are reported and analysed as measured, without censoring or substitution.

Data analysis

Non-parametric methods were used throughout because aflatoxin concentrations were strongly right-skewed. Contamination was summarised by product using medians and ranges alongside means. Differences among products were tested using the Kruskal–Wallis test, followed by Dunn's post hoc test with Benjamini–Hochberg control of the false discovery rate. Differences between raw and processed products were tested using the Mann–Whitney U test, with the rank-biserial correlation reported as the effect size. Temporal trends in annual medians were assessed for each product using the Mann–Kendall trend test, implemented as the Kendall rank correlation (tau-b) of annual median on year, with a Benjamini–Hochberg correction across the nine products with at least four sampled years.

To summarise how the products relate across contamination metrics simultaneously, each product was profiled by four features (the $\log_{10}$ median, $\log_{10}$ interquartile range, $\log_{10}$ maximum concentration, and the percentage of samples exceeding the applicable limit) which were standardised and then subjected to principal component analysis and Ward hierarchical clustering using Euclidean distances. All analyses were performed in R 4.5.3[28]. The Kruskal–Wallis and Mann–Whitney U tests, Kendall rank-correlation trend tests, Benjamini–Hochberg adjustment, principal component analysis and hierarchical clustering

used base R stats; Dunn's post hoc test used PMCMRplus 1.9.12, the compact-letter display multcompView 0.1.12, and the rank-biserial effect size rcompanion 2.5.4. Figures were produced with ggplot2 4.0.3. All tests were two-tailed, and statistical significance was set at $P < 0.05$.

Compliance was evaluated against product-specific total-aflatoxin thresholds, listed with their instruments in Supplementary Table S1. The eight ready-to-eat products were judged against the European Union maximum for ready-to-eat foods (4 µg/kg; Commission Regulation (EU) 2023/915)[11] and the Malawian national limit (10 µg/kg; MS 302)[12]. The two infant and weaning foods (corn-soy blend and porridge flour) were judged against the Codex maximum level for cereal-based foods for infants and young children (5 µg/kg; CXS 193–1995)[14] and the Malawian infant-food limit (0.1 µg/kg; MS 90:2018)[13]. The EU sets its limit for this food category at aflatoxin B1 (0.1 µg/kg) rather than total aflatoxins, so the infant foods could not be assessed against an EU standard using the total aflatoxin measurements reported here; percentages exceeding an EU limit therefore refer only to the 1,017 ready-to-eat samples. For comparison with earlier work, samples were additionally assessed against uniform thresholds of 4 and 10 µg/kg irrespective of product category. Products were classified as raw commodities (maize grain, peanuts, beans, rice, macadamia) or processed/value-added products (maize flour, peanut butter, peanut flour, corn-soy blend, porridge flour) for comparative analysis (Supplementary Table S4).

Dietary exposure and cancer risk assessment

To place the measured concentrations in a public health context, we conducted an illustrative assessment of dietary exposure and cancer risk. Because product-specific consumption data for the study population were not collected, intake parameters were drawn from the published literature, and results are presented as scenarios rather than definitive population estimates. Estimated daily intake (EDI, ng/kg body weight/day) was calculated as

$$EDI = \frac{C \times IR}{\mathrm{BW}} \qquad (1)$$

where C is the aflatoxin concentration (µg/kg), IR the food intake rate (g/day) and BW the body weight (kg). For adults, maize intake was taken as 300–383 g/day (central estimate 337 g/day) and body weight as 60 kg. For infants, corn-soy blend intake was taken as 50–100 g/day and body weight as 9 kg (intake ranges from published Malawian and regional dietary data; see Supplementary Information). The margin of exposure (MOE) was calculated as

$$MOE = \frac{\mathrm{BMD}L_{10}}{\mathrm{EDI}} \qquad (2)$$

using a benchmark dose lower limit ($BMDL_{10}$) of 400 ng/kg bw/day for AFB1; an MOE below 10,000 indicates a public health concern[29]. Population cancer risk was estimated using JECFA average potency values of 0.3 and 0.01 cancers per year per 100,000 population per ng/kg bw/day for hepatitis-B-surface-

antigen (HBsAg) positive and negative individuals respectively[20]. This was combined with an assumed adult HBsAg prevalence of 8%, within the range reported for sub-Saharan African populations[30], to give a population-average potency. Full parameter values and sources are presented in the Supplementary Information.

Declarations

Competing interests

D.S.M., T.M., B.K., and S.K. are employees of the Malawi Bureau of Standards (MBS), the national regulatory authority that produced the compliance testing records analysed in this study. MBS did not participate in designing the analysis, interpreting the results, or deciding to publish. The authors received no compensation or benefits beyond their usual salaries. L.M., J.M., B.T., and M.M. declare no conflicts of interest. No author has any financial or non-financial conflicts to disclose.

Funding

This work received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. It was supported institutionally by the Malawi Bureau of Standards and the University of Malawi.

Author Contribution

D.S.M.: conceptualisation, investigation, data curation, formal analysis and writing of the original draft. L.M.: methodology, validation, and review and editing. J.M.: supervision, and review and editing. T.M.: investigation and resources. B.K.: supervision, and review and editing. S.K.: investigation and resources. B.T.: supervision, and review and editing. M.M.: conceptualisation, formal analysis, supervision, and review and editing. All authors reviewed and approved the final manuscript.

Acknowledgement

The authors thank the laboratory analysts and technical staff of the MBS Food and Environment Laboratory who performed the sample analyses during the study period, and the MBS Quality Assurance Unit for maintaining the sample registration and archiving systems that underlie this dataset.

Data Availability

The samples analysed were submitted to the Malawi Bureau of Standards by commercial entities for routine regulatory compliance testing. Individual records are linked to identifiable submitters and constitute confidential commercial information; the raw dataset therefore cannot be made publicly

available. A de-identified dataset containing product type, collection year and analytical result (the variables used in this analysis) is available from the corresponding author on reasonable request and subject to authorisation by the Malawi Bureau of Standards.

References

1. Eskola, M. et al. Worldwide contamination of food-crops with mycotoxins: validity of the widely cited 'FAO estimate' of 25%. *Crit. Rev. Food Sci. Nutr.* **60**, 2773–2789. 10.1080/10408398.2019.1658570 (2020).
2. Alim, M. et al. Survey of mycotoxins in retail market cereals, derived products and evaluation of their dietary intake. *Food Control*. **84**, 471–477. 10.1016/j.foodcont.2017.08.034 (2018).
3. Al-Taher, F. et al. Detection and quantitation of mycotoxins in infant cereals in the U.S. market by LC-MS/MS using a stable isotope dilution assay. *Food Control*. **72**, 27–35. 10.1016/j.foodcont.2016.07.027 (2017).
4. Blankson, G. K. & Mill-Robertson, F. C. Aflatoxin contamination and exposure in processed cereal-based complementary foods for infants and young children in greater Accra, Ghana. *Food Control*. **64**, 212–217. 10.1016/j.foodcont.2015.12.032 (2016).
5. Do, T. H. et al. Dietary exposure and health risk characterization of aflatoxin B1, ochratoxin A, fumonisin B1, and zearalenone in food from different provinces in Northern Vietnam. *Food Control*. **112**, 107108. 10.1016/j.foodcont.2020.107108 (2020).
6. Huong, B. T. M. et al. Total dietary intake and health risks associated with exposure to aflatoxin B1, ochratoxin A and fuminisins of children in Lao Cai Province, Vietnam. *Toxins* 11, 638; (2019). 10.3390/toxins11110638
7. Matumba, L., Van Poucke, C., Monjerezi, M., Njumbe Ediage, E. & De Saeger Concentrating aflatoxins on the domestic market through groundnut export: a focus on Malawian groundnut value and supply chain. *Food Control*. **51**, 236–239. 10.1016/j.foodcont.2014.11.035 (2015).
8. Ismail, A. et al. Aflatoxin in foodstuffs: occurrence and recent advances in decontamination. *Food Res. Int.* **113**, 74–85. 10.1016/j.foodres.2018.06.067 (2018).
9. Jallow, A., Xie, H., Tang, X., Qi, Z. & Li, P. Worldwide aflatoxin contamination of agricultural products and foods: from occurrence to control. *Compr. Rev. Food Sci. Food Saf.* **20**, 2332–2381. 10.1111/1541-4337.12734 (2021).
10. Lukwago, F. B., Mukisa, I. M., Atukwase, A., Kaaya, A. N. & Tumwebaze, S. Mycotoxin contamination in foods consumed in Uganda: a 12-year review (2006–18). *Sci. Afr.* **3**, e00054. 10.1016/j.sciaf.2019.e00054 (2019).
11. European Commission. Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) 1881/2006. *Off J. Eur. Union*. **L 119**, 103–157 (2023).

12. Malawi Bureau of Standards. *Contaminants and Toxins in Food — General Standard MS 302:2008* (Malawi Bureau of Standards, 2008).
13. Malawi Bureau of Standards. *High-Protein Cereal-Based Foods for Infants and Young Children — Specification MS 90:2018* 2nd edn (Malawi Bureau of Standards, 2018).
14. Codex Alimentarius Commission. General Standard for Contaminants and Toxins in Food and Feed CXS 193–1995 (adopted 1995, revised 2009, amended 2025) (FAO/WHO. (2025).
15. Matumba, L. et al. A survey of the incidence and level of aflatoxin contamination in a range of locally and imported processed foods on Malawian retail market. *Food Control*. **39**, 87–91. 10.1016/j.foodcont.2013.09.068 (2014).
16. Mwalwayo, D. S. & Thole, B. Prevalence of aflatoxin and fumonisins (B1 + B2) in maize consumed in rural Malawi. *Toxicol. Rep.* **3**, 173–179. 10.1016/j.toxrep.2016.01.010 (2016).
17. Matumba, L., Van Poucke, C., Njumbe Ediage, E., Jacobs, B. & De Saeger, S. Effectiveness of hand sorting, flotation/washing, dehulling and combinations thereof on the decontamination of mycotoxin-contaminated white maize. *Food Addit. Contam. Part. A*. **32**, 960–969. 10.1080/19440049.2015.1029535 (2015).
18. Matumba, L., Van Poucke, C., Njumbe Ediage, E. & De Saeger, S. Keeping mycotoxins away from the food: does the existence of regulations have any impact in Africa? *Crit. Rev. Food Sci. Nutr.* **57**, 1584–1592. 10.1080/10408398.2014.993021 (2017).
19. Nakai, V. K. et al. Distribution of fungi and aflatoxins in a stored peanut variety. *Food Chem.* **106**, 285–290. 10.1016/j.foodchem.2007.05.087 (2008).
20. Liu, Y. & Wu, F. Global burden of aflatoxin-induced hepatocellular carcinoma: a risk assessment. *Environ. Health Perspect.* **118**, 818–824. 10.1289/ehp.0901388 (2010).
21. Gong, Y. Y. et al. Postweaning exposure to aflatoxin results in impaired child growth: a longitudinal study in Benin, West Africa. *Environ. Health Perspect.* **112**, 1334–1338. 10.1289/ehp.6954 (2004).
22. Monyo, E. S. et al. Occurrence and distribution of aflatoxin contamination in groundnuts (*Arachis hypogaea* L) and population density of aflatoxigenic Aspergilli in Malawi. *Crop Prot.* **42**, 149–155. 10.1016/j.cropro.2012.07.004 (2012).
23. Seetha, A. et al. Occurrence of aflatoxins and its management in diverse cropping systems of central Tanzania. *Mycotoxin Res.* **33**, 323–331. 10.1007/s12550-017-0286-x (2017).
24. Le, Q. N. et al. Reveal Q + MAX for detection of total aflatoxin in corn, almonds, pistachios, walnuts, and peanuts. *J. AOAC Int.* **102**, 525–531. 10.5740/jaoacint.18 (2019).
25. US Department of Agriculture. Grain Inspection, Packers and Stockyards Administration, Federal Grain Inspection Service. Performance Verified Mycotoxin Test Kits: Aflatoxin (USDA, (2016).
26. US Department of Agriculture, Agricultural Marketing Service, Federal Grain Inspection Service. FGIS Approved Mycotoxin Rapid Test Kits. USDA, (2022). https://www.ams.usda.gov/sites/default/files/media/FGISApprovedMycotoxinRapidTestKits.pdf

27. Ng'ambi, J. T. et al. Micro-climatic variations across Malawi have a greater influence on contamination of maize with aflatoxins than with fumonisins. *Mycotoxin Res.* **39**, 33–44. 10.1007/s12550-022-00471-1 (2023).
28. R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, (2026). https://www.R-project.org/
29. EFSA Panel on Contaminants in the Food Chain (CONTAM). Risk assessment of aflatoxins in food. *EFSA J.* **18**, e06040. 10.2903/j.efsa.2020.6040 (2020).
30. Quintas, A., Cuboia, N. & Cordeiro, L. Seroprevalence of hepatitis B virus surface antigen among African blood donors: a systematic review and meta-analysis. *Front. Public. Health*. **12**, 1434816. 10.3389/fpubh.2024.1434816 (2024).

Figures

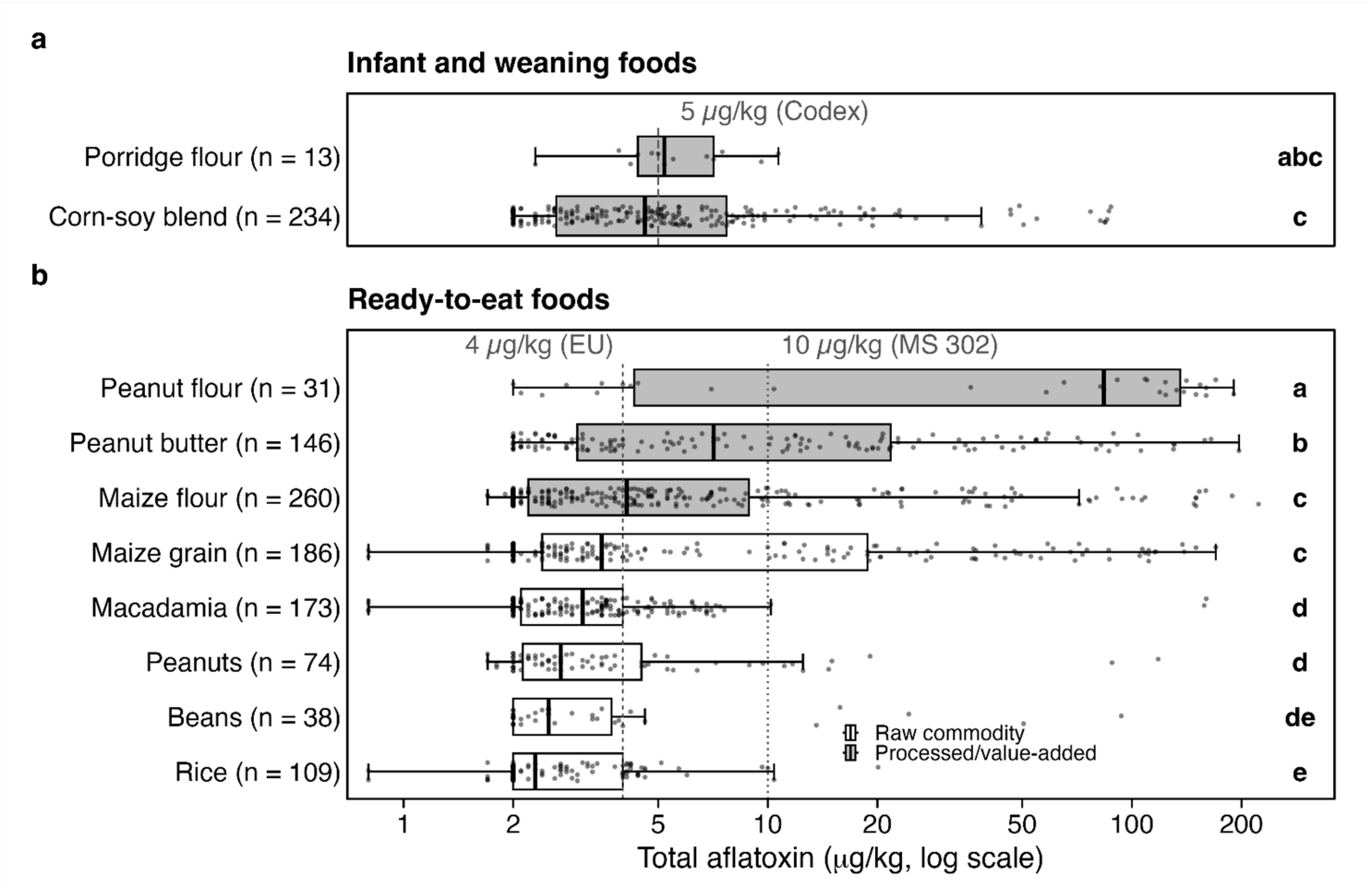


Figure 1

Distribution of total aflatoxin concentrations by food product. (**a**) The two infant and weaning foods. (**b**) The eight ready-to-eat products. Bold letters denote significance groups from Dunn's post hoc test with Benjamini–Hochberg control of the false discovery rate (33 of 45 pairwise comparisons significant at

adjusted $P < 0.05$); the test was run across all ten products simultaneously, so letters are comparable between panels and products sharing a letter do not differ significantly.

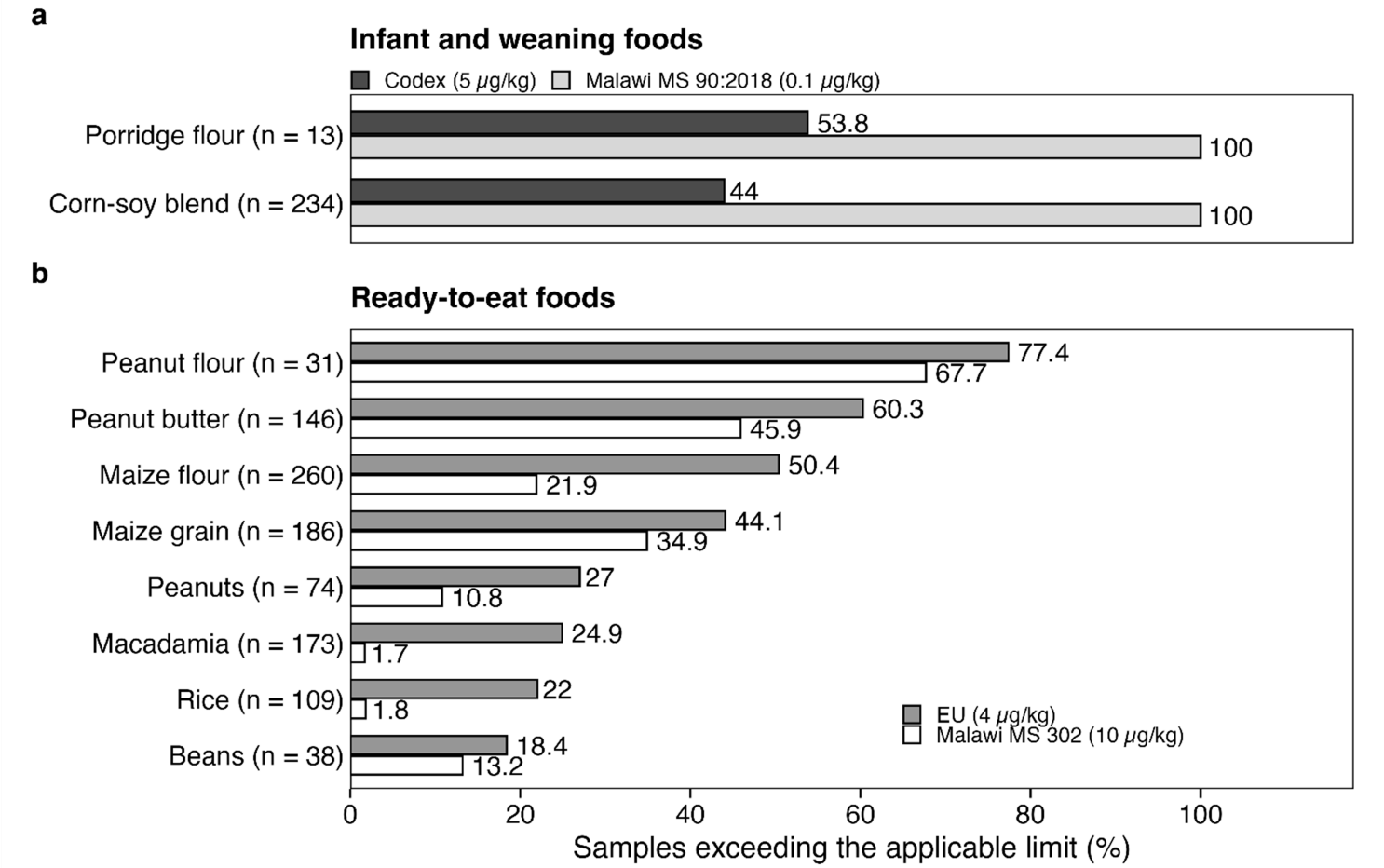


Figure 2

Regulatory non-compliance by food product, as percentage of samples exceeding the applicable total-aflatoxin limit. (**a**) The two infant and weaning foods, assessed against the Codex limit of 5 µg/kg (CXS 193-1995, 2025 edition) and the Malawian limit of 0.1 µg/kg (MS 90:2018). (**b**) The eight ready-to-eat products, assessed against the EU limit of 4 µg/kg and the Malawian limit of 10 µg/kg (MS 302), ordered by EU exceedance.

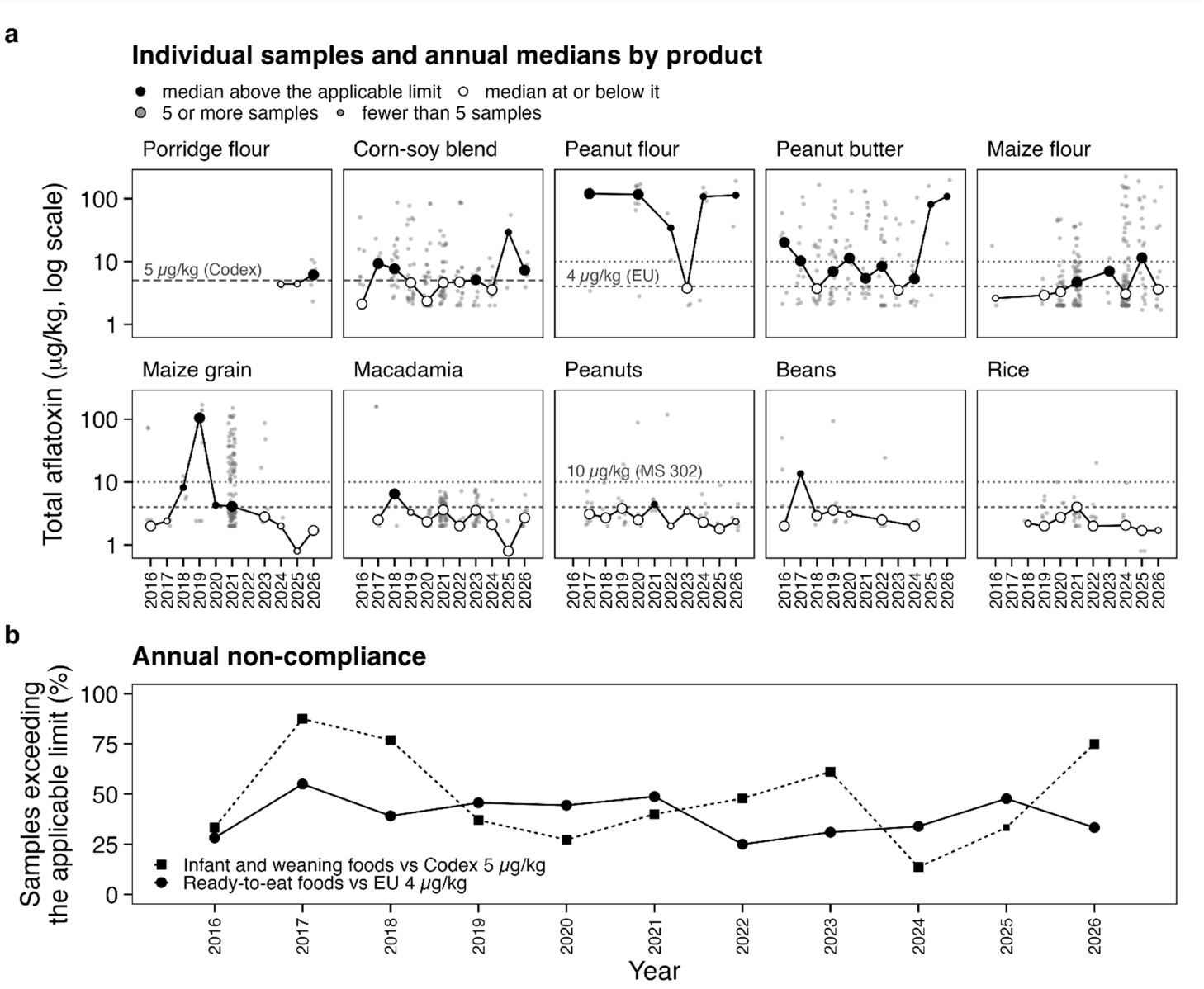


Figure 3

Temporal pattern of total aflatoxin contamination, 2016–2026. (**a**) Every sample (grey points, horizontally jittered; larger points mark years with five or more samples) and the annual median (circles, filled when above the applicable limit and open when at or below it) for each of the ten products, ordered with the infant and weaning foods first and the remainder by descending overall median. Each facet carries only the limits that govern that product. (**b**) Annual percentage of samples exceeding the applicable limit.

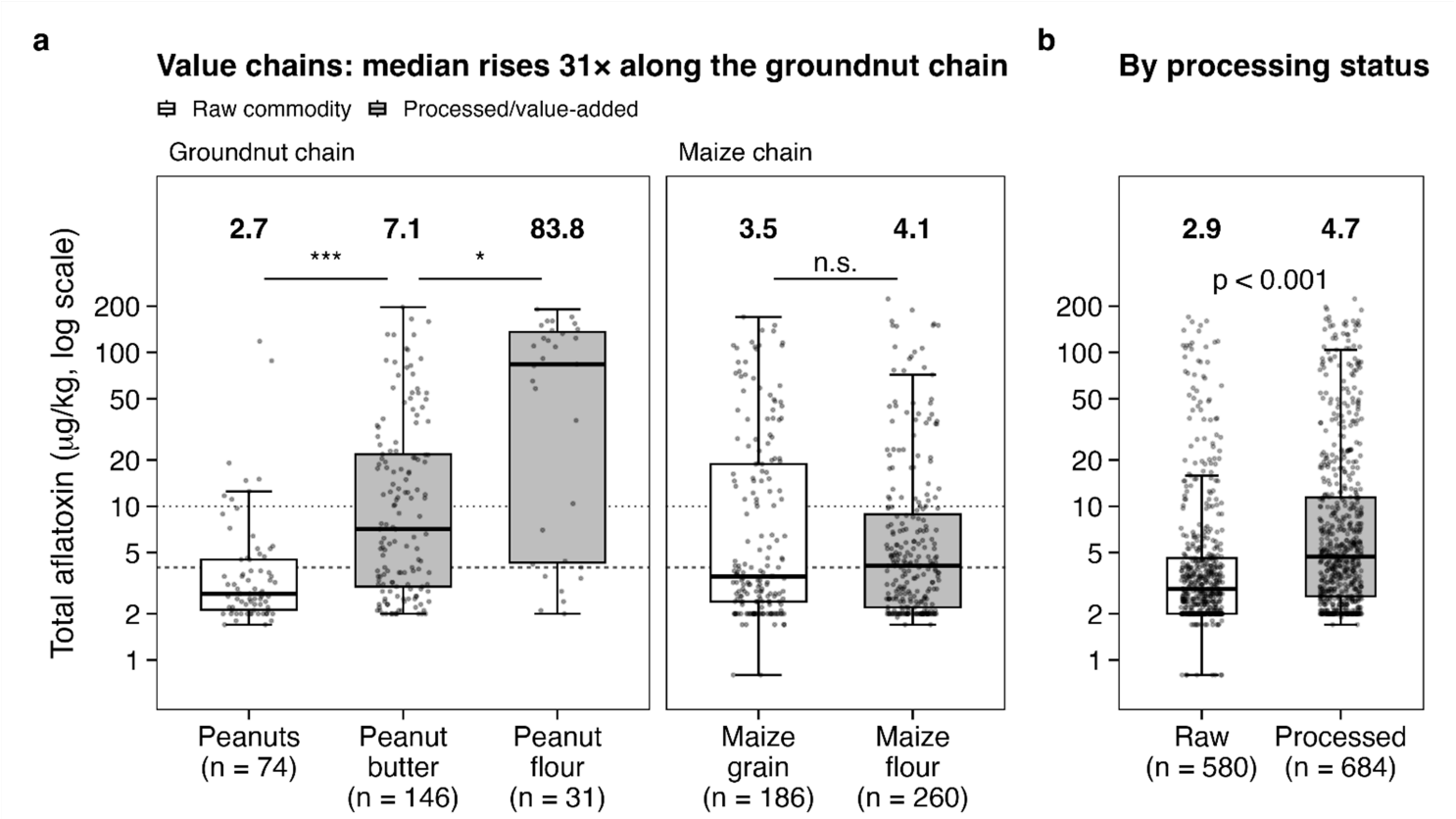


Figure 4

Total aflatoxin along two value chains and by processing status. (**a**) Distribution of total aflatoxin (µg/kg, log scale) in the groundnut chain (peanuts to peanut butter to peanut flour) and the maize chain (grain to flour), in chain order rather than by median. Benjamini–Hochberg-adjusted *P* values from the Dunn test reported in Fig. 1 are shown for each adjacent step: *** $P < 0.001$, * $P < 0.05$, n.s., not significant. Median contamination values are also provided. (**b**) All 1,264 samples grouped by processing status, with the same box, whisker and point conventions.

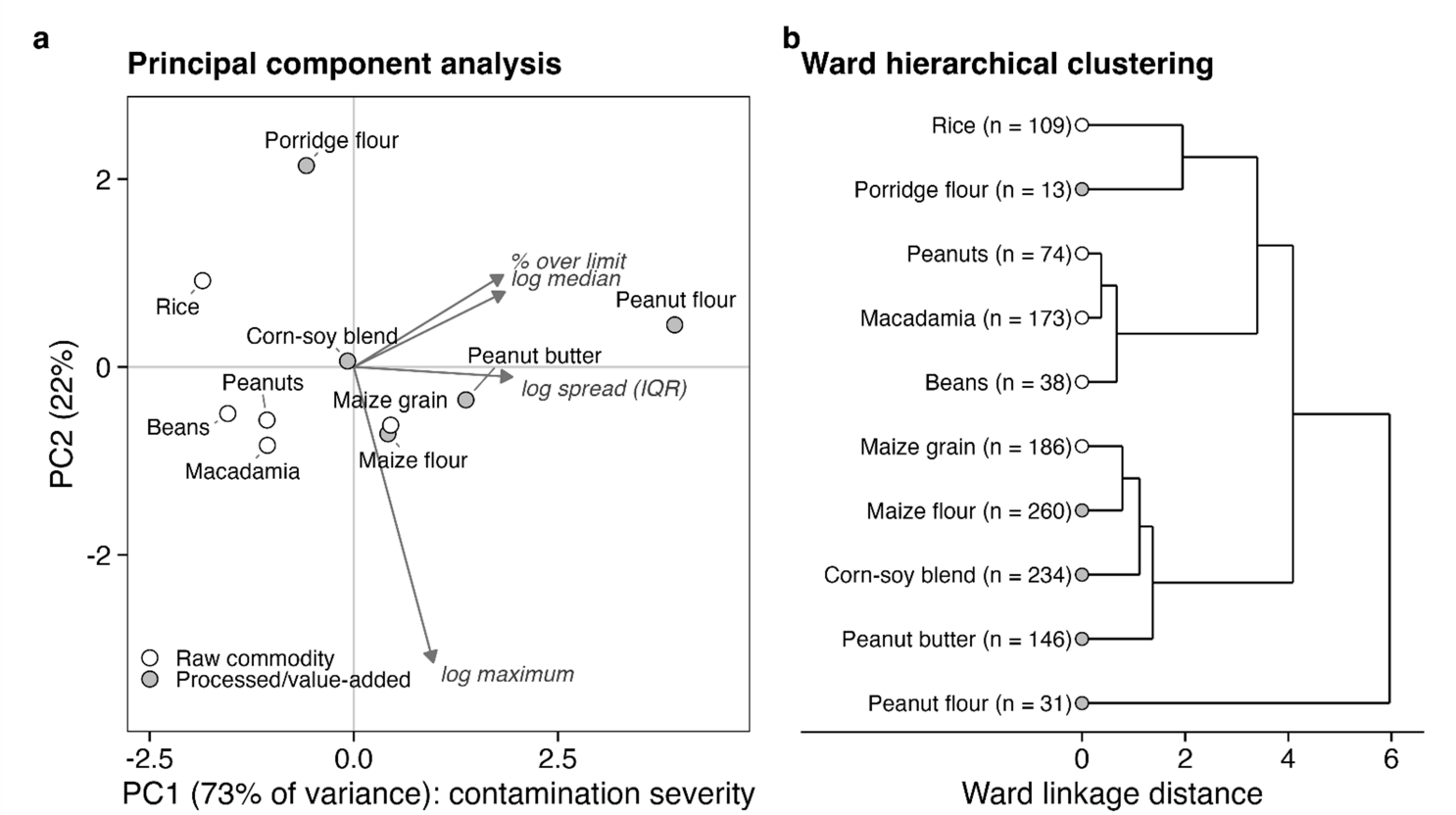


Figure 5

Multivariate structure of aflatoxin contamination across the ten products. (**a**) Principal component analysis of the ten products described by four features: the $\log_{10}$ median, $\log_{10}$ interquartile range and $\log_{10}$ maximum concentration, and the percentage of samples exceeding the applicable limit (the EU limit for ready-to-eat products, the Codex limit for the two infant foods). (**b**) Ward hierarchical clustering dendrogram (Euclidean distance, Ward linkage) of the same four standardised features. Peanut flour separates from all other products; the high-severity cluster contains both raw (maize grain) and processed (maize flour, corn-soy blend, peanut butter) products, and the low-contamination cluster contains rice, porridge flour, peanuts, macadamia and beans, showing that severity tracks the commodity and its value chain rather than processing status.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- MwalwayoetalSciRepSupplementaryInformation.docx