WHO estimates of the global, regional, and national disease burden of nine foodborne chemicals, 2000–21: an updated data synthesis

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Summary

Background We updated WHO estimates of the global, regional, and national foodborne disease burden caused by chemical hazards. We estimated incidence, mortality, and disability-adjusted life-years (DALYs) of aflatoxins B1 and M1, inorganic arsenic, lead, methylmercury, cadmium, dioxin, peanut allergy, and cassava cyanide for 2000–21.

Methods We used data from systematic reviews, established dose-response relationships, the Global Burden of Disease Study 2021, and, where applicable, a structured expert judgment study. We used disease-specific models and a hierarchical meta-regression model with geographical clustering and global linear time trend with uncertainty propagation.

Findings In 2021, the nine foodborne chemicals caused 6·26 million (95% uncertainty interval [UI] 3·36–10·30) cases, 1·12 million (0·40–2·10) deaths, and 29·8 million (12·9–53·1) DALYs globally. Inorganic arsenic and lead caused the highest burden. Cardiovascular diseases due to inorganic arsenic and lead caused 88·9% of foodborne chemical deaths and 76·5% of foodborne chemical DALYs. The greatest DALY rate was estimated for the South-East Asia region, with 789 DALYs (272–1660) per 100 000 people mostly due to inorganic arsenic and lead (94·2%). The region of the Americas carried the highest foodborne chemical DALY rate in children younger than 5 years, with 749 DALYs (435–1260) per 100 000 children, mainly due to the effect of methylmercury on intellectual disability (91·0%). DALY rates from dioxin showed the steepest decrease from 2000 to 2021.

Interpretation Dietary exposure to chemicals causes a substantial global disease burden. An integrated response with ongoing non-communicable disease prevention efforts is key. Granular assessment including subnational exposure contexts is essential to ensure equity.

Funding WHO.

Introduction

Dietary exposure to chemical hazards has raised concerns within the global health community for decades. In 1953, the sixth World Health Assembly expressed the view that chemical substances in food might usefully be investigated.[1] Toxicological risk assessment of chemicals is an approach for evaluating whether given exposure levels are safe, but does not provide tangible insights regarding the magnitude of the public health impact. In contrast, the burden of disease approach weighs hazards on a common scale and allows for comparison of the impact on global health across chemical hazards, and with other hazards, such as bacteria, parasites, and viruses.

WHO established the Foodborne Disease Burden Epidemiology Reference Group (FERG) in 2007 and estimated the global foodborne disease burden for selected hazards commonly transmitted via food, including three chemical hazards: dioxins and dioxin-like polychlorinated biphenyls (dl-PCBs), aflatoxin B1, and konzo due to cassava cyanide.[2] Subsequent independent estimates of the 2015 global disease burden caused by dietary exposure of four metals were later published.[3] Although this was one of the first efforts to quantify the burden of foodborne chemicals, especially on the global level, the global burden of disease from foodborne chemicals has largely been unrecognised. This information is crucial to support investments in food safety.

Through the mandate by the 73rd World Health Assembly Resolution on strengthening efforts on food safety, FERG reconvened in 2021 to advise WHO on the methodology to estimate the burden of foodborne diseases at a global, regional, and for the first time, national level. Within FERG, the Chemicals and Toxins Task Force (CTTF) advise WHO on the assessment of the foodborne chemical disease burden.[4,5] We aimed to estimate the global, regional, and national disease burden of nine foodborne chemical hazards from 2000 to 2021.

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Research in context

Evidence before this study

In 2015, WHO published global estimates of foodborne disease, including chemical hazards, advised by the WHO technical advisory group, the Foodborne Disease Burden Epidemiology Reference Group (FERG). These provided estimates for cassava cyanide, peanut allergy (not global estimates), aflatoxin B1, and dioxins and dioxin-like polychlorinated biphenyls. These four chemicals combined caused 20 000 deaths and 1·01 million healthy life-years lost in 2010. Independent, subsequent studies of the disease burden caused by four metals (lead, inorganic arsenic, methylmercury, and cadmium) reported more than 9 million healthy life-years lost in 2015 globally.

Added value of this study

This study provides updated and refined estimates of the 2010 WHO global foodborne chemical disease burden plus additional hazards (aflatoxin M1, inorganic arsenic, cadmium, lead, and methylmercury) and associated non-communicable diseases. This 2026 edition includes for the first time country-level estimates and time-trend analysis. Despite a decrease in the disease burden from 2000 to 2021, the persistent contribution of foodborne chemicals to cardiovascular diseases (in particular, ischaemic heart disease), cancers, and intellectual disability remains considerable. It highlights the neurotoxicity of methylmercury and lead, and related burden in children younger than 5 years. This new assessment improves understanding about the relative contributions to the global burden of various chemical hazards, and sheds light on burden disparities between geographical areas and across age groups.

Implications of all the available evidence

This study highlights the under-recognised link between food safety and non-communicable diseases. These estimates provide evidence to inform risk management decisions and related resources allocation, and might contribute to more holistic assessments, legitimately balancing stringency of food safety measures with trade-offs on food security and nutrition.

Methods

Overview

We followed a standard FERG protocol that included prioritisation criteria for hazards, computational framework, and centralised, consistent data analyses.[6] For each hazard, we employed a set of different methodologies, namely the risk assessment approach, counterfactual analysis, and categorical attribution, to estimate incidence and mortality caused by dietary exposure (table 1; appendix 1 pp 5–23).[6,7] We collected data for the analysis from systematic reviews, applied dose-response relationships from internationally recognised organisations, employed data from WHO and the Global Burden of Disease Study 2021, and a structured expert judgment study.[8] An overview of the analysis is presented in a flowchart in appendix 1 (p 6). We followed reporting guidelines for global health (GATHER) and burden of disease (STROBOD) studies (appendix 1 pp 24–30).[9,10] We present global, regional, and national estimates of the disease burden caused by dietary exposure to nine chemical hazards from 2000 to 2021.[11,12]

See Online for appendix 1

Selections of hazards and outcomes

We complemented the chemical hazard inventory from FERG for 2007–15 with a review of recent scientific evaluations and regulatory reports from national and international authorities.[13] We identified the health outcomes either for single chemicals or for chemical groups. Thereafter, we screened 39 chemicals using predefined criteria of perceived frequency of occurrence, perceived severity of cases, and perceived economic impact of hazard, identifying hazards with clear public health relevance and sufficient supporting data and evidence (appendix 1 pp 4, 31–32).[6] In addition to the hazards, for which the global burden of foodborne disease had been estimated for 2010, the 2026 update added aflatoxin M1; peanut allergy (previously estimated for selected regions only); and four metals: cadmium, inorganic arsenic, lead, and methylmercury.

Informed by expert input from commissioned research teams, we excluded prenatal and postnatal thyroid impairments attributed to dioxins and dl-PCBs, which were included as health outcomes in the 2010 estimates, and only considered 2,3,7,8-tetrachlorodibenzo para dioxin (hereafter referred to as dioxin) out of the total group of dioxins and dl-PCBs. For the newly included chemicals, the selected health outcomes comprised hepatocellular carcinoma (hereafter referred to as liver cancer) related to dietary exposure to aflatoxin M1. For the four metals, the CTTF advised inclusion of the health outcomes from the previous 2015 global estimates with two additions: ischaemic heart disease caused by dietary exposure to inorganic arsenic, following recent assessments and cardiovascular disease caused by dietary exposure to lead.[3,14,15] The chemicals and health outcomes included are summarised in table 1.

Data sources

Data collection for burden estimation was for most chemicals commissioned through a WHO call for applications. Commissioned teams conducted either literature searches or systematic reviews, most of which are described in PROSPERO protocols (appendix 1 p 32). Data collection for lead was not commissioned as it was decided to base the estimates on the Global Burden of Disease Study 2021 lead disease burden and a structured expert judgment study.[8] Where relevant, CTTF or commissioned researchers collected information on dose-response relationships for computing probability of disease from most recent reports of international or national organisations. We used disease

	Outcome	Overall methodology*		Disease model assumptions*		
		Disease burden†	Dietary exposure assessment	Duration	Disability weight (95% uncertainty interval)	Mortality
Dioxin	Male infertility	Risk assessment approach	Dioxin breast milk concentrations	26 years (from age 18–45 years)	0·008 (0·003–0·015)	Non-fatal
Aflatoxin B1	Liver cancer	Counterfactual analysis	Occurrence in maize and peanuts from systematic literature review combined with consumption of maize and peanuts from FAOSTAT	Not applicable	Not applicable	Not applicable
Aflatoxin M1	Liver cancer	Counterfactual analysis	Occurrence in milk from systematic literature review combined with consumption of milk from FAOSTAT and WHO	Not applicable	Not applicable	Not applicable
Cassava cyanide	Konzo	Categorical attribution	Not applicable	Fatal: 3 years (range 1–7)	0·063 (0·047–0·080)	Case-fatality rate: 21%
Cassava cyanide	Konzo	Categorical attribution	Not applicable	Non-fatal: lifelong	0·063 (0·047–0·080)	Non-fatal
Peanut allergy	Living with peanut allergy	Categorical attribution	Not applicable	Lifelong	0·015 (0·007–0·025)	Mortality rates from systematic literature review
Inorganic arsenic	Lung cancer	Counterfactual analysis	Dietary exposure from systematic literature review	Not applicable	Not applicable	Not applicable
Inorganic arsenic	Skin cancer	Counterfactual analysis	Dietary exposure from systematic literature review	Not applicable	Not applicable	Not applicable
Inorganic arsenic	Bladder cancer	Counterfactual analysis	Dietary exposure from systematic literature review	Not applicable	Not applicable	Not applicable
Inorganic arsenic	Ischaemic heart disease	Counterfactual analysis	Dietary exposure from systematic literature review	Not applicable	Not applicable	Not applicable
Cadmium	Chronic kidney disease stage 4	Risk assessment approach	Dietary exposure from systematic literature review	Lifelong	0·104 (0·07–0·147)	Non-fatal
Cadmium	Chronic kidney disease stage 5	Risk assessment approach	Dietary exposure from systematic literature review	Lifelong	0·569 (0·389–0·727)	Case-fatality rates by country
Lead	Cardiovascular disease	GBD lead burden combined with proportion foodborne	Foodborne proportion of total burden due to lead obtained from structured expert judgement study	Not applicable	Not applicable	Not applicable
Lead	Intellectual disability (all classes)	GBD lead burden combined with proportion foodborne	Foodborne proportion of total burden due to lead obtained from structured expert judgement study	Not applicable	Not applicable	Not applicable
Methylmercury	Borderline intellectual disability	Risk assessment approach	Hair or blood methylmercury concentrations from systematic literature review (assuming dietary exposure is main contributor in the general population)	Lifelong	0·011 (0·005–0·02)	Non-fatal
Methylmercury	Mild intellectual disability	Risk assessment approach	Hair or blood methylmercury concentrations from systematic literature review (assuming dietary exposure is main contributor in the general population)	Lifelong	0·043 (0·026–0·064)	Non-fatal
Methylmercury	Moderate intellectual disability	Risk assessment approach	Hair or blood methylmercury concentrations from systematic literature review (assuming dietary exposure is main contributor in the general population)	Lifelong	0·1 (0·066–0·142)	Non-fatal
Methylmercury	Severe intellectual disability	Risk assessment approach	Hair or blood methylmercury concentrations from systematic literature review (assuming dietary exposure is main contributor in the general population)	Lifelong	0·16 (0·107–0·226)	Non-fatal
Methylmercury	Profound intellectual disability	Risk assessment approach	Hair or blood methylmercury concentrations from systematic literature review (assuming dietary exposure is main contributor in the general population)	Lifelong	0·200 (0·133–0·283)	Non-fatal

*All details are presented in appendix 1 (pp 5–23). †Disease burden methodology refers to the overall approaches applied to estimate incidence, mortality, and disability-adjusted life-years; counterfactual analysis refers to the approach in which the proportion of total incidence and mortality of an outcome is attributed to a given hazard (eg, foodborne chemical); categorical attribution refers to the direct attribution of an incident case to the cause (eg, an individual diagnosed with peanut allergy); risk assessment approach refers to the methodology in which (dietary) exposure to a hazard (chemical) is integrated with a dose response relationship quantifying the probability of a given outcome as a function of the exposure (eg, the estimation of male infertility incidence from exposure of dioxin in breast milk).

Table 1: **Summary of included chemicals, methods for estimating incidence, and disease model parameters for estimating disability-adjusted life-years**

	Outcome	Cases (mean, 95% UI)	Deaths (mean, 95% UI)	DALYs (mean, 95% UI)
Dioxin	Male infertility	37 000 (16 900 to 78 900)	0	7730 (2340 to 18 500)
Aflatoxin B1	Hepatocellular carcinoma	14 000 (5920 to 28 000)	13 200 (5570 to 26 400)	412 000 (179 000 to 813 000)
Aflatoxin M1	Hepatocellular carcinoma	29 (16 to 48)	27 (15 to 45)	895 (487 to 1570)
Cassava cyanide	Konzo	145 (50 to 335)	31 (10 to 72)	2530 (837 to 5890)
Peanut allergy	Living with peanut allergy	281 000 (143 000 to 512 000)	5 (0 to 16)	290 000 (111 000 to 577 000)
Inorganic arsenic	Lung cancer	120 000 (40 000 to 268 000)	90 500 (30 400 to 196 000)	2 350 000 (771 000 to 5 070 000)
Inorganic arsenic	Skin cancer	117 (11 to 631)	48 (4 to 263)	1240 (87 to 6640)
Inorganic arsenic	Bladder cancer	48 100 (20 700 to 90 900)	20 300 (8140 to 38 000)	453 000 (176 000 to 855 000)
Inorganic arsenic	Ischaemic heart disease	2 040 000 (625 000 to 5 260 000)	530 000 (183 000 to 1 280 000)	12 600 000 (3 930 000 to 31 700 000)
Cadmium	Chronic kidney disease stage 4	146 (16 to 690)	0	236 (25 to 1130)
Cadmium	Chronic kidney disease stage 5	56 (7 to 325)	47 (5 to 294)	1170 (136 to 6080)
Lead	Cardiovascular diseases	1 580 000 (–176 000 to 3 930 000)	466 000 (–52 300 to 1 180 000)	10 200 000 (–1 160 000 to 25 200 000)
Lead	Intellectual disability	118 000 (33 200 to 242 000)	0	1 030 000 (293 000 to 2 130 000)
Methylmercury	Borderline intellectual disability	1 640 000 (834 000 to 3 190 000)	0	1 230 000 (411 000 to 2 760 000)
Methylmercury	Mild intellectual disability	371 000 (204 000 to 665 000)	0	1 100 000 (492 000 to 2 180 000)
Methylmercury	Moderate intellectual disability	10 900 (5380 to 19 600)	0	74 800 (32 300 to 148 000)
Methylmercury	Severe intellectual disability	1100 (276 to 2990)	0	12 000 (2930 to 32 000)
Methylmercury	Profound intellectual disability	446 (94 to 2110)	0	6000 (1180 to 27 800)
Total	..	6 260 000 (3 360 000 to 10 300 000)	1 120 000 (404 000 to 2 100 000)	29 800 000 (12 900 000 to 53 100 000)

DALYs=disability-adjusted life-years. UIs=uncertainty intervals.

Table 2: **Mean global numbers of foodborne incident cases, deaths, and DALYs by chemical and health outcome, with 95% UIs, 2021**

envelopes from WHO and estimates from the 2021 Global Burden of Disease Study for 2000–21, either obtained directly from the Institute for Health Metrics and Evaluation (IHME) or via the Global Burden of Disease results tool. We identified additional data either through our review or through a country consultation. We used the UN country-level population data for 2000–21 as demographic data.[6] All data sources, decisions, and assumptions are detailed and referenced in appendix 1 (pp 5–23).

Estimating incidence and mortality for each hazard

Details on the methodology used to estimate incidence and mortality for each hazard (ie, systematic reviews, dose-response models, and the assumptions and decisions involved) are provided in appendix 1 (pp 5–23). A brief overview for each hazard is presented below.

Under a counterfactual analysis approach, we derived population-attributable fractions (PAFs) to estimate incident cases of outcomes related to aflatoxins and inorganic arsenic. For each country, we calculated excess risk from aflatoxin B1 and M1 by multiplying country-specific dietary exposure via peanuts and maize and milk, respectively, by potency factors based on a multiplicative model for combined effects of aflatoxin exposure and hepatitis B virus (HBV) infection. We applied a similar potency-factor approach for arsenic-related skin cancers. For lung cancer, bladder cancer, and ischaemic heart disease, we calculated PAFs using a model describing lifetime extra risk, as a function of lifetime inorganic arsenic exposure applied to country-specific dietary exposure.

We used a risk assessment approach to estimate male infertility due to dioxin, cadmium-induced chronic kidney disease, and intellectual disability caused by methylmercury. A dose-response model estimated reductions in sperm concentration in men exposed to dioxin, and male infertility incidence, was derived using WHO reference values. For cadmium, we applied a dose-response function relating urinary cadmium to glomerular filtration rate (GFR) to estimate age-corrected population GFR changes, which we used to estimate the annual incidence of chronic kidney disease stages 4 and 5. Based on an established relationship between loss of intelligence quotient (IQ) points in children and maternal exposure to methylmercury, we estimated intellectual disability by modelling IQ distribution shifts in children.

We applied a categorical attribution for konzo and peanut allergy. We identified konzo cases through a systematic review of cassava-related disease burden, primarily outbreak investigations, cross-sectional studies, and surveys. We included studies reporting case definitions, temporal onset, and population base. For peanut allergy, we collected national-specific prevalence and mortality from peanut-induced anaphylaxis. We converted prevalence to incidence assuming onset before age 5 years and lifelong duration.

Finally, we employed a source attribution structured expert judgment study to estimate the proportion of disease burden of cardiovascular diseases and intellectual disability attributable to dietary exposure of lead. Experts provided uncertainty assessments for subregional-specific attribution proportions to transmission pathways, including food, which were aggregated using mathematical validated methods. We combined resulting uncertainty distributions with national envelopes for lead-induced (all sources of exposure) intellectual disability and nine cardiovascular

	Dioxin	Aflatoxin B1	Aflatoxin M1	Cassava cyanide	Peanut allergy	Inorganic arsenic	Cadmium	Lead	Methylmercury	Total
African region										
Foodborne incidence rate	0·332 (0·067 to 1·05)	0·227 (0·125 to 0·387)	<0·001 (<0·001 to 0·002)	0·012 (0·004 to 0·029)	4·15 (1·55 to 10·3)	5·72 (1·04 to 18·6)	<0·001 (<0·001 to <0·001)	7·67 (–0·336 to 22·7)	22·5 (9·92 to 42·3)	40·6 (22·5 to 70·3)
Foodborne mortality rate	0	0·213 (0·119 to 0·361)	<0·001 (<0·001 to 0·002)	0·003 (<0·001 to 0·006)	<0·001 (<0·001 to <0·001)	1·29 (0·316 to 3·72)	<0·001 (<0·001 to <0·001)	1·72 (–0·144 to 5·22)	0	3·23 (0·789 to 7·65)
Foodborne DALY rate	0·07 (0·01 to 0·248)	8·04 (4·29 to 13·7)	0·032 (0·009 to 0·088)	0·217 (0·072 to 0·506)	3·80 (1·14 to 9·71)	34·2 (8·47 to 98·5)	<0·001 (<0·001 to 0·001)	44·8 (–1·60 to 132·7)	25·2 (11·5 to 48·4)	116·4 (51·0 to 232·3)
Foodborne DALY rate for those younger than 5 years	0	0	0	0·117 (0·039 to 0·272)	24·9 (7·48 to 63·7)	0	0	2·94 (0·300 to 9·16)	165·5 (75·4 to 318·1)	193·5 (96·3 to 347·7)
Foodborne DALY rate for those 5 years or older	0·083 (0·012 to 0·292)	9·48 (5·06 to 16·2)	0·038 (0·011 to 0·104)	0·235 (0·078 to 0·548)	0·004 (<0·001 to 0·014)	40·3 (10·0 to 116·2)	<0·001 (<0·001 to 0·001)	52·3 (–2·15 to 155·4)	0	102·5 (30·1 to 234·8)
Region of the Americas										
Foodborne incidence rate	0·256 (0·084 to 0·720)	0·221 (0·087 to 0·459)	<0·001 (<0·001 to <0·001)	0	4·35 (2·14 to 8·47)	11·7 (4·14 to 32·4)	<0·001 (<0·001 to <0·001)	3·72 (–0·172 to 15·7)	37·2 (21·5 to 61·1)	57·5 (36·1 to 89·6)
Foodborne mortality rate	0	0·199 (0·079 to 0·411)	<0·001 (<0·001 to <0·001)	0	<0·001 (<0·001 to <0·001)	5·08 (1·79 to 13·4)	<0·001 (<0·001 to <0·001)	0·910 (–0·061 to 3·95)	0	6·19 (2·48 to 15·0)
Foodborne DALY rate	0·054 (0·012 to 0·179)	4·95 (2·00 to 10·2)	0·004 (0·002 to 0·011)	0	4·62 (1·71 to 9·89)	104·6 (37·3 to 277·8)	<0·001 (<0·001 to <0·001)	18·7 (–0·685 to 82·2)	46·9 (25·4 to 80·8)	179·8 (96·5 to 356·9)
Foodborne DALY rate for those younger than 5 years	0	0	0	0	67·2 (24·8 to 143·8)	0	0	0·600 (0·017 to 2·67)	681·2 (369·1 to 1175·0)	749·0 (435·3 to 1263·6)
Foodborne DALY rate for those 5 years or older	0·058 (0·013 to 0·193)	5·31 (2·15 to 11·0)	0·005 (0·002 to 0·012)	0	0·004 (<0·001 to 0·012)	112·3 (40·0 to 298·4)	<0·001 (<0·001 to <0·001)	20·0 (–0·759 to 88·0)	0	137·7 (56·2 to 330·1)
South-East Asia region										
Foodborne incidence rate	0·381 (0·066 to 1·44)	0·303 (0·058 to 0·885)	<0·001 (<0·001 to <0·001)	0	3·42 (0·955 to 8·99)	62·5 (12·7 to 201·4)	0·007 (<0·001 to 0·044)	43·2 (0·009 to 99·8)	31·4 (12·7 to 69·6)	141·2 (56·4 to 291·4)
Foodborne mortality rate	0	0·291 (0·055 to 0·847)	<0·001 (<0·001 to <0·001)	0	<0·001 (<0·001 to <0·001)	15·8 (3·67 to 46·2)	0·002 (<0·001 to 0·014)	11·1 (–1·29 to 26·6)	0	27·2 (7·43 to 59·5)
Foodborne DALY rate	0·080 (0·011 to 0·338)	8·81 (1·67 to 25·6)	0·013 (0·005 to 0·028)	0	3·42 (0·757 to 9·77)	425·4 (98·6 to 1256·7)	0·052 (0·001 to 0·346)	314·6 (6·31 to 715·7)	36·5 (15·9 to 82·4)	788·8 (272·3 to 1662·2)
Foodborne DALY rate for those younger than 5 years	0	0	0	0	41·1 (9·08 to 117·6)	0	0	50·8 (11·0 to 109·4)	438·8 (191·1 to 991·8)	530·7 (262·6 to 1103·4)
Foodborne DALY rate for those 5 years or older	0·087 (0·012 to 0·369)	9·61 (1·82 to 27·9)	0·014 (0·006 to 0·030)	0	0·004 (<0·001 to 0·013)	464·0 (107·5 to 1370·6)	0·057 (0·001 to 0·378)	338·5 (2·98 to 774·3)	0	812·2 (257·0 to 1762·7)
European region										
Foodborne incidence rate	1·22 (0·456 to 2·96)	0·027 (0·009 to 0·071)	<0·001 (<0·001 to <0·001)	0	2·87 (1·62 to 4·66)	11·9 (3·88 to 32·5)	<0·001 (<0·001 to <0·001)	13·3 (–1·04 to 40·1)	16·5 (9·47 to 29·8)	45·9 (25·1 to 82·2)
Foodborne mortality rate	0	0·025 (0·009 to 0·066)	<0·001 (<0·001 to <0·001)	0	<0·001 (<0·001 to <0·001)	4·35 (1·58 to 11·2)	<0·001 (<0·001 to <0·001)	4·08 (–0·397 to 12·0)	0	8·45 (2·70 to 19·3)

(Table 3 continues on next page)

	Dioxin	Aflatoxin B1	Aflatoxin M1	Cassava cyanide	Peanut allergy	Inorganic arsenic	Cadmium	Lead	Methylmercury	Total
(Continued from previous page)										
Foodborne DALY rate	0·253 (0·068 to 0·693)	0·695 (0·225 to 1·91)	0·003 (0·001 to 0·008)	0	3·21 (1·29 to 6·53)	82·8 (30·1 to 211·5)	<0·001 (<0·001 to <0·001)	69·4 (–5·10 to 198·8)	21·8 (11·4 to 41·1)	178·1 (77·4 to 362·1)
Foodborne DALY rate for those younger than 5 years	0	0	0	0	55·2 (22·1 to 112·3)	0	0	1·76 (0·254 to 5·19)	375·4 (195·8 to 706·5)	432·4 (247·8 to 761·7)
Foodborne DALY rate for those 5 years or older	0·269 (0·072 to 0·736)	0·738 (0·239 to 2·03)	0·004 (0·001 to 0·009)	0	0·004 (<0·001 to 0·012)	87·9 (32·0 to 224·6)	<0·001 (<0·001 to 0·001)	73·5 (–5·47 to 210·9)	0	162·4 (57 to 358·6)
Eastern Mediterranean region										
Foodborne incidence rate	1·12 (0·121 to 4·27)	0·039 (0·017 to 0·08)	<0·001 (<0·001 to 0·001)	0	4·55 (1·77 to 10·8)	12·4 (1·68 to 43·9)	<0·001 (<0·001 to <0·001)	9·30 (–0·249 to 36·0)	37·9 (17·8 to 78·7)	65·3 (35·3 to 122·4)
Foodborne mortality rate	0	0·038 (0·016 to 0·077)	<0·001 (<0·001 to 0·001)	0	<0·001 (<0·001 to <0·001)	2·48 (0·459 to 8·25)	<0·001 (<0·001 to <0·001)	2·20 (–0·187 to 8·61)	0	4·72 (1·02 to 13·9)
Foodborne DALY rate	0·234 (0·02 to 0·951)	1·23 (0·529 to 2·48)	0·018 (0·009 to 0·035)	0	4·61 (1·38 to 11·9)	66 (12·5 to 224·3)	<0·001 (<0·001 to 0·001)	58·0 (–0·423 to 220·6)	45·1 (20·8 to 93·9)	175·2 (74 to 415·5)
Foodborne DALY rate for those younger than 5 years	0	0	0	0	38·5 (11·5 to 99·6)	0	0	6·54 (1·17 to 21·7)	377·0 (174·0 to 783·9)	422·0 (210·6 to 861·6)
Foodborne DALY rate for those 5 years or older	0·266 (0·022 to 1·08)	1·4 (0·601 to 2·82)	0·021 (0·01 to 0·039)	0	0·004 (<0·001 to 0·013)	75·0 (14·2 to 254·8)	<0·001 (<0·001 to 0·001)	65·0 (–1·07 to 248·1)	0	141·6 (35·3 to 403·1)
Western Pacific region										
Foodborne incidence rate	0·138 (0·052 to 0·306)	0·12 (0·046 to 0·306)	<0·001 (<0·001 to <0·001)	0	2·90 (1·20 to 6·10)	27·5 (10·9 to 67·6)	0·003 (0·001 to 0·009)	25·1 (–1·70 to 103·0)	14·7 (6·58 to 37·1)	70·5 (28·4 to 154·8)
Foodborne mortality rate	0	0·112 (0·042 to 0·287)	<0·001 (<0·001 to <0·001)	0	<0·001 (<0·001 to <0·001)	9·86 (4·25 to 22·7)	<0·001 (<0·001 to 0·001)	7·90 (–0·591 to 32·6)	0	17·9 (5·80 to 43·5)
Foodborne DALY rate	0·028 (0·008 to 0·071)	3·69 (1·41 to 9·34)	0·002 (<0·001 to 0·004)	0	3·25 (1·03 to 7·43)	202·8 (87·7 to 435·8)	0·017 (0·007 to 0·038)	151·4 (–9·67 to 617·1)	18·4 (8·11 to 40·3)	379·5 (144·7 to 867·6)
Foodborne DALY rate for those younger than 5 years	0	0	0	0	56·1 (17·7 to 128·2)	0	0	2·31 (0·157 to 7·82)	317·1 (140·0 to 695·3)	375·5 (187·7 to 752·3)
Foodborne DALY rate for those 5 years or older	0·030 (0·008 to 0·076)	3·92 (1·50 to 9·91)	0·002 (<0·001 to 0·004)	0	0·004 (<0·001 to 0·012)	215·3 (93·1 to 462·6)	0·018 (0·007 to 0·040)	160·5 (–10·5 to 654·7)	0	379·8 (130·4 to 899·0)
Global										
Foodborne incidence rate	0·470 (0·214 to 1·00)	0·178 (0·075 to 0·356)	<0·001 (<0·001 to <0·001)	0·002 (<0·001 to 0·004)	3·57 (1·81 to 6·50)	28·1 (10·0 to 69·0)	0·003 (<0·001 to 0·012)	21·5 (–0·866 to 52·0)	25·6 (15·1 to 46·0)	79·4 (42·7 to 130·9)

(Table 3 continues on next page)

	Dioxin	Aflatoxin B1	Aflatoxin M1	Cassava cyanide	Peanut allergy	Inorganic arsenic	Cadmium	Lead	Methylmercury	Total
(Continued from previous page)										
Foodborne mortality rate	0	0·167 (0·071 to 0·335)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	8·14 (3·44 to 17·7)	<0·001 (<0·001 to 0·004)	5·92 (-0·664 to 15·0)	0	14·2 (5·13 to 26·6)
Foodborne DALY rate	0·098 (0·03 to 0·235)	5·24 (2·27 to 10·3)	0·011 (0·006 to 0·020)	0·032 (0·011 to 0·075)	3·68 (1·41 to 7·32)	195·7 (80·9 to 437·5)	0·018 (0·003 to 0·093)	142·2 (-1·89 to 336·6)	30·8 (16·7 to 55·6)	377·8 (163·3 to 674·8)
Foodborne DALY rate for those younger than 5 years	0	0	0	0·031 (0·010 to 0·071)	42·8 (16·4 to 85·2)	0	0	15·1 (4·02 to 31·7)	358·8 (194·8 to 647·6)	416·7 (246·4 to 725·7)
Foodborne DALY rate for those 5 years or older	0·107 (0·032 to 0·257)	5·73 (2·49 to 11·3)	0·012 (0·007 to 0·022)	0·032 (0·011 to 0·075)	0·004 (<0·001 to 0·013)	214·1 (88·5 to 478·6)	0·020 (0·003 to 0·102)	154·1 (-3·56 to 366·7)	0	374·1 (142·2 to 700·5)

Countries by WHO region (appendix 1, Table S9). DALYs=disability-adjusted life-years. UIs=uncertainty intervals.

Table 3: **Mean rates of foodborne incidence, mortality, and DALYs per 100 000 population by chemical and health outcome, age-group, and WHO region with 95% UIs, 2021**

disease outcomes obtained from the 2021 Global Burden of Disease Study.[8,16]

We assumed intellectual disability due to methylmercury and lead, male infertility due to dioxin, and chronic kidney disease stage 4 due to cadmium to be non-fatal. We obtained case-fatality ratios or mortality rates for cadmium-related chronic kidney disease stage 5, konzo, and peanut allergy from literature reviews. For aflatoxins, inorganic arsenic, and lead, we applied the estimated PAFs or food-specific proportions to deaths, years lived with disability (YLDs), and years of life lost (YLLs) envelopes from WHO or the 2021 Global Burden of Disease Study. These envelopes cover cancers of the liver, lung, bladder, and skin, as well as ischaemic heart disease and cardiovascular diseases.

Burden estimation

We used a standardised approach to address data gaps and estimate cases, deaths, and disability-adjusted life-years (DALYs) by country and year. A Bayesian hierarchical meta-regression model with geographical clustering and a global linear time trend was used to smooth and impute country-year-specific input data. The uncertainty of the input parameters was propagated by 500 Monte Carlo simulations through the full model, with the resulting posterior distribution reflecting the combined effect of all sources of uncertainty. If possible, study-specific covariates were added into the model (eg, diagnostic method) to account for systematic error.

We used disease-specific computational disease-models defined by incidence rates and probability parameters to estimate cases, deaths, and DALYs. We used a standard approach to calculate the DALYs, YLDs, and YLLs due to premature mortality. Where relevant, the duration and disability weight for each hazard can be found in table 1 and appendix 1 (pp 5–23). Demographic data were sourced from the UN World Population Prospects 2024 Revision. The computational methodology is fully described elsewhere.[6]

Role of the funding source

WHO funded reviews, review updates, the structured expert judgment study that provided data for this analysis, and Sciensano (CDB and LV), who did the computations for this work. WHO managed the overall project and the country consultation process that identified additional data, although CTTF determined whether data met the inclusion criteria before incorporating them in the analyses. WHO cleared the paper in terms of methods and approach. WHO staff (LI, YM, and CR) participated in drafting the manuscript and in the decision to submit it for publication.

Results

In 2021, the nine foodborne chemical hazards caused an estimated 6·26 million (95% uncertainty interval [UI] 3·36 to 10·30) incident cases (table 2), with 2·21 million (0·79 to 5·44) due to inorganic arsenic, 2·02 million (1·19 to 3·62)

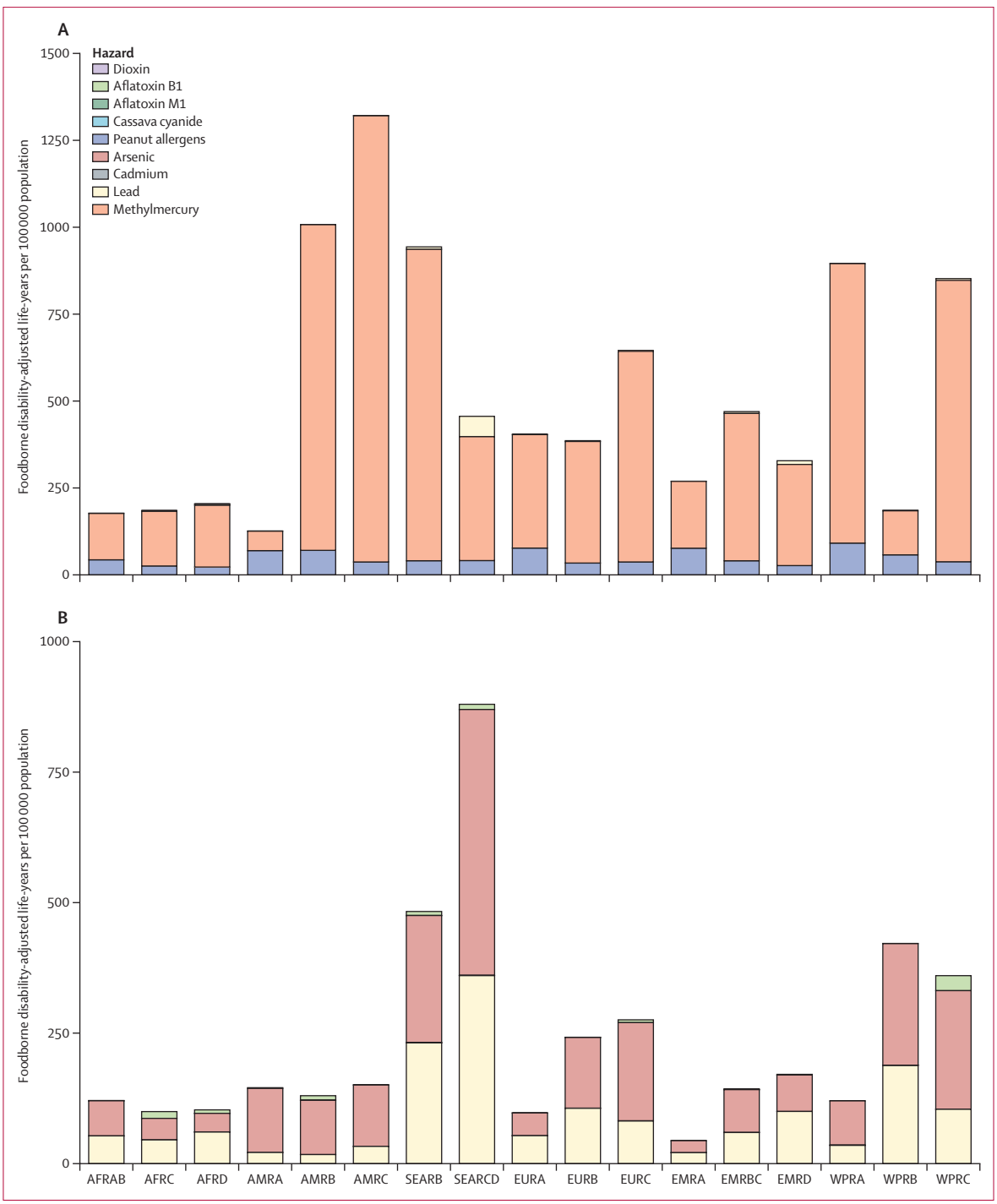
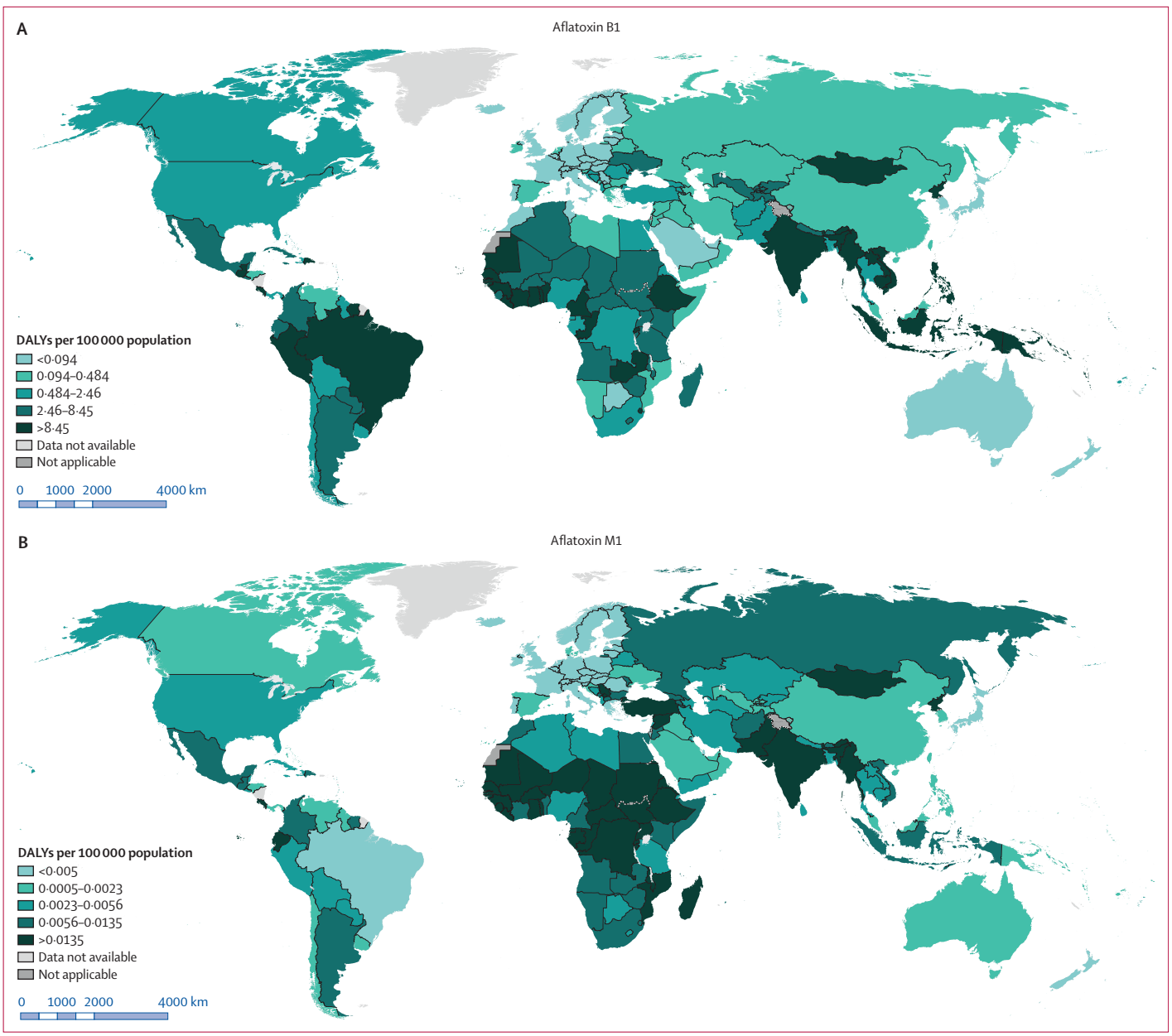


Figure 1: **Contribution to foodborne disability-adjusted life-years per 100 000 population by each chemical, age group, and subregional cluster**
(A) Foodborne disability-adjusted life-year rates for those younger than 5 years by chemical and subregional cluster. (B) Foodborne disability-adjusted life-year for those 5 years or older by chemical and subregional cluster. Countries by subregional clusters (appendix 1 p 61). Countries were grouped into subregional clusters A to D by the six WHO regions and World Bank income classification for fiscal year 2023–24. AFRAB=African region AB. AFRC=African region C. AFRD=African region D. AMRA=Region of the Americas A. AMRB=Region of the Americas B. AMRC=Region of the Americas C. SEARB=South-East Asia region B. SEARCD=South-East Asia region CD. EURA=European region A. EURB=European region B. EURC=European region C. EMRA=Eastern Mediterranean region A. EMRBC=Eastern Mediterranean region BC. EMRD=Eastern Mediterranean region D. WPRA=Western Pacific region A. WPRB=Western Pacific region B. WPRC=Western Pacific region C.



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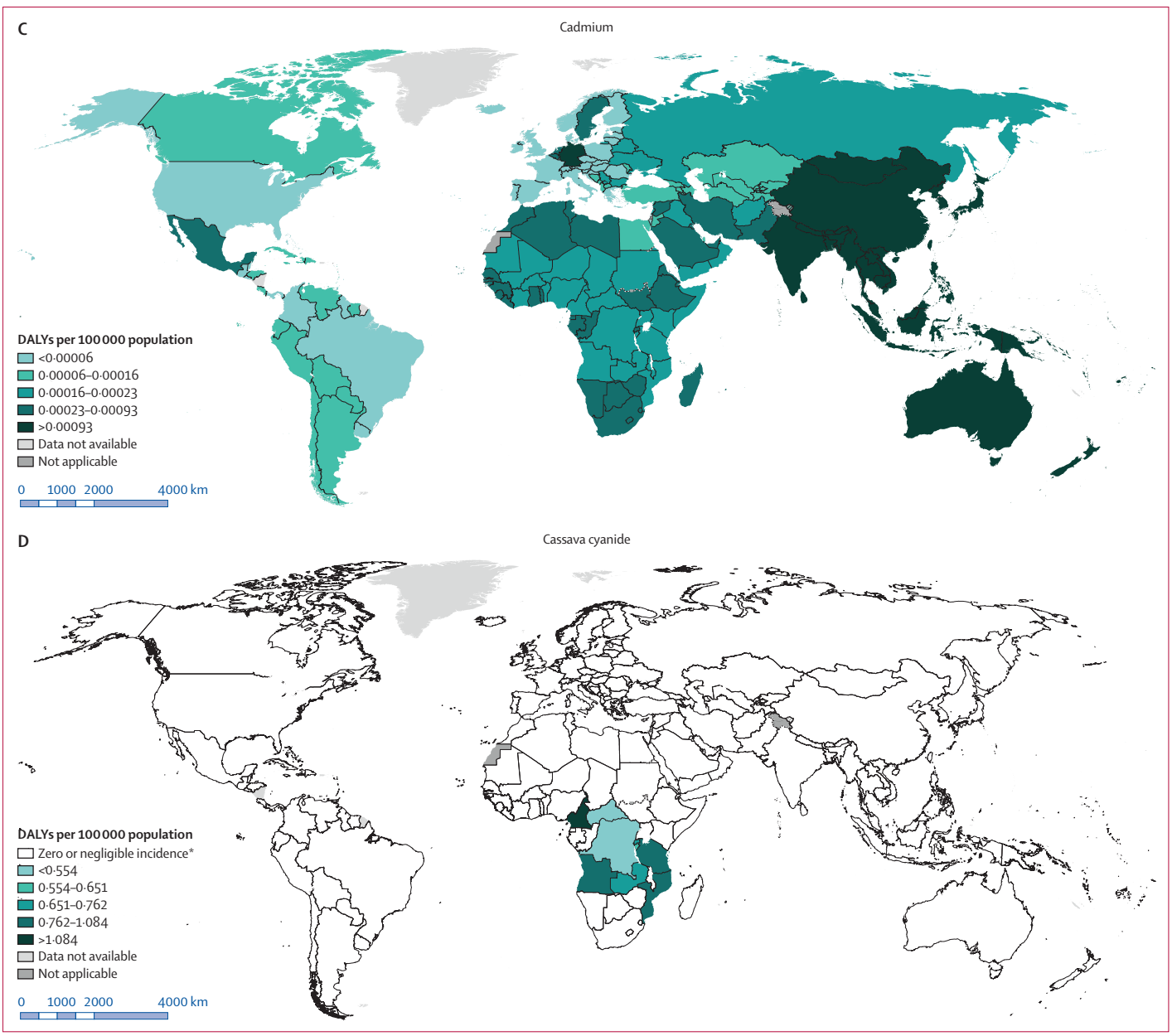
due to methylmercury, and 1·70 million (–0·07 to 4·10) due to lead.

Most of the 1·12 million (95% UI 0·40–2·10) deaths were due to dietary exposure to inorganic arsenic (57·2%) and lead (41·6%; table 2). Liver cancer caused by dietary exposure to aflatoxin B1 caused 13 200 (5570–26 400) deaths globally, being the third contributor with about 1·2% of total deaths in relation to assessed chemicals.

In total, the nine chemical hazards caused 29·8 million (95% UI 12·9 to 53·1) DALYs globally for 2021 (table 2). Inorganic arsenic and lead were the largest contributors to the loss of healthy life-years with 51·8% and 37·6%, respectively. Despite not causing deaths, methylmercury was the third contributor, making up 8·2% of total DALYs and affecting mostly children younger than 5 years. Aflatoxin B1 and peanut allergy each contributed approximately 1% of total DALYs by chemical hazards, while dioxin, cassava cyanide, cadmium, and aflatoxin M1 combined caused 12 600 (5500 to 26 200) DALYs globally, or less than 0·1% of total DALYs due to chemicals. Cardiovascular diseases from inorganic arsenic and lead caused 12·6 million (3·93 to 31·7) and 10·2 million (–1·16 to 25·2) DALYs, respectively, so cardiovascular diseases alone caused 76·5% of total DALYs due to chemicals (table 2).



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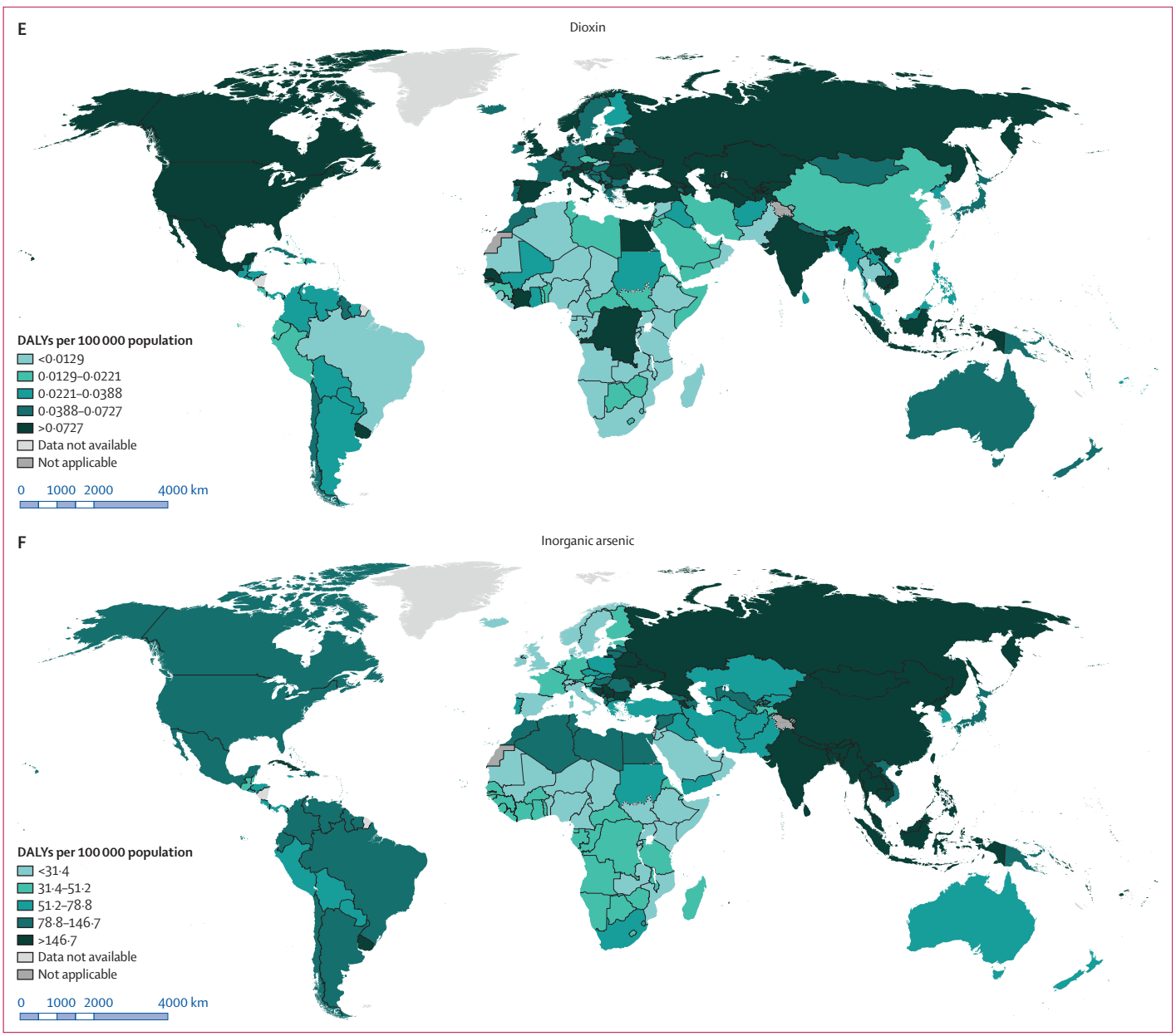
See Online for appendix 2

Cancers from inorganic arsenic contributed to another 9·4% of total DALYs or 2·80 million DALYs, predominantly via lung cancer (83·8%), bladder cancer (16·2%), and skin cancer (<0·1%). Intellectual disability from lead and methylmercury caused 1·03 million DALYs (95% UI 0·29–2·13) and 2·43 million DALYs (1·31–4·38), respectively. 412 000 DALYs were caused by liver cancer from aflatoxin B1 (179 000–813 000) and less than 1000 DALYs from aflatoxin M1. Regional exposure estimates for aflatoxin B1, aflatoxin M1, cadmium, inorganic arsenic, and methylmercury are shown in appendix 2 (pp 4–8). Imputed PAFs for aflatoxin B1, M1, and inorganic arsenic and associated diseases are shown in appendix 2 (pp 9–14).

Across regions, the South-East Asia region (SEAR) was carrying the highest DALY rate in 2021, with 789 DALYs (95% UI 272–1662) per 100 000 people (table 3; figure 1), followed by the Western Pacific region (WPR) carrying a burden of 380 DALYs (145–868) per 100 000. In 2021, the disease burdens were similar in magnitude across the region of the Americas (AMR; 180 DALYs per 100 000), the European region (EUR; 178 DALYs per 100 000), and the Eastern Mediterranean region (EMR; 175 DALYs



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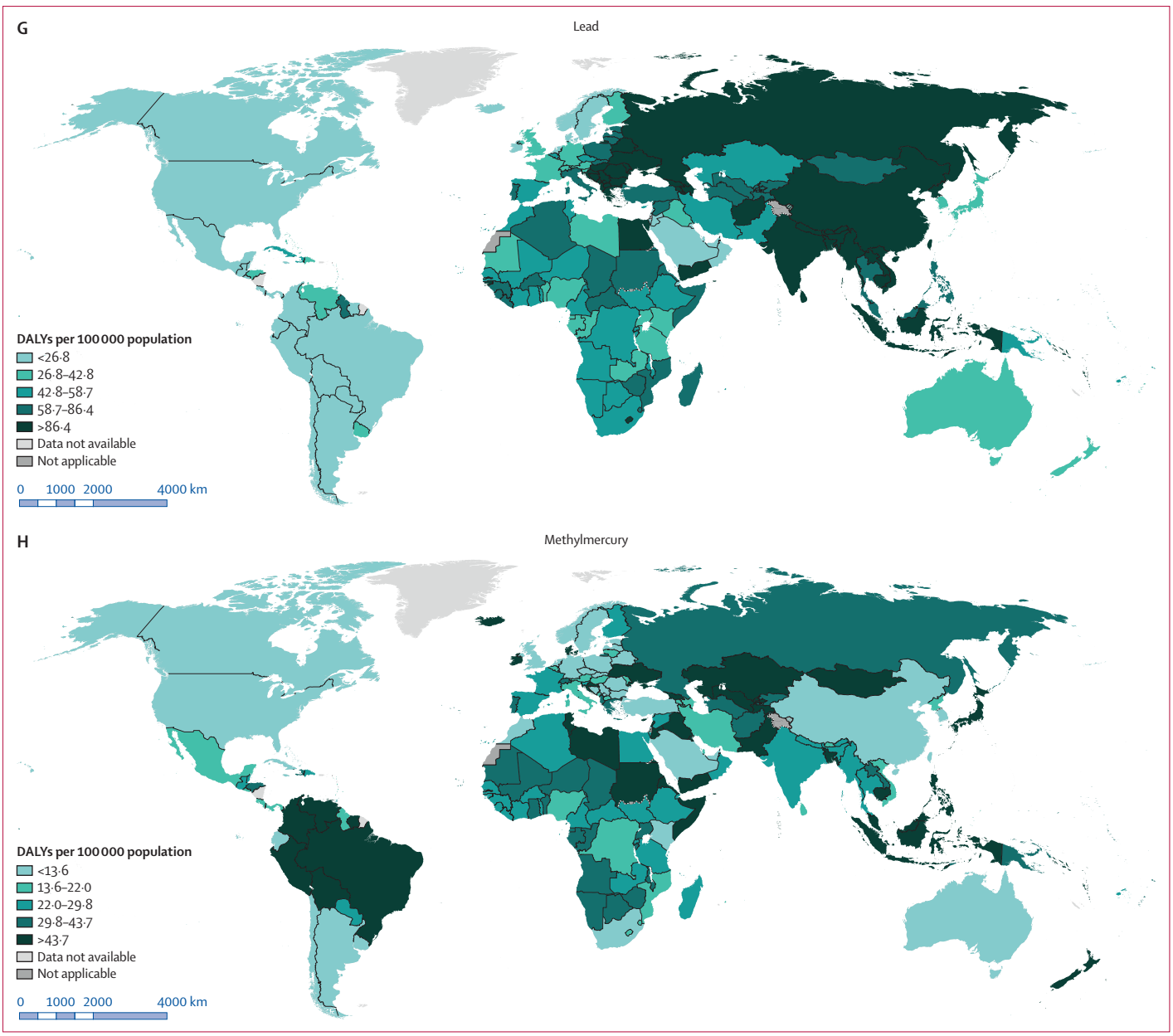
per 100 000), and slightly lower in the African region (AFR; 116 DALYs per 100 000). Although inorganic arsenic was the largest contributor to DALY rates in most regions, the importance of metals differed by regions. In AFR, lead (38·5% of total DALY rate) contributed more than inorganic arsenic (29·4% of total DALY rate) to the burden, whereas in AMR, methylmercury contributed (26·1% of total DALY rate) more than lead (10·4% of total DALY rate) to the burden. Across regions, the contribution to total DALY per 100 000 of aflatoxin B1 was the highest in AFR with 7%. The DALY rate of peanut allergy was in the same order of magnitude across all regions. The national-level distribution for each chemical hazard is presented in figure 2.

Globally in 2021, 2·8 million DALYs (95% UI 1·7–4·9) were attributed to children younger than 5 years.[2,3] Across all regions, maternal methylmercury exposure causing loss of IQ points in children was the largest contributor to DALYs rates for children younger than 5 years (86·1%; table 3). For all regions except SEAR, methylmercury DALYs in children younger than 5 years were followed by peanut allergy. In SEAR, lead was the second contributor to DALY rates in children younger than 5 years (9·6%), while it



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was third in other regions (3·6% globally). Cassava cyanide modestly contributed to the regional disease burden in children younger than 5 years in AFR only.

The global burden due to the nine chemical hazards decreased from 36·0 million (95% UI 18·9–58·7) in 2000 to 29·8 million (12·9–53·1) DALYs in 2021 (approximately a 17% decrease).[2,3] The decrease in DALY rates from 2000 to 2021 was seen for all hazards except lead, peanut allergy, and cadmium, and across all regions (figure 3; appendix 2 pp 15–22). Inorganic arsenic, lead, and methylmercury remained the main contributors to global foodborne chemical DALYs in both 2000 to 2021. Dioxin was the fourth largest contributor in 2000 but moved down to the sixth contributor in 2021 (appendix 2 p 23). Regionally, the chemicals contributing most to disease burden were consistent in both 2020 and 2021, except for aflatoxin B1. Of the chemicals, inorganic arsenic had the largest absolute decrease in DALYs per 100 000 from 347 (138–689) to 196 (80·9–437) from 2000 to 2021, whereas dioxin had the largest relative decline from 14·7 DALYs (3·6–38·9) per 100 000 to 0·098 (0·030–0·235).[2,3]

Discussion

Our updated WHO estimates of the global disease burden from dietary chemical exposure show that in 2021 these hazards caused about 30 million DALYs. Four metals,

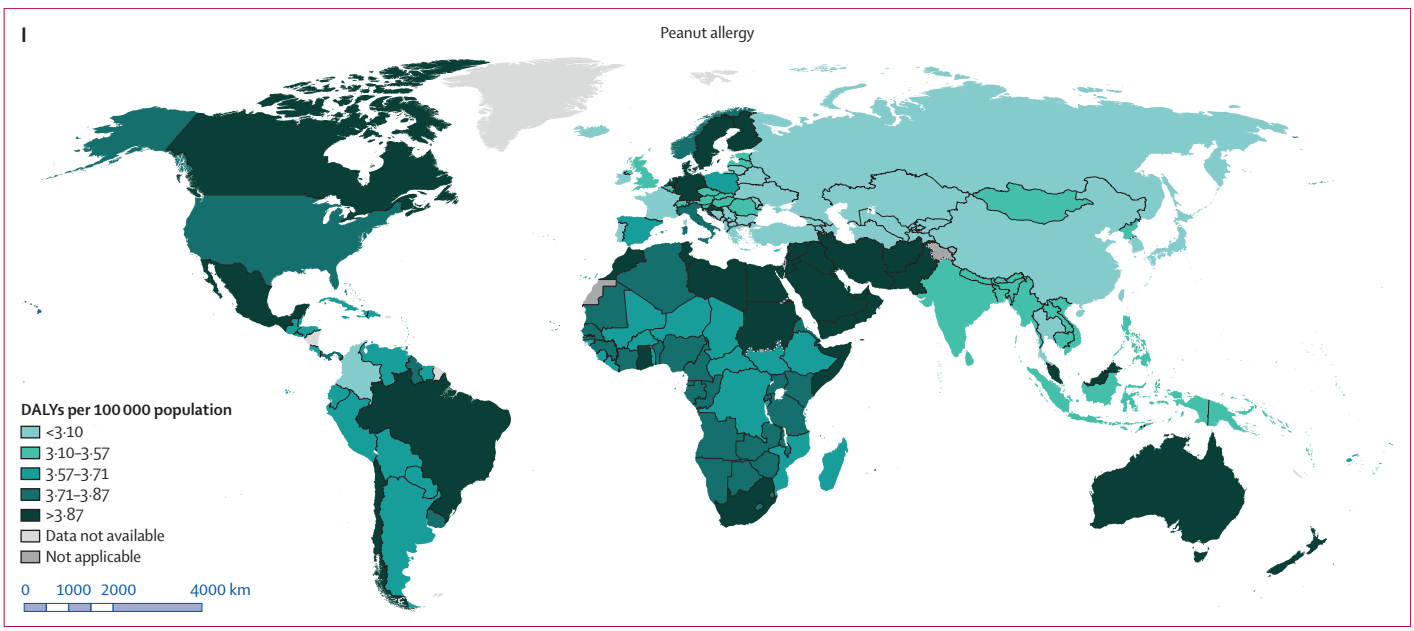

Figure 2: **Mean national rates of foodborne chemical DALYs per 100 000 population in 2021**
Mean foodborne DALYs per 100 000 population for aflatoxin B1 (A), aflatoxin M1 (B), cadmium (C), cassava cyanide (D), dioxin (E), inorganic arsenic (F), lead (G), methylmercury (H), and peanut allergy (I). DALYs=disability-adjusted life-years. *These countries or areas are considered to have no human cases of konzo.

absent from the 2010 estimates, accounted for over 97·6% of the chemical burden. We shed light on the significant contribution of these hazards to the global NCD burden.

Our estimates suggest that dietary exposure to inorganic arsenic alone represents the largest contributor to the foodborne disease burden. The analysis shows an indicative decreasing time trend in exposure between 2000 and 2021 (appendix 2 p 7), also reported in the literature.[17] However, the regional burden in 2021 remains unevenly distributed: SEAR and WPR carry the highest DALY rates, with India and China accounting for 64% of global DALYs due to inorganic arsenic. Ischaemic heart disease dominates the burden, comprising 81·8% of inorganic arsenic DALYs. A modest proportion of the global burden of ischaemic heart disease is attributable to dietary inorganic arsenic (appendix 2 p 11). However, the fact that ischaemic heart disease is the leading cause of global DALYs in 2023 translates into a substantial absolute burden from inorganic arsenic.[18]

The substantial disease burden due to dietary lead exposure (11·2 million DALYs) is also a reflection of this metal's prominent role among major risk factors contributing to the global burden of disease.[18] Globally, at least 85% of the contribution of lead to foodborne DALYs is caused by cardiovascular diseases, primarily ischaemic heart disease and ischaemic and haemorrhagic strokes. The considerable number of DALYs associated with inorganic arsenic and lead reflects the impact of dietary chemical contaminants on cardiovascular health and adds to the proportion of global disease burden from behavioural and environmental risk factors.

Our assessment shows that cancers account for 10·8% of total foodborne chemical DALYs, involving lung, bladder, and skin tumours associated with arsenic, and liver cancer with aflatoxins. Lung cancer, which is the leading cause of cancer mortality worldwide, represents 73% of DALYs from cancer for 2021. Although tobacco smoking is the predominant cause of lung cancer, 15–20% of cases occur in non-smokers, with common risk factors including radon, air pollution, asbestos or silica, and family history.[19] The estimated 2·3 million DALYs from arsenic-related lung cancer underscore the overlooked adverse impact of foodborne inorganic arsenic. Aflatoxin B1 carries the highest disease burden among non-metal hazards, accounting for 1·4% of total DALYs and with the highest DALY rates in SEAR and AFR. Aflatoxins are fungal toxins produced mainly by *Aspergillus flavus* and *Aspergillus parasiticus* in various foods. Among roughly twenty related metabolites, aflatoxin B1 is the most potent carcinogen. Humans are primarily exposed via contaminated maize and peanuts, and via milk by its metabolite aflatoxin M1. Although its absolute burden is considerably lower than arsenic, lead, or methylmercury, it is notable because liver cancer is the third leading cause of cancer mortality globally and the primary cause in sub-Saharan Africa.[20] Our estimates of aflatoxin disease burden reflect exposure through maize and peanuts. Exposure through other cereals (eg, rice, sorghum, and wheat) also contribute to the dietary exposure, more prominently in some regions than other.[21] The global prevalence of mycotoxins in food crops above detectable levels is estimated at 60–80%, a trend expected to increase due to the climate crisis.[22]

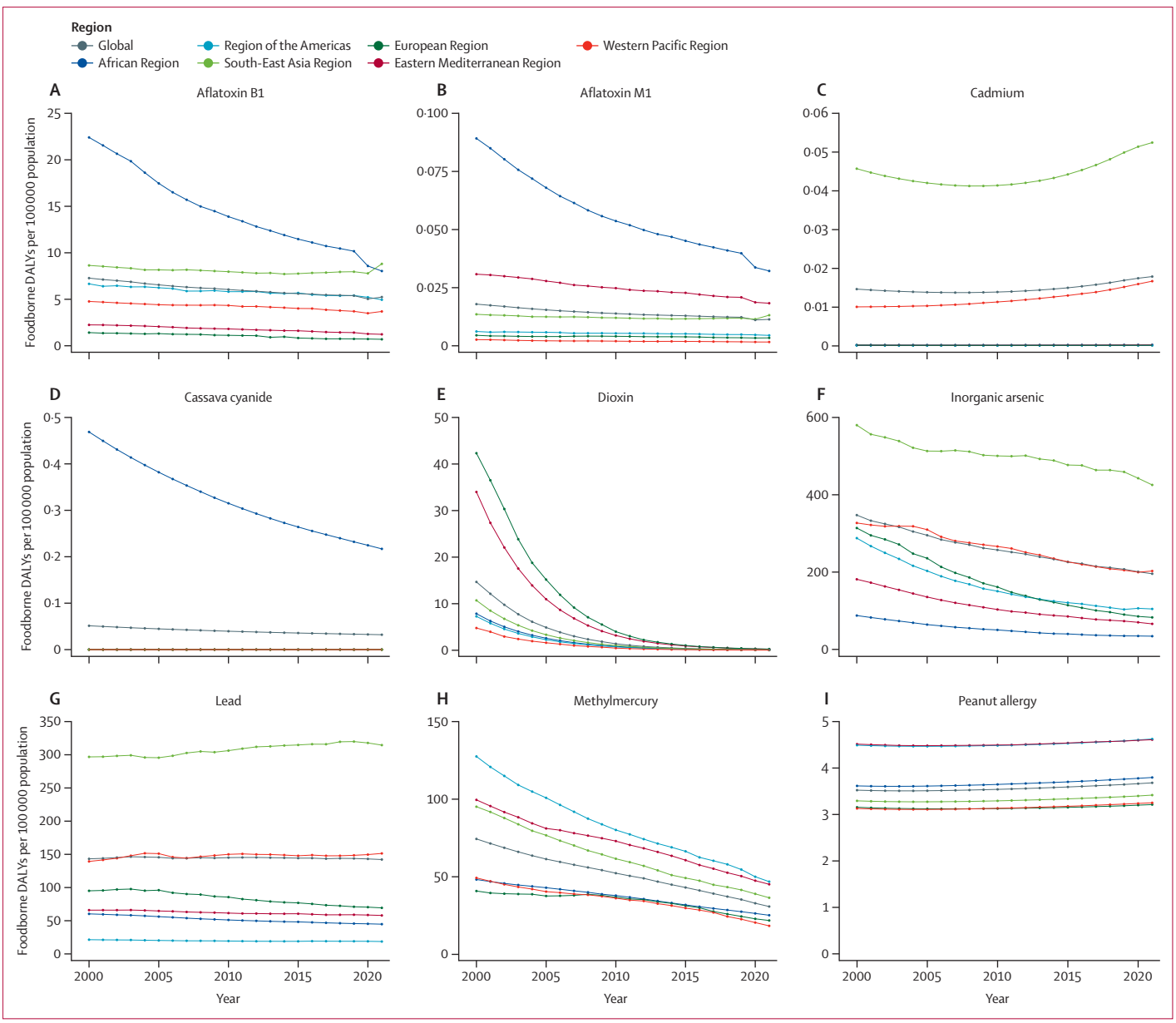

Figure 3: **Annual foodborne chemical DALYs per 100 000 population, globally and by WHO region, 2000–21**
Mean foodborne DALYs per 100 000 people for aflatoxin B1 (A), aflatoxin M1 (B), cadmium (C), cassava cyanide (D), dioxin (E), inorganic arsenic (F), lead (G), methylmercury (H), and peanut allergy (I). Countries by WHO region (appendix 1 P 61). DALYs=disability-adjusted life-years.

Both methylmercury and lead affect neurodevelopment during fetal life and childhood. Borderline intellectual disability represents most of the burden from maternal exposure to methylmercury. Although borderline intellectual functioning is not a diagnosable disorder, individuals can present the need for support similar to those with disorders of intellectual disability from mild to profound.[23] Assessing the disease burden caused by dietary exposure to neurotoxicants such as methylmercury and lead without the aggregation of all intellectual disability classes would underestimate their effect, as the leftward shift of the entire population distribution of IQ scores does not only affect the individuals in the extreme lower tails.[24,25] The foodborne disease burden of the neurotoxicants reflects the inequity in who carries the burden. Methylmercury and lead burden are carried by children younger than 5 years and anthropogenic activities amplified by high fish consumption highly affect certain communities.

Four of the chemicals combined contributed less than 1% of the chemical disease burden. Male infertility from dioxin exposure has decreased from 2000 to 2021, reflecting the observed decrease in human breast milk levels. Continued

efforts to control dioxin and dl-PCBs emissions from industrial processes and waste incineration practices will further mitigate human exposure levels, bioaccumulation, and disease burden.[26] Across regions between 2000 and 2021, peanut allergy DALY counts have increased, following apparent increases in the prevalence of peanut allergy.[27] Consistent with previous reports, our estimates indicate aflatoxin M1 in milk does not substantially contribute to global liver cancer disease burden.[28] This is in stark contrast to often strict aflatoxin M1 standards in milk, and calls for reconsidering stringency levels, specifically in low-income and middle-income countries, weighting adverse impacts on public health against nutritional benefits, food security, and livelihoods. Dietary exposure to cadmium presents a minor contribution to chronic kidney disease risk factors, as previously found.[3] Konzo due to cassava cyanide is a local and volatile issue that we could estimate for nine African countries, where the konzo modestly contributed to DALY rates.

The current analysis adds five chemical hazards to the previous global estimates of the foodborne disease burden. Nevertheless, the global burden of disease caused by dietary exposure to chemicals remains incomplete. Due to data gaps, we were unable to estimate burden for relevant foodborne chemicals, including pesticide residues, perfluoroalkyl and polyfluoroalkyl substances, process contaminants, and mycotoxins other than aflatoxin B1 and M1 (including co-occurrence of fumonisins). Moreover, not all health effects of selected hazards could be included, such as osteoporosis associated with cadmium, impaired growth caused by aflatoxin B1, and acute aflatoxicosis.[29] Dioxins and dl-PCBs are classified as carcinogenic to humans based on strong evidence in animals and robust mechanistic data.[30] However, the absence of a link to specific cancer sites and a clear dose-response relationship hinders estimating the cancer burden from dioxins and dl-PCBs and so the potential burden has not been included. Regarding inorganic arsenic, beyond ischaemic heart disease and the three cancer sites, assessments concluded that evidence supports a causal link with hypertension, type 2 diabetes, decreased birthweight, spontaneous abortion, stillbirth, infant mortality, congenital heart disease, chronic kidney disease, and neurodevelopmental effects.[14,15]

This global analysis was limited by unevenly distributed exposure data availability across geographies. To address these limitations, we applied a Bayesian hierarchical meta-regression model with geographical clustering and a global time trend to impute missing values and quantify uncertainty. While effective, this approach is inherently less optimal than relying on complete, high-quality data. The structured expert judgment study providing the proportion of lead attributed to diet is a transparent and validated approach to mathematically aggregate experts' judgment and associated uncertainty distributions. However, we acknowledge the limitation of an overall low number of expert assessments for many subregions; more expert assessments could contribute to an increased level of confidence in the results.[8] We were unable to capture combined effects of chemical mixtures, for which data and standardised methods for estimating burden are currently lacking. We aggregated PAFs of different exposures for the same outcome by simple addition. This overestimates the burden as covariance between risk factors is ignored, although validation studies suggest that the overestimation is relatively small. A multiplicative aggregation is possible under the assumption of complete control for confounders, including mutual adjustment, which is difficult to confirm when relying on literature without full control over confounder selection.[31]

In conclusion, our analysis adds to the evidence describing the impact of environmental chemicals on disease burden via different exposure pathways. This study provides a compass for policymakers to set food safety priority action and a shift in awareness of the link between food safety and NCDs, particularly cardiovascular diseases. The foodborne disease burden of chemicals remains incomplete. Our estimates suffer from the missing contribution of important chemical groups, which does not imply that their burden is null. In addition to this, the databases on which our estimates rely are continuously updated, which might influence the ranking of chemicals by magnitude of DALYs and therefore the overall conclusions. This warrants recurrent updates of the present analysis. Lastly, our study does not reflect specific subnational dietary exposures. However, in the context of highly exposed populations—for example, living in proximity of mining sites, within hotspots of spice adulteration, and users of artisanal cookware made from scrap metal—this calls for national and subnational studies to ensure equitable protection of populations from unsafe dietary patterns.[32,33]

WHO Foodborne Disease Burden Epidemiology Reference Group for 2021–2025:
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Contributors
LSJ, AA, MAH, FAN, RJL, AHH, and LI were responsible for the conceptualisation of ideas, and formulation or evolution of overarching research goals and aims. LV, CDB, BD, and GFN were responsible for the management of activities to annotate (produce metadata), scrub data, and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later re-use. LSJ, AA, LV, BD, GFN, STT, and HGR were responsible for the application of statistical, mathematical, computational, or other formal techniques to analyse or synthesise study data. CR and YM were responsible for the acquisition of the financial support for the project leading to this publication. LSJ, AA, MAH, FAN, GFN, STT, HGR, HG, and LI were responsible for conducting a research and investigation process, specifically performing the experiments, or data and evidence collection. LSJ, AA, LV, CDB, BD, GFN, SMP, STT, HGR, and HG were responsible for the development or design of methodology, and creation of models. LSJ, AA, RJL, AHH, CR, YM, and LI were responsible for the management and coordination responsibility for the research activity planning and execution. LV, CDB, BD, and CR were

responsible for the provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools. LSJ, LV, CDB, BD, GFN, STT, and HGR were responsible for the programming and software development; designing computer programmes; implementation of the computer code and supporting algorithms; and testing of existing code components. LSJ, AA, RJL, AHH, CR, YM, and LI were responsible for the oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team. LSJ, AA, MAH, FAN, GFN, SMP, STT, HGR, HG, RJL, and LI were responsible for the verification, whether as a part of the activity or separate, of the overall replication or reproducibility of results or experiments and other research outputs. LV and BD were responsible for the preparation, creation or presentation of the published work, specifically visualisation and data presentation. LSJ, AA, MAH, FAN, and LI were responsible for the preparation, creation or presentation of the published work, specifically writing the initial draft (including substantive translation). All authors were responsible for the preparation, creation or presentation of the published work by those from the original research group, specifically critical review, commentary, or revision, including pre-publication or post-publication stages. LSJ, AA, and LV directly accessed and verified all underlying data reported in this report.

Declaration of interests

All members of the WHO Foodborne Disease Burden Epidemiology Reference Group had the opportunity to attend up to two meetings, with expenses covered by WHO. BD, CDB, and LV declare payments made to their institutions by WHO as contractor for computational process. BD, CDB, LV, and SMP declare payments made to their institutions by the European Food Safety Agency to estimate burden of foodborne zoonoses in the EU or EEA. STT and HGR declare payments to their institutions from WHO for the systematic review of dioxin. LSJ declares payment to institution from WHO for the systematic review of peanut allergy. HG declares payment from WHO for the systematic review of inorganic arsenic, and travel grants from the European Food Safety Authority to attend a workshop on the Bayesian benchmark dose tool. RJL declares a grant to employments institution from New Zealand Institute of Public Health and Forensic Science; and an advisory board role for New Zealand Food Safety. STT declares a research grant held by institution from Independent Research Fund Denmark. YM, CR, and LI are employees of WHO.

Data sharing

Data collected for this study will be publicly available at https://www.who.int/teams/nutrition-and-food-safety/monitoring-nutritional-status-and-food-safety-and-events/foodborne-disease-estimates/2nd-edition-(2026). The overall protocol and statistical analysis plan are available.[6] The analysis code will be available via GitHub (https://github.com/fbdburden).

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