WHO estimates of the global, regional, and national foodborne burdens of 14 invasive parasitic diseases, 2000–21: an updated data synthesis

Lucy J Robertson*, Yuki Minato*, Brecht Devleesschauwer, Carlotta Di Bari, Louise Vaes, Karen H Keddy, Banchob Sripa, Kim Fernandez, Sara M Pires, Shannon E Majowicz, Robin J Lake, Charlee Roberts, Gabriela F Nane, Mirjam E Kretzschmar, Lapo Mughini-Gras, Ali Rostami, Hélène Carabin, Christine M Budke, Meritxell Donadeu, Paul R Torgerson*, on behalf of the WHO Foodborne Disease Burden Epidemiology Reference Group for 2021–25†

Summary

Background Over 10 years ago, WHO estimates of hazard-specific foodborne disease burdens showed that parasites exert considerable health burdens globally. We updated these estimates, focusing on 14 invasive parasitic diseases.

Methods Incidences, deaths, and disability-adjusted life-year (DALY) burdens were estimated for each parasitic disease from 2000 to 2021, using data from systematic reviews and the Global Burden of Diseases, Injuries, and Risk Factors Study. For some diseases, structured expert judgement was used to estimate proportions of foodborne infection. Data were pooled via hierarchical meta-regression models with uncertainty propagated through Monte Carlo simulations following disease-specific computational models defined by incidence rates and probability parameters.

Findings We estimated that 277 million illnesses were caused by potentially foodborne invasive parasites, with approximately 171 million attributable to foodborne transmission. Considerable heterogeneity by parasite, in magnitude and uncertainty, was observed. Of 4·89 million foodborne DALYs associated with these diseases, highest contributions were from *Taenia solium* (1·3 million) and *Clonorchis sinensis* (0·921 million), both also associated with most foodborne deaths. Burden was greatest in the region of the Americas, predominantly due to Chagas disease, followed by the African region, where neurocysticercosis-associated epilepsy caused most burden. Burdens decreased globally from 2000 to 2021, except in the Western Pacific region, where the burden, predominantly associated with clonorchiasis, is rising.

Interpretation Foodborne parasitoses cause considerable suffering, with some populations and regions particularly at risk. These data provide a baseline by which effects of interventions can be assessed and emphasis directed to those parasites exerting the greatest burden.

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*Contributed equally

†Members listed at the end of the Article

Parasitology Unit, Department of Paraclinical Science, Faculty of Veterinary Medicine, Norwegian University of Life Sciences, Ås, Norway (Prof L J Robertson PhD); **Department of Nutrition and Food Safety, World Health Organization, Geneva, Switzerland** (Y Minato MPH, C Roberts MPhil MAE); **Department of Epidemiology and Public Health, Sciensano, Brussels, Belgium** (B Devleesschauwer PhD, C Di Bari MSc, L Vaes MSc, K Fernandez MSc); **Department of Translational Physiology, Infectiology and Public health, Ghent University, Merelbeke, Belgium** (B Devleesschauwer, C Di Bari); **Department of Veterinary Tropical Diseases, Faculty of Veterinary Science, University of Pretoria, Pretoria, South Africa** (Prof K H Keddy PhD); **Department of Tropical Medicine, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand** (Prof B Sripa PhD); **National Food Institute, Technical University of Denmark, Lyngby, Denmark** (S M Pires PhD); **School of Public Health Sciences, University of Waterloo, Waterloo, ON, Canada** (Prof S E Majowicz PhD); **Institute of Public Health and Forensic Science, Christchurch, New Zealand** (R J Lake PhD); **Delft Institute of Applied Mathematics, Faculty of**

Introduction

Foodborne disease, an important global public health challenge, poses a substantial threat to achieving the UN Sustainable Development Goals. In 2007, WHO established the Foodborne Disease Burden Epidemiology Reference Group (FERG) to provide advice on estimating disease burden for selected foodborne hazards. The Parasitic Disease Task Force (PDTF) within FERG advised on regional and global estimates for 2010 of the health burden (in disability-adjusted life-years [DALYs]) for 12 parasitic diseases and the estimated proportion attributable to food.[1]

Estimating foodborne disease burdens is important, not only regionally and globally, but also nationally, due to multiple factors affecting local disease incidence.[2] Thus, in 2021, WHO established a new iteration of FERG, with a similar mandate.[3] Five researchers with expertise in parasitology were invited to join PDTF (BD, KHK, LJR, BS, PRT).

Our goal was to update global and regional estimates of burdens (in DALYs) of 14 invasive parasitic foodborne diseases for 2021, using a similar approach to that for the 2010 estimates, and including one further parasitosis (Chagas disease). National-level burdens were also estimated, as were annual trends from 2000 to 2021.

Methods

Overview

Methodology followed a framework developed by the FERG Computational Task Force.[4] Relevant reporting guidelines (GATHER and The Standardised Reporting of Burden of Disease Studies) were followed.

Electrical Engineering, Mathematics and Computer Science, Delft University of Technology, Delft, Netherlands (G F Nane PhD); Department of Epidemiology and Health Economics, University Medical Center Utrecht, Utrecht University, Utrecht, Netherlands (Prof M E Kretzschmar PhD); Center for Complex Systems Studies, Utrecht University, Utrecht, Netherlands (Prof M E Kretzschmar); Interdisciplinary Center for the Mathematical Modeling of Infectious Disease Dynamics, University of Münster, Germany (Prof M E Kretzschmar); Institute for Public Health and the Environment, Center for Infectious Disease Control, Bilthoven, Netherlands (Prof L Mughini-Gras PhD); Utrecht University, Faculty of Veterinary Medicine, Utrecht, Netherlands (Prof L Mughini-Gras); Infectious Diseases and Tropical Medicine Research Center, Health Research Institute, Babol University of Medical Sciences, Babol, Iran (A Rostami PhD); Department of Pathology and Microbiology, Faculty of Veterinary Medicine, Université de Montréal, Saint-Hyacinthe, QC, Canada (Prof H Carabin PhD); Department of Social and Preventive Medicine, School of Public Health, Université de Montréal, Montreal, QC, Canada (Prof H Carabin); Groupe de Recherche en Épidémiologie des Zoonoses et Santé Publique, Saint-Hyacinthe, QC, Canada (Prof H Carabin); Centre de recherche en santé publique, Université de Montréal et CIUSSS du Centre-Sud-de-l'Île-de-Montréal, Montréal, QC, Canada (Prof H Carabin); Texas A&M University, College of Veterinary Medicine & Biomedical Sciences, College Station, TX, USA (Prof C M Budke PhD); Department of Biosciences, Melbourne Veterinary School, University of Melbourne, Werribee, VIC, Australia (M Donadeu MSc); Malaria and Neglected Tropical Diseases, World Health Organization, Geneva, Switzerland (M Donadeu); Section of Veterinary Epidemiology, Vetsuisse Faculty, University of

Research in context

Evidence before this study

Foodborne parasitic diseases cause substantial morbidity and mortality globally, with an excess burden occurring in low-income and middle-income countries. The previous global study on the effect of foodborne parasites showed that 12 potentially foodborne parasites accounted for 8·78 million disability-adjusted life-years (DALYs) in 2010. Of these 8·78 million DALYs, 76% could be directly attributable to foodborne disease. The invasive foodborne parasitic diseases with highest incidence were ascariasis and toxoplasmosis. Cysticercosis (2·78 million DALYs), trematodiases (2·02 million DALYs), and toxoplasmosis (825 000 DALYs) were responsible for the largest proportions, primarily due to years lived with disability. In 2010, the African region had the greatest foodborne parasitic disease burden, with 232 DALYs per 100 000 people, followed by 158 DALYs per 100 000 people in the Western Pacific region and 80 DALYs per 100 000 people in the South-East Asia region.

Added value of this study

This study updates previous estimates for foodborne parasitic diseases using comparable methodology, but also includes *Trypanosoma cruzi*, the causative agent of Chagas disease. This study further refines the previous global and regional burdens and, by calculating burdens at a national level, provides an evidence-base for country-specific interventions. Burdens of different foodborne parasites were estimated over time, from 2000 to 2021. At a pathogen-specific level, toxoplasmosis estimates were separated into acquired versus congenital disease. Combined estimates for disease due to *Fasciolopsis* and *Fasciola* were included and, based on pathogenicity, geographical, and epidemiological differences, opisthorchiasis was considered by *Opisthorchis* species, *O viverrini* and *O felineus*.

Implications of all the available evidence

The additional evidence in this study has provided a better understanding of the relevance of invasive foodborne parasitic disease, emphasising the importance of specific parasites and changing disease patterns (globally, regionally, and nationally), enabling country-specific risk-ranking of these pathogens. Moreover, this study advances knowledge by including previously excluded pathogens; foodborne Chagas disease was shown to exert a sizeable burden in Latin America. Although the estimates show that, overall, burdens of foodborne parasitic diseases are decreasing globally, there were notable exceptions; clonorchiasis, in particular, seems to be increasing. Furthermore, despite only considering one of the many psychoneurological sequelae it causes, cysticercosis continues to exert a notable public health impact, which should inspire a concerted effort to tackle the recalcitrance of *Taenia solium* to eradication. National estimates can guide countries to design need-based interventions. By focusing on those parasites that contribute DALYs due to foodborne disease (versus other transmission routes), we provide countries with baseline information, facilitating the opportunity to monitor the success of development and implementation of specific interventions to reduce foodborne transmission of parasitic diseases.

30 parasites with potential for foodborne transmission were ranked for consideration for inclusion (appendix pp 4–5). All parasitoses covered in the previous estimates were included, with toxoplasmosis considered as two separate diseases (congenital or acquired). Three additional invasive parasitic diseases (Chagas disease, anisakidosis, toxocariasis) were recommended due to their potential to rank as highly as some hazards already included. Chagas disease was included following publication of a strongly argued opinion.[5] However, anisakidosis and toxocariasis were not. Taeniosis due to *Taenia saginata* infection and rat lungworm disease due to *Angiostrongylus* spp infection were also excluded. Reasons behind these exclusions are provided in the appendix (pp 4–5).

Estimating incident cases and sequelae for 14 invasive parasitic diseases

Systematic reviews were commissioned by WHO to summarise data on incidence, prevalence, and mortality of 13 of the 14 parasitic diseases included. Five teams were commissioned to conduct these reviews. Review protocols were registered in PROSPERO and reviews followed WHO methodological standards (appendix p 6). Data were extracted at national level into a standardised spreadsheet.[4] No systematic review was commissioned for Chagas disease. Estimates were derived from draw-level estimates that were obtained directly from the Institute for Health Metrics and Evaluation (IHME) and The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2021, and were stratified by age, sex, country, and year for 2000–21.[6]

Incidence, prevalence, and case-fatality ratios for each disease were estimated for 2000 to 2021. Model selection was guided by the FERG computational framework[4] and previous methodology,[1] with adjustments made based on data availability and expert consultation (appendix pp 7–15). A modified approach was required for foodborne trematodiases, for which a substantial proportion of incident cases are subclinical. Symptomatic proportions were applied as described in the appendix (pp 7–15).

Two additional differences from previous estimates[1] were introduced. First, due to the epidemiology of *Fasciolopsis*, particularly food types associated with transmission, this parasite was grouped with *Fasciola*, rather than with fishborne minute intestinal flukes (MIFs). Second, the *Opisthorchis* genus was assessed at species level (*Opisthorchis viverrini* and *Opisthorchis felineus*) rather than combined; this reflects differences in geographical distribution, epidemiology, disease sequelae between the species, and data availability.

In previous estimates,[1] the burden from foodborne *Ascaris* infection used data from IHME. Here, data from a previous systematic review were updated[7] and applied to derive incidence, inferred from prevalence data, assuming a 1-year parasite life expectancy.

For toxoplasmosis, a greater proportion of cases with chorioretinitis was applied for the region of the Americas to account for greater virulence among non-archetypal genotypes of *Toxoplasma gondii* predominating in South America.[1]

For neurocysticercosis, caused by central nervous system infection with *Taenia solium* metacestode larvae, we applied, as previously, an approach based on prevalent epilepsy cases,[1] supported by a systematic review (appendix pp 7–14). A proportion of epilepsy cases was attributed to neurocysticercosis. The population at risk was approximated based on sanitation levels in rural areas, pig populations and husbandry routines, and cultural practices, with support from WHO Neglected Tropical Diseases unit. For further details on country-level estimates of populations at risk see the appendix (pp 7–14, 16–19).

After assimilation of the preliminary data, WHO conducted a country consultation in which national focal points, designated by WHO member states, were provided with draft individual estimates for their respective countries. National focal points were invited to review and provide feedback and, if relevant, supply data to refine the estimates. This additional information resulted in a zero incidence of symptomatic *Ascaris* infection being assumed for all high-income countries in the WHO European region (appendix p 16). When other data met review inclusion criteria,[4] these were included. In addition, when uncertainty about national incidence persisted for specific diseases, appropriate experts were contacted to obtain informed opinions.

Disease models

For each of the 14 parasitic diseases, a disease model was developed[4] to assign disability weights and duration of non-fatal disease sequelae (appendix pp 7–14). Disability weights for sequelae were generally based on those used previously,[1,8] with the exceptions of *Paragonimus* and *Ascaris* infections.

For alveolar echinococcosis, a low case–fatality ratio was assumed for higher-income countries in the region of the Americas and the European region (appendix pp 7–14), due to the presence of well developed strategies for disease management. For other endemic countries, a case–fatality ratio approaching 100% was assumed; if appropriate chemotherapy is absent, lethal outcomes are likely.[1]

For cystic echinococcosis, it was assumed that only 10% of cases in endemic countries sought treatment and thus were officially reported (appendix pp 7–14). Lower mortality rates and lower disability weights were used for cases not seeking treatment (appendix pp 7–14).

For *Paragonimus*, a published disability weight was used,[9] whereas for *Ascaris* we used the same country-specific years lived with disability (YLD) per case as applied in GBD (2021),[6] which accounts for variations in distribution of relevant health states. For Chagas disease, absent from 2010 estimates, the GBD (2021) disability weight was applied (appendix pp 7–14).[6]

Calculation of DALYs

DALYs were estimated following the incidence-based approach wherever feasible.[4] For neurocysticercosis due to *T solium*, a modified methodology was required due to the nature of available data.[1] Duration and disability weights were then applied to estimate YLD. An analogous approach was used to estimate mortality and years of life lost (YLLs). YLLs were calculated from the WHO normative life tables. No age weighting or time discounting was applied.[4]

Estimation of foodborne attribution proportion

For ascariasis, Chagas disease, cystic echinococcosis, and disease caused by *Fasciola* spp and *Fasciolopsis*, we drew on results from structured expert judgements (SEJ).[10] Attribution proportions were generated for 17 subregional country clusters (appendix p 16). Assessments were provided by 28 experts for 149 hazard–subregion combinations. Experts provided uncertainty estimates for these combinations, except for Chagas disease, for which attribution was determined only for the region of the Americas, for which six experts assessed acute disease. For *Ascaris* spp, four experts represented the entire African region. Uncertainty distributions of attribution proportions were obtained by aggregating experts' distributions.[10] Although SEJ estimates for cystic echinococcosis were consistent with empirical data,[11] SEJ estimates indicated insufficient expert familiarity with *Echinococcus multilocularis*; thus, attribution of alveolar echinococcosis to foodborne transmission was instead extracted from a published systematic review.[11] Similarly, for toxoplasmosis, the attributable proportion of foodborne transmission estimated for 2010 was used.[12] For the other parasitoses considered here, transmission was considered 100% foodborne.

Data analysis

FERG applied an analytical framework to address data gaps and estimate cases, sequelae, deaths, and DALYs.[4] General data cleaning was done for each parasite (appendix pp 7–14). A probabilistic modelling approach was used to characterise probabilities of death and specific health states and their durations. Missing country-level incidence, prevalence, and case–fatality data were imputed using a hierarchical meta-regression model (appendix p 15). Uncertainty around input parameters' distributions was propagated through Monte Carlo simulations with 500 estimates of cases, deaths, or DALYs. Countries where there was no foodborne transmission or infection, or where there was infection but disease did not occur, were set a priori to zero incidence (appendix pp 7–14). The UN country–year-level population data for 2000 to 2021

Zürich, Zürich, Switzerland
(Prof P R Torgerson PhD)

Correspondence to:
Prof Lucy J Robertson,
Parasitology Unit, Department of Paraclinical Science, Faculty of Veterinary Medicine, Norwegian University of Life Sciences, Ås 1432, Norway
lucy.robertson@nmbu.no

See **Online** for appendix

(2024 World Population Prospects Revision) were used in all calculations. Disease-specific computational models, defined by incidence rates and probability parameters, each with its own distribution, were then applied. All-parasite total values were derived from summing individual estimates. The computational methodology used, including modelling of individual health states and mortality, is fully described elsewhere.[4]

Role of the funding source

WHO funded the reviews, the review updates, the computations (Sciensano), the SEJ study (WHO assisted in recruiting experts and elicitors), and expert consultation (University of Florida). WHO managed the overall project and the country consultation process that identified additional data. WHO technical officers (YM and CR) participated in the work, the drafting of the manuscript, and the decision to submit it for publication. The University of Zurich generously offered to fund the APC of this article.

Results

In 2021, an estimated 277 million illnesses were caused by potentially foodborne invasive parasites (table 1). Among these illnesses, approximately 171 million were attributed to foodborne transmission; it is relevant to note source attribution estimates were not obtained by the same approach for all parasites (appendix pp 7–14). For further result exploration, including national-level estimates and time trends for all hazards, WHO's Global Health Observatory[13] is available via WHO's interactive dashboard.[14]

Among foodborne diseases due to these parasites, nematode infections accounted for most illnesses (approximately 143 million cases, predominantly due to ascariasis), followed by systemic protozoal infections (about 26·2 million cases, driven mainly by acquired toxoplasmosis).

Among the three cestode infections considered, most foodborne illnesses were cystic echinococcosis due to *E granulosus s.l.,* causing approximately 261 000 cases. Neurocysticercosis-associated epilepsy from *T solium* larval infection caused about 247 000 illnesses. Because human infection (via pork consumption from an infected pig) is necessary for the parasite lifecycle, all *T solium* infections were considered foodborne (table 1). Among the trematodes, most foodborne illnesses were associated with MIF (1·06 million cases).

Among the parasites we considered, *Trichinella* spp caused fewest cases overall (1540), whereas *E multilocularis* accounted for fewest foodborne illnesses (less than 1000 cases).

Most diseases associated with invasive foodborne parasites had greater frequency and impact among people older than 5 years (appendix p 20); exceptions were congenital toxoplasmosis and ascariasis. For congenital toxoplasmosis, transmission to the fetus occurs in utero; although no incidence and mortality rates are described for those older than 5 years, DALYs are nevertheless present (appendix p 20). Some sequelae might develop later in life, particularly retinochoroiditis, with peaks reported at ages 7 and 12 years.[15] For foodborne ascariasis, incidence in individuals younger than 5 years was estimated at 93·6 million in 2021, with over 760 deaths and approximately 191 000 associated DALYs. For individuals 5 years and older, we estimated around 49 million incident foodborne ascariasis illnesses, 400 deaths, and 88 000 DALYs.[13,14]

The three invasive parasitic diseases associated with the highest estimated mean number of foodborne deaths in 2021 were neurocysticercosis-associated epilepsy (over 13 000 deaths), clonorchiasis (over 10 000 deaths), and Chagas disease due to *Trypanosoma cruzi* infection (over 5700 deaths). Several foodborne parasitoses were associated with negligible mortality, including acquired toxoplasmosis, Fasciolidae infections, and MIF and *O felineus* infections. For these parasites, the DALY value is identical to YLD.[13,14]

For many parasites (*T solium*, *Trichinella* spp, *Clonorchis sinensis*, MIF, both *Opisthorchis* species, and *Paragonimus* spp), transmission is solely foodborne (table 1); values for all transmission routes and foodborne transmission are thus identical. Of the mean total of 6·51 million DALYs associated with potentially foodborne parasites in 2021, most were associated with acquired toxoplasmosis (1·42 million) and *T solium* (1·30 million). However, considering only foodborne DALYs (4·89 million), those with the highest contribution were *T solium* (1·3 million) and *C sinensis* (0·921 million). All parasites contributed measurable health impacts, but there is considerable heterogeneity regarding both magnitude and uncertainty (figure 1). The corresponding figure for all transmission routes (appendix p 25), is broadly similar; the main exception is *E multilocularis*, with lower estimates for foodborne DALYs for alveolar echinococcosis, and considerably wider uncertainty.

The relative effects of different parasitic diseases transmitted by food also varied by world region (tables 2–4; appendix pp 28–41). Several potentially foodborne parasitic diseases occur globally, some occurring commonly regardless of location (eg, acquired toxoplasmosis; tables 2–4). Other foodborne parasitic diseases occur in all regions, but at differing incidence rates (eg, Fasciolidae infections; tables 2–4). For some parasites, regional associations are clear: foodborne Chagas disease occurs only in the region of the Americas, *E multilocularis* infection does not occur in the African region or elsewhere in the southern hemisphere, and *C sinensis* occurs almost exclusively in the Western Pacific region. Whereas *O felineus* occurs exclusively in the European region, *O viverrini* occurs only in the South-East Asia region and Western Pacific region.

These incidence rates are also reflected in public health impact; the DALY proportions by parasite for each region in 2021 (figure 2A) show clear regional differences across foodborne parasite burden. The highest DALY rates were in the region of the Americas; here, Chagas disease was responsible for over 50% of the burden.

	Illnesses	Deaths	DALYs	Proportion foodborne	Foodborne illnesses	Foodborne deaths	Foodborne DALYs
Protozoa	54 100 000 (51 400 000–57 400 000)	8200 (7120–9410)	2 490 000 (1 820 000–3 350 000)	0·484 (0·370–0·589)	26 200 000 (19 900 000–31 900 000)	6230 (5430–7120)	1 410 000 (1 010 000–1 940 000)
Toxoplasma gondii (acquired)	53 800 000 (51 100 000–57 100 000)	0 (0–0)	1 420 000 (851 000–2 270 000)	0·484 (0·370–0·589)	26 000 000 (19 700 000–31 800 000)	0 (0–0)	712 000 (417 000–1 180 000)
Toxoplasma gondii (congenital)	149 000 (141 000–159 000)	1030 (521–1730)	360 000 (247 000–506 000)	0·479 (0·367–0·583)	71 400 (54 600–88 100)	495 (239–880)	175 000 (113 000–258 000)
Trypanosoma cruzi	159 000 (139 000–182 000)	7170 (6260–8180)	710 000 (541 000–919 000)	0·467 (0·153–0·845)	74 300 (24 400–135 000)	5740 (5010–6540)	522 000 (349 000–768 000)
Cestodes	1 110 000 (768 000–1 600 000)	21 800 (16 500–28 600)	1 820 000 (1 350 000–2 430 000)	0·464 (0·325–0·605)	509 000 (338 000–770 000)	15 200 (11 500–19 400)	1 430 000 (1 020 000–1 930 000)
Echinococcus granulosus (s.l.)	848 000 (535 000–1 330 000)	5230 (1930–11 100)	415 000 (180 000–783 000)	0·308 (0·169–0·482)	261 000 (124 000–497 000)	1610 (495–3950)	128 000 (45 900–293 000)
Echinococcus multilocularis	10 700 (7 690–14 000)	3330 (1660–5510)	106 000 (56 400–170 000)	0·093 (0·009–0·387)	989 (106–4110)	289 (9–1410)	9290 (376–43 900)
Taenia solium	247 000 (156 000–358 000)	13 300 (9980–17 300)	1 300 000 (903 000–1 800 000)	1·000 (1·000–1·000)	247 000 (156 000–358 000)	13 300 (9980–17 300)	1 300 000 (903 000–1 800 000)
Nematodes	220 000 000 (191 000 000–252 000 000)	1800 (911–3020)	437 000 (347 000–550 000)	0·646 (0·444–0·813)	143 000 000 (95 000 000–185 000 000)	1170 (539–2080)	280 000 (175 000–394 000)
Ascaris spp	220 000 000 (191 000 000–252 000 000)	1800 (907–3020)	436 000 (347 000–550 000)	0·646 (0·444–0·813)	143 000 000 (95 000 000–185 000 000)	1160 (535–2070)	279 000 (174 000–394 000)
Trichinella spp	1540 (699–3550)	4 (0–23)	334 (86–1510)	1·000 (1·000–1·000)	1540 (699–3550)	4 (0–23)	334 (86–1510)
Trematodes	1 290 000 (378 000–3 750 000)	11 200 (3280–28 600)	1 770 000 (663 000–4 060 000)	0·998 (0·984–1·000)	1 280 000 (378 000–3 750 000)	11 200 (3280–28 600)	1 760 000 (659 000–4 050 000)
Clonorchis sinensis	56 200 (13 800–149 000)	10 200 (2480–27 300)	921 000 (215 000–2 550 000)	1·000 (1·000–1·000)	56 200 (13 800–149 000)	10 200 (2480–27 300)	921 000 (215 000–2 550 000)
Fasciola spp and *Fasciolopsis* spp	134 000 (27 700–425 000)	0 (0–0)	595 000 (112 000–2 020 000)	0·988 (0·891–1·000)	133 000 (27 700–425 000)	0 (0–0)	588 000 (111 000–2 010 000)
Minute intestinal flukes*	1 060 000 (189 000–3 310 000)	0 (0–0)	90 200 (15 700–289 000)	1·000 (1·000–1·000)	1 060 000 (189 000–3 310 000)	0 (0–0)	90 200 (15 700–289 000)
Opisthorchis felineus	7710 (624–38 700)	0 (0–0)	881 (70–4230)	1·000 (1·000–1·000)	7710 (624–38 700)	0 (0–0)	881 (70–4230)
Opisthorchis viverrini	7710 (847–34 500)	36 (4–163)	28 000 (2950–122 000)	1·000 (1·000–1·000)	7710 (847–34 500)	36 (4–163)	28 000 (2950–122 000)
Paragonimus spp	18 700 (803–107 000)	962 (286–2060)	135 000 (22 900–597 000)	1·000 (1·000–1·000)	18 700 (803–107 000)	962 (286–2060)	135 000 (22 900–597 000)
Total	277 000 000 (247 000 000–309 000 000)	43 100 (32 100–61 200)	6 510 000 (4 890 000–8 920 000)	0·615 (0·452–0·757)	171 000 000 (122 000 000–214 000 000)	33 800 (24 100–50 900)	4 890 000 (3 490 000–7 100 000)

Data shown are mean (95% uncertainty intervals). DALYs=disability-adjusted life-years. *Includes but is not limited to species of *Carneophallus, Echinostoma, Gymnophalloides, Haplorchis, Heterophyes, Lecithodendrium, Microphallus,* and *Plagiorchis.*

Table 1: **Mean number of foodborne illnesses, deaths, and DALYs by parasite, 2021**

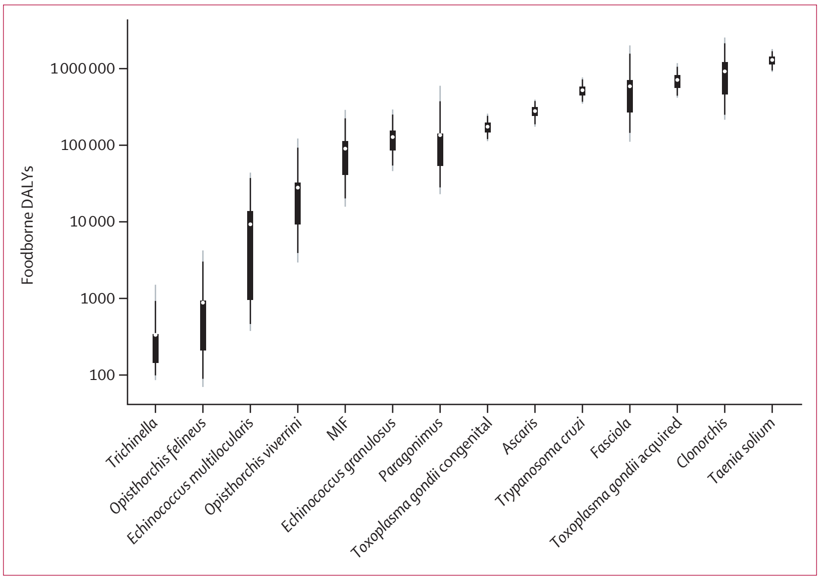


Figure 1:* Boxplot comparing the relative mean foodborne DALYs per parasite infection in 2021, including uncertainty intervals

White dots show the mean on a logarithmic scale, thick black lines show IQR, thin black lines show 90% uncertainty intervals, and thin grey lines show 95% uncertainty intervals. These data are derived from 500 DALY draws, obtained by multiplying the draw-level estimates with draw-level source attribution and relevant disease parameters. The logarithmic scale is used because DALYs vary across several orders of magnitude (from hundreds to millions), allowing differences between pathogens to remain visible across the full range of values. DALY=disability-adjusted life-year. MIF=minute intestinal flukes.

Acquired toxoplasmosis or neurocysticercosis-associated epilepsy cause either the highest or second highest foodborne burden in all regions (appendix p 26). However, some parasitoses occur among the top five in single regions only (eg, Chagas disease in the region of the Americas, clonorchiasis in the Western Pacific region, paragonimiasis in the Western Pacific region). A few parasites are not among the top five in any region (eg, trichinellosis, opisthorchiasis, and alveolar echinococcosis).

At the country level (figure 2B), the burden of foodborne transmission for each parasitosis was considered. Despite variations between countries within the same region, similarities were observed between geographically proximate countries and with similar features relevant for transmission.

Time trends between 2000 and 2021 generally show a downward trend for incidence (appendix p 27). However, although mortality rates from foodborne invasive parasitoses have fallen considerably in the region of the Americas, this decrease is less apparent in the South-East Asia region, the African region, and the Eastern Mediterranean region, and virtually unchanged in the European region (figure 3A). Importantly, mortality rate in the Western Pacific region rose steadily from 2000 to 2021; here, foodborne DALYs decreased from 2000 until around 2011, then plateaued and began rising, with the rate in 2021 similar to the rate in 2005 (figure 3B).

Although some parasites remain at the same relative position over the period (figure 3C), including *T solium* (neurocysticercosis-associated epilepsy) as highest contributor, others show substantial changes. Foodborne DALYs associated with *Paragonimus* spp reduced between 2000 and 2021, whereas those from *Clonorchis* rose markedly.

Discussion

We present updated disease-burden estimates from foodborne infection with 14 invasive parasitoses, 11 of which are targeted among the WHO neglected tropical disease goals for 2030.[16] Among these parasitoses, neurocysticercosis-associated epilepsy has the highest public health burden globally, consistent with previous estimates.[1] Other parasitoses, such as trichinellosis, continue to exert a low burden. Our results highlight that these invasive, often chronic, parasitoses can cause serious disability or death, resulting in a substantial disease burden, which occurs disproportionately in low-income and middle-income countries (LMICs). By providing country-level data for the first time, national health services could adopt tools to focus interventions.[4]

In the Western Pacific region, the burden of foodborne parasitoses is rising. One parasitosis that appears to be increasing is clonorchiasis. Potential reasons include increased consumption of raw or undercooked fish in urban areas of China, perhaps associated with the growing aquaculture industry.[17] Additionally, warmer, wetter weather might exert a positive effect on snail and fish host populations, as well as expanding their ranges.[18,19]

Previously, foodborne DALYs associated with alveolar echinococcosis were estimated to be higher than those associated with cystic echinococcosis, despite wide uncertainty intervals.[1] This greater burden was due to the higher fatality ratio for alveolar echinococcosis than for cystic echinococcosis, despite cystic echinococcosis having considerably higher incidence. Furthermore, the mean foodborne proportion for alveolar echinococcosis (0·47) was more than twice that for cystic echinococcosis (0·21), although the uncertainties were wide. In the current iteration, the mean foodborne proportion for cystic echinococcosis increased to 0·308, but for alveolar echinococcosis it decreased to 0·093, resulting in higher mean foodborne DALYs in 2021 for cystic echinococcosis than for alveolar echinococcosis. A meta-analysis of source attribution indicated that around 23% of cystic echinococcosis illnesses could be foodborne.[11] Although around 33% of alveolar echinococcosis cases in Europe could be foodborne, in highly endemic LMICs outside Europe, contaminated water and infected dog contact probably play a greater role, reducing the foodborne fraction proportionally. The lower overall case–fatality ratio in 2021 compared with 2010 is probably due to advances in case management, especially albendazole chemotherapy.[1] Furthermore, alveolar echinococcosis incidence is apparently decreasing in China, perhaps reflecting nationwide control programmes introduced over the past 20 years, including anthelmintic treatment of dogs. A decreased incidence in China offsets

	African region	Region of the Americas	South-East Asia region	European region	Eastern Mediterranean region	Western Pacific region	Global
Protozoa	455·5 (268·1 to 662·5)	364·3 (249·3 to 485·4)	396·3 (140·6 to 645·4)	372·3 (273·4 to 466·6)	461·7 (294·0 to 634·5)	102·8 (59·2 to 156·5)	332·6 (252·2 to 405·3)
Toxoplasma gondii (acquired)	453·7 (266·7 to 660·2)	356·3 (243·2 to 475·4)	395·3 (140·2 to 644·2)	371·6 (272·9 to 465·7)	459·9 (292·8 to 632·0)	102·6 (59·0 to 156·3)	330·7 (250·6 to 403·2)
Toxoplasma gondii (congenital)	1·76 (1·02 to 2·50)	0·701 (0·440 to 0·956)	0·994 (0·366 to 1·57)	0·688 (0·508 to 0·865)	1·77 (1·07 to 2·53)	0·167 (0·095 to 0·256)	0·906 (0·694 to 1·12)
Trypanosoma cruzi	0 (0 to 0)	7·27 (2·39 to 13·2)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0·943 (0·310 to 1·71)
Cestodes	10·8 (5·66 to 17·8)	2·98 (1·72 to 4·93)	5·80 (3·68 to 8·33)	2·69 (1·16 to 5·40)	3·67 (0·895 to 8·20)	9·39 (2·85 to 21·1)	6·47 (4·29 to 9·78)
Echinococcus granulosus (s.l.)	3·92 (0·812 to 9·29)	1·11 (0·266 to 2·85)	0·680 (0·128 to 1·97)	2·66 (1·14 to 5·37)	3·67 (0·895 to 8·20)	7·11 (1·08 to 18·4)	3·31 (1·58 to 6·31)
Echinococcus multilocularis	0 (0 to 0)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	0·020 (0·009 to 0·036)	<0·001 (<0·001 to <0·001)	0·042 (<0·001 to 0·205)	0·013 (0·001 to 0·052)
Taenia solium	6·83 (3·46 to 11·4)	1·87 (1·08 to 2·97)	5·12 (3·20 to 7·61)	0·008 (0·002 to 0·019)	0 (0 to 0)	2·24 (0·611 to 5·20)	3·14 (1·98 to 4·55)
Nematodes	2255·8 (1·86 to 4046·0)	1168·9 (95·3 to 2223·5)	3629·1 (2083·1 to 4872·3)	135·3 (16·1 to 444·9)	1559·0 (93·5 to 3243·9)	851·5 (11·7 to 1725·9)	1809·6 (1205·9 to 2349·8)
Ascaris spp	2255·8 (1·85 to 4046·0)	1168·8 (95·2 to 2223·4)	3629·1 (2083·1 to 4872·3)	135·2 (16·1 to 444·8)	1559·0 (93·5 to 3243·8)	851·5 (11·6 to 1725·9)	1809·6 (1205·9 to 2349·7)
Trichinella spp	0·017 (0·003 to 0·050)	0·033 (0·012 to 0·088)	0·022 (0·003 to 0·075)	0·037 (0·024 to 0·063)	0·004 (<0·001 to 0·012)	0·008 (0·001 to 0·023)	0·020 (0·009 to 0·045)
Trematodes	1·74 (0·333 to 6·11)	2·29 (0·457 to 6·95)	27·2 (6·40 to 78·7)	5·56 (1·00 to 17·3)	12·5 (3·14 to 36·4)	27·7 (7·07 to 82·7)	16·3 (4·80 to 47·6)
Clonorchis sinensis	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	<0·001 (<0·001 to <0·001)	0 (0 to 0)	2·91 (0·715 to 7·75)	0·713 (0·175 to 1·90)
Fasciola spp and *Fasciolopsis* spp	1·40 (0·213 to 5·26)	2·26 (0·449 to 6·93)	2·52 (0·144 to 13·4)	0·152 (0·016 to 0·746)	1·28 (0·288 to 3·91)	1·56 (0·093 to 7·14)	1·68 (0·351 to 5·39)
Minute intestinal flukes†	0 (0 to 0)	0 (0 to 0)	24·4 (4·62 to 75·7)	4·58 (0·547 to 15·6)	11·2 (2·11 to 35·5)	22·3 (3·27 to 77·3)	13·5 (2·40 to 42·1)
Opisthorchis felineus	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0·823 (0·066 to 4·13)	0 (0 to 0)	0 (0 to 0)	0·098 (0·008 to 0·491)
Opisthorchis viverrini	0 (0 to 0)	0 (0 to 0)	0·147 (0·017 to 0·618)	0 (0 to 0)	0 (0 to 0)	0·243 (0·023 to 1·19)	0·098 (0·011 to 0·438)
Paragonimus spp	0·341 (0·008 to 2·20)	0·03 (<0·001 to 0·211)	0·133 (0·001 to 0·912)	0·002 (<0·001 to 0·009)	0 (0 to 0)	0·605 (0·018 to 4·08)	0·237 (0·01 to 1·36)
Total	2723·8 (410·6 to 4470·3)	1538·5 (461·0 to 2585·9)	4058·4 (2470·3 to 5303·2)	515·8 (340·9 to 828·2)	2036·9 (598·2 to 3759·0)	991·3 (141·6 to 1872·4)	2165·0 (1552·5 to 2714·6)

Data are shown to 3 significant figures or a maximum of 3 decimal places. *Countries by WHO region are shown in the appendix (p 16). †Includes but is not limited to species of *Carneophallus, Echinostoma, Gymnophalloides, Haplorchis, Heterophyes, Lecithodendrium, Microphallus,* and *Plagiorchis*.

Table 2: **Mean incidence rates of foodborne illnesses per 100 000 people, by WHO region*, with 95% uncertainty intervals, 2021**

	African region	Region of the Americas	South-East Asia region	European region	Eastern Mediterranean region	Western Pacific region	Global
Protozoa	0·012 (0·005 to 0·023)	0·566 (0·494 to 0·645)	0·007 (0·002 to 0·014)	0·005 (0·002 to 0·008)	0·012 (0·005 to 0·022)	0·001 (<0·001 to 0·002)	0·079 (0·069 to 0·090)
Toxoplasma gondii (acquired)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Toxoplasma gondii (congenital)	0·012 (0·005 to 0·023)	0·005 (0·002 to 0·009)	0·007 (0·002 to 0·014)	0·005 (0·002 to 0·008)	0·012 (0·005 to 0·022)	0·001 (<0·001 to 0·002)	0·006 (0·003 to 0·011)
Trypanosoma cruzi	0 (0 to 0)	0·561 (0·490 to 0·640)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0·073 (0·064 to 0·083)
Cestodes	0·420 (0·257 to 0·627)	0·067 (0·044 to 0·095)	0·332 (0·245 to 0·421)	0·020 (0·007 to 0·042)	0·022 (0·005 to 0·058)	0·125 (0·046 to 0·253)	0·193 (0·146 to 0·246)
Echinococcus granulosus (s.l.)	0·024 (0·004 to 0·069)	0·007 (0·001 to 0·020)	0·004 (<0·001 to 0·013)	0·016 (0·004 to 0·038)	0·022 (0·005 to 0·058)	0·044 (0·005 to 0·137)	0·020 (0·006 to 0·050)
Echinococcus multilocularis	0 (0 to 0)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	0·003 (<0·001 to 0·009)	<0·001 (<0·001 to <0·001)	0·013 (<0·001 to 0·072)	0·004 (<0·001 to 0·018)
Taenia solium	0·395 (0·230 to 0·598)	0·060 (0·039 to 0·086)	0·328 (0·243 to 0·417)	<0·001 (<0·001 to <0·001)	0 (0 to 0)	0·068 (0·022 to 0·153)	0·169 (0·127 to 0·219)
Nematodes	0·018 (<0·001 to 0·042)	0·01 (<0·001 to 0·024)	0·030 (0·013 to 0·054)	0·001 (<0·001 to 0·004)	0·013 (<0·001 to 0·030)	0·007 (<0·001 to 0·017)	0·015 (0·007 to 0·026)
Ascaris spp	0·018 (<0·001 to 0·042)	0·01 (<0·001 to 0·024)	0·030 (0·013 to 0·053)	0·001 (<0·001 to 0·004)	0·013 (<0·001 to 0·030)	0·007 (<0·001 to 0·017)	0·015 (0·007 to 0·026)
Trichinella spp	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to 0·001)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)
Trematodes	<0·001 (<0·001 to <0·001)	0·004 (0·001 to 0·008)	<0·001 (<0·001 to 0·003)	<0·001 (<0·001 to <0·001)	0 (0 to 0)	0·581 (0·168 to 1·48)	0·143 (0·042 to 0·363)
Clonorchis sinensis	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	<0·001 (<0·001 to <0·001)	0 (0 to 0)	0·532 (0·129 to 1·42)	0·13 (0·032 to 0·347)
Fasciola spp and *Fasciolopsis* spp	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Minute intestinal flukes†	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Opisthorchis felineus	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Opisthorchis viverrini	0 (0 to 0)	0 (0 to 0)	<0·001 (<0·001 to 0·003)	0 (0 to 0)	0 (0 to 0)	0·001 (<0·001 to 0·006)	<0·001 (<0·001 to 0·002)
Paragonimus spp	<0·001 (<0·001 to <0·001)	0·004 (0·001 to 0·008)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to <0·001)	0 (0 to 0)	0·048 (0·014 to 0·104)	0·012 (0·004 to 0·026)
Total	0·450 (0·286 to 0·655)	0·646 (0·568 to 0·732)	0·369 (0·275 to 0·459)	0·026 (0·012 to 0·048)	0·048 (0·022 to 0·086)	0·714 (0·278 to 1·62)	0·429 (0·305 to 0·647)

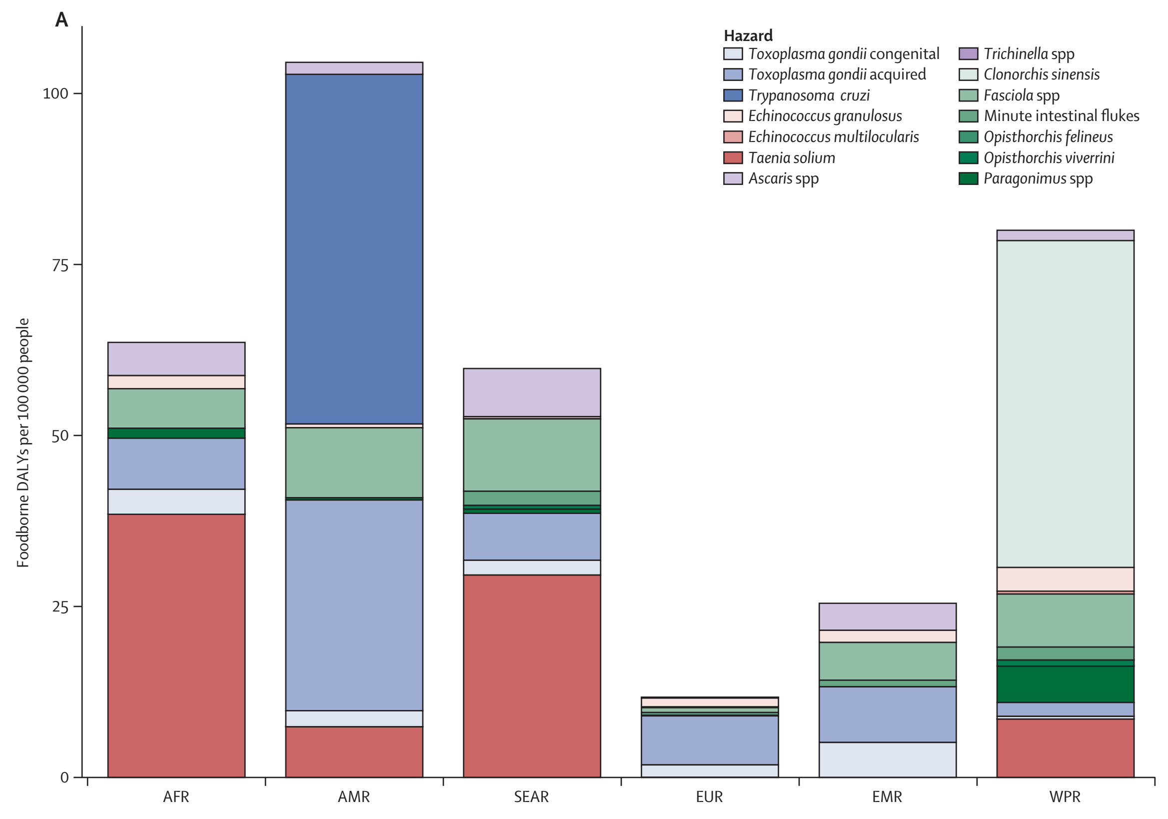
Data are shown to 3 significant figures or a maximum of 3 decimal places. *Countries by WHO region are shown in the appendix (p 16). †Includes but is not limited to species of *Carneophallus, Echinostoma, Gymnophalloides, Haplorchis, Heterophyes, Lecithodendrium, Microphallus,* and *Plagiorchis.*

Table 3: **Mean rates of foodborne deaths per 100 000 people, by WHO region*, with 95% uncertainty intervals, 2021**

	African region	Region of the Americas	South-East Asia region	European region	Eastern Mediterranean region	Western Pacific region	Global
Protozoa	11·1 (6·08 to 18·4)	84·3 (59·4 to 120·4)	9·02 (3·34 to 17·3)	8·97 (5·27 to 14·1)	13·3 (7·22 to 21·0)	2·43 (1·22 to 4·34)	17·9 (12·8 to 24·6)
Toxoplasma gondii (acquired)	7·48 (3·68 to 13·7)	30·8 (15·0 to 54·3)	6·87 (2·28 to 14·1)	7·17 (3·97 to 11·9)	8·15 (4·18 to 13·9)	2·03 (0·936 to 3·84)	9·04 (5·29 to 15·0)
Toxoplasma gondii (congenital)	3·65 (1·90 to 6·10)	2·34 (1·20 to 3·73)	2·15 (0·810 to 3·84)	1·8 (1·08 to 2·72)	5·12 (2·56 to 8·31)	0·394 (0·198 to 0·696)	2·22 (1·43 to 3·28)
Trypanosoma cruzi	0 (0 to 0)	51·1 (34·1 to 75·1)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	6·63 (4·43 to 9·75)
Cestodes	40·4 (23·0 to 65·0)	7·96 (4·79 to 11·9)	29·9 (21·2 to 40·7)	1·45 (0·526 to 3·04)	1·79 (0·384 to 4·33)	12·4 (4·93 to 24·7)	18·2 (13·0 to 24·6)
Echinococcus granulosus (s.l.)	1·93 (0·346 to 5·24)	0·542 (0·117 to 1·41)	0·337 (0·058 to 1·01)	1·3 (0·400 to 2·92)	1·79 (0·384 to 4·32)	3·47 (0·444 to 10·1)	1·62 (0·583 to 3·72)
Echinococcus multilocularis	0 (0 to 0)	<0·001 (<0·001 to <0·001)	<0·001 (<0·001 to 0·003)	0·118 (0·031 to 0·306)	<0·001 (<0·001 to <0·001)	0·423 (<0·001 to 2·25)	0·118 (0·005 to 0·558)
Taenia solium	38·5 (21·4 to 63·4)	7·42 (4·33 to 11·1)	29·6 (20·9 to 40·2)	0·031 (0·009 to 0·073)	0 (0 to 0)	8·54 (2·48 to 20·0)	16·5 (11·5 to 22·9)
Nematodes	4·84 (0·005 to 8·93)	1·76 (0·143 to 3·49)	7·04 (3·87 to 9·85)	0·126 (0·016 to 0·380)	3·93 (0·226 to 8·52)	1·51 (0·022 to 3·46)	3·55 (2·23 to 5·01)
Ascaris spp	4·84 (0·004 to 8·93)	1·75 (0·140 to 3·49)	7·03 (3·86 to 9·84)	0·122 (0·013 to 0·377)	3·93 (0·226 to 8·52)	1·51 (0·021 to 3·46)	3·55 (2·21 to 5·00)
Trichinella spp	0·002 (<0·001 to 0·005)	0·004 (0·001 to 0·014)	0·01 (<0·001 to 0·066)	0·004 (0·002 to 0·008)	<0·001 (<0·001 to 0·001)	0·001 (<0·001 to 0·004)	0·004 (0·001 to 0·019)
Trematodes	7·23 (1·28 to 26·0)	10·6 (2·07 to 34·1)	13·8 (2·32 to 66·7)	1·20 (0·274 to 4·19)	6·47 (1·77 to 18·6)	63·6 (20·0 to 151·2)	22·4 (8·36 to 51·5)
Clonorchis sinensis	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	<0·001 (<0·001 to 0·001)	0 (0 to 0)	47·8 (11·2 to 132·2)	11·7 (2·73 to 32·3)
Fasciola spp and *Fasciolopsis* spp	5·77 (0·805 to 22·4)	10·2 (1·82 to 33·9)	10·6 (0·567 to 62·0)	0·706 (0·069 to 3·37)	5·51 (1·10 to 17·4)	7·75 (0·411 to 35·7)	7·46 (1·41 to 25·5)
Minute intestinal flukes†	0 (0 to 0)	0 (0 to 0)	2·08 (0·375 to 6·50)	0·388 (0·048 to 1·52)	0·953 (0·17 to 3·04)	1·90 (0·283 to 6·73)	1·15 (0·200 to 3·67)
Opisthorchis felineus	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0·094 (0·007 to 0·452)	0 (0 to 0)	0 (0 to 0)	0·011 (<0·001 to 0·054)
Opisthorchis viverrini	0 (0 to 0)	0 (0 to 0)	0·528 (0·059 to 2·42)	0 (0 to 0)	0 (0 to 0)	0·888 (0·079 to 4·11)	0·355 (0·037 to 1·55)
Paragonimus spp	1·45 (0·036 to 9·33)	0·331 (0·065 to 1·42)	0·619 (0·006 to 4·19)	0·009 (<0·001 to 0·045)	0 (0 to 0)	5·31 (1·01 to 22·0)	1·72 (0·291 to 7·59)
Total	63·6 (42·6 to 92·5)	104·6 (75·7 to 145·7)	59·8 (40·1 to 111·5)	11·7 (7·37 to 17·7)	25·5 (15·4 to 40·2)	80·0 (34·5 to 170·2)	62 (44·3 to 90·1)

Data are shown to 3 significant figures or a maximum of 3 decimal places. DALY=disability-adjusted life-year. *Countries by WHO region are shown in the appendix (p 16). †Includes but is not limited to species of *Carneophallus, Echinostoma, Gymnophalloides, Haplorchis, Heterophyes, Lecithodendrium, Microphallus,* and *Plagiorchis*.

Table 4: **Mean rates of foodborne DALYs per 100 000 people, by WHO region*, with 95% uncertainty intervals, 2021**



(Figure 2 continues on next page)

increases in Europe, Central Asia, and North America, resulting in a substantial decrease in global case numbers.

The burden from neurocysticercosis was lower in 2021 than reported in 2010,[1] reflecting improved access to sanitation in endemic countries, and thus lower population at risk. Increased intensification and controls in pork production in middle-income countries is also relevant; this is particularly noticeable in Latin America.[20] Thus, global incidence has decreased by approximately one third, despite an increasing global population.

Estimates for toxoplasmosis are probably improved from those previously reported,[1] as more data are available. Fetal deaths remain a contentious issue for burden estimation, as stillbirths and abortions were not attributed any DALY estimates.

Foodborne Chagas disease was an important inclusion in current estimates. Despite foodborne transmission becoming increasingly recognised, it remains only briefly mentioned in burden estimates.[21] Our 2021 estimates indicate that the foodborne burden is substantially higher than previous speculative approximations,[5] exceeding the foodborne DALY count for ten of the 14 invasive parasitoses considered and surpassing global DALY estimates for Chagas disease in 2023, covering all transmission routes and burden in non-endemic locations.[21] This finding reflects methodological differences, and our assumption of a higher proportion of symptomatic acute disease than the 5% assumed by others.[21]

Although we included foodborne *T cruzi* in our estimates, we excluded infections with Anisakidae, *Angiostrongylus* spp, and *Toxocara* spp. Previously, Anisakidae were considered an uncommon cause of foodborne disease and were thus excluded.[1] Several reports describe anisakidosis as an emerging issue;[22] infection prevalence is rising in marine mammals, potentially reflecting population increases,[23] resulting in more infected fish with heavier worm burdens.[24] Whether this increased prevalence causes more human anisakidosis is uncertain, but one review indicated that cases are increasing.[25] Thus, reconsidering anisakidosis in future foodborne disease burden estimates will be important.

Human infections with *Angiostrongylus* spp are emerging.[26] Although the parasite is becoming established in more regions, potentially through the spread of infected definitive (rat) and intermediate (gastropod) hosts, human infections remain largely limited to case reports, with insufficient data to estimate global burden. However, infection severity (when *Angiostrongylus cantonensis* is the infecting species) and parasite spread suggest that angiostrongyliasis should be considered in future foodborne disease burden estimates.

Toxocara infects domestic dogs and cats globally; transmission to people can occur from food contaminated with

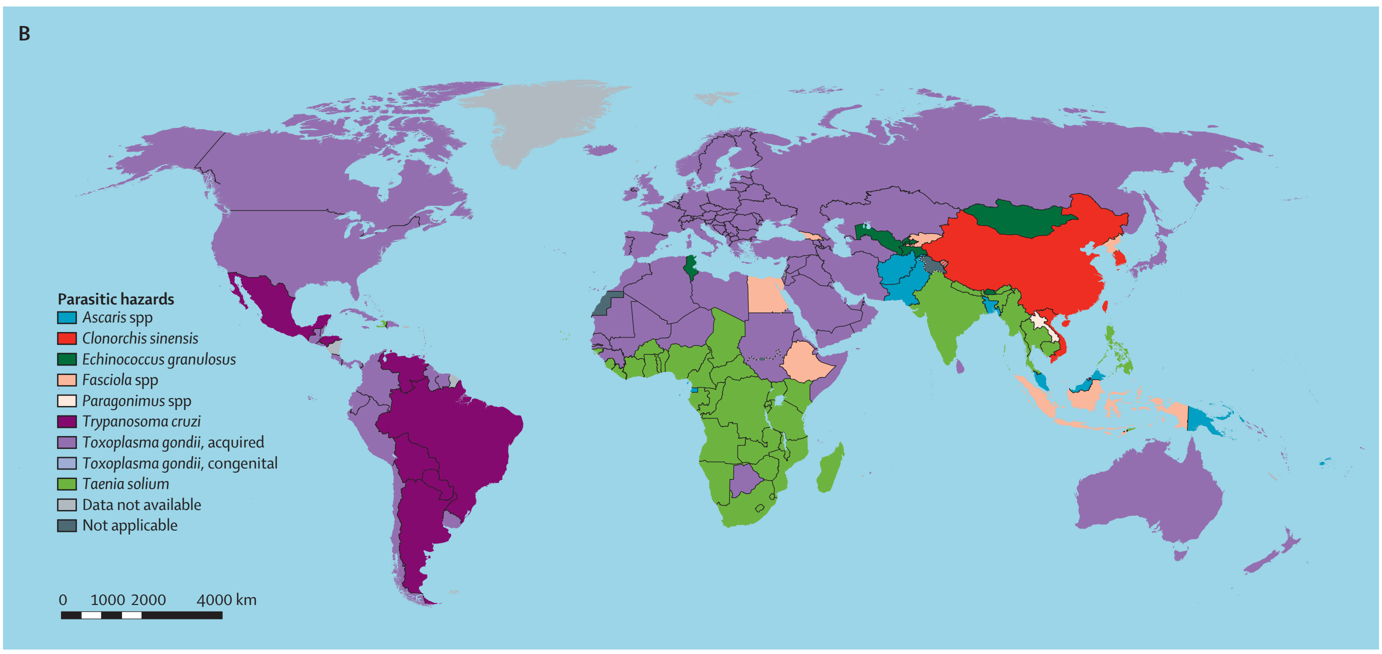


Figure 2: **Regional and country-level differences in foodborne DALYs from different invasive parasites**
(A) Bar chart showing the relative mean foodborne DALYs per parasite infection in 2021 according to WHO region. (B) Global map showing the invasive parasite resulting in the highest foodborne health burden (DALYs) per country. The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of WHO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement. Map data © [2026] WHO. AFR=African region. AMR=Region of the Americas. DALY=disability-adjusted life-year. EMR=Eastern Mediterranean region. EUR=European region. SEAR=South-East Asia region. WPR=Western Pacific region.

Toxocara eggs or from undercooked meat of infected paratenic hosts.[27] As serological surveys indicate widespread human infection, especially in LMICs, with sequelae that are occasionally severe,[27] this parasite should be considered for inclusion in future foodborne disease burden estimates.

Neurocysticercosis remains the invasive parasitic disease inflicting the highest burden in 2021. In most higher-income countries, *T solium* has been essentially eliminated due to appropriate sanitation access and strict controls in the pork food chain. Given that eradicating cysticercosis by disrupting the human–pig–environment transmission cycle is an achievable goal, in reach by implementing an integrated One Health approach,[28,29] it should be prioritised on the global health agenda.

Although our results provide useful information by which estimated burdens of foodborne diseases can be compared between diseases and disease groups, over time, locations, and different demographic groups, our study has various limitations. Readers should remember that the numbers provided are only estimates and should be aware of wide uncertainty intervals for many parasitoses. Limited numbers of studies might result in biased data and large uncertainty. Most invasive parasites are highly localised, both within and between countries, creating challenges for extrapolation and imputation, especially when data are scarce. Efforts were made to account for this by, for example, distinguishing nationwide versus localised studies, or explicitly quantifying population at risk. Nonetheless, the effect is not necessarily sufficiently diluted. Many parasitoses have sequelae that were not considered here. For example, in toxoplasmosis, sequelae are not only ocular, but also neuropsychiatric.[30] Similarly, considering only epilepsy for cysticercosis underestimates the burden; other sequelae include potentially fatal cranial hypertension, chronic headache, visual impairment, meningeal syndromes, and stroke, which are not included here due to lack of population-level data, method heterogeneity, and biases. Source attribution using SEJ presented limitations but could be useful when empirical evidence is insufficient. Biologically implausible transmission routes suggested during SEJ indicated lack of hazard familiarity. More stringent selection of experts could increase precision, but fewer participants might decrease robustness.

In conclusion, despite substantial reductions in several regions, foodborne invasive parasitic diseases continue to impose a considerable burden on human health, particularly in LMICs. Cysticercosis, a theoretically eradicable disease, still contributes substantially to global burden, more than a decade after previous estimates. Likewise, clonorchiasis and Chagas disease, although geographically restricted, exert a substantial impact among exposed populations. Acquired toxoplasmosis remains globally

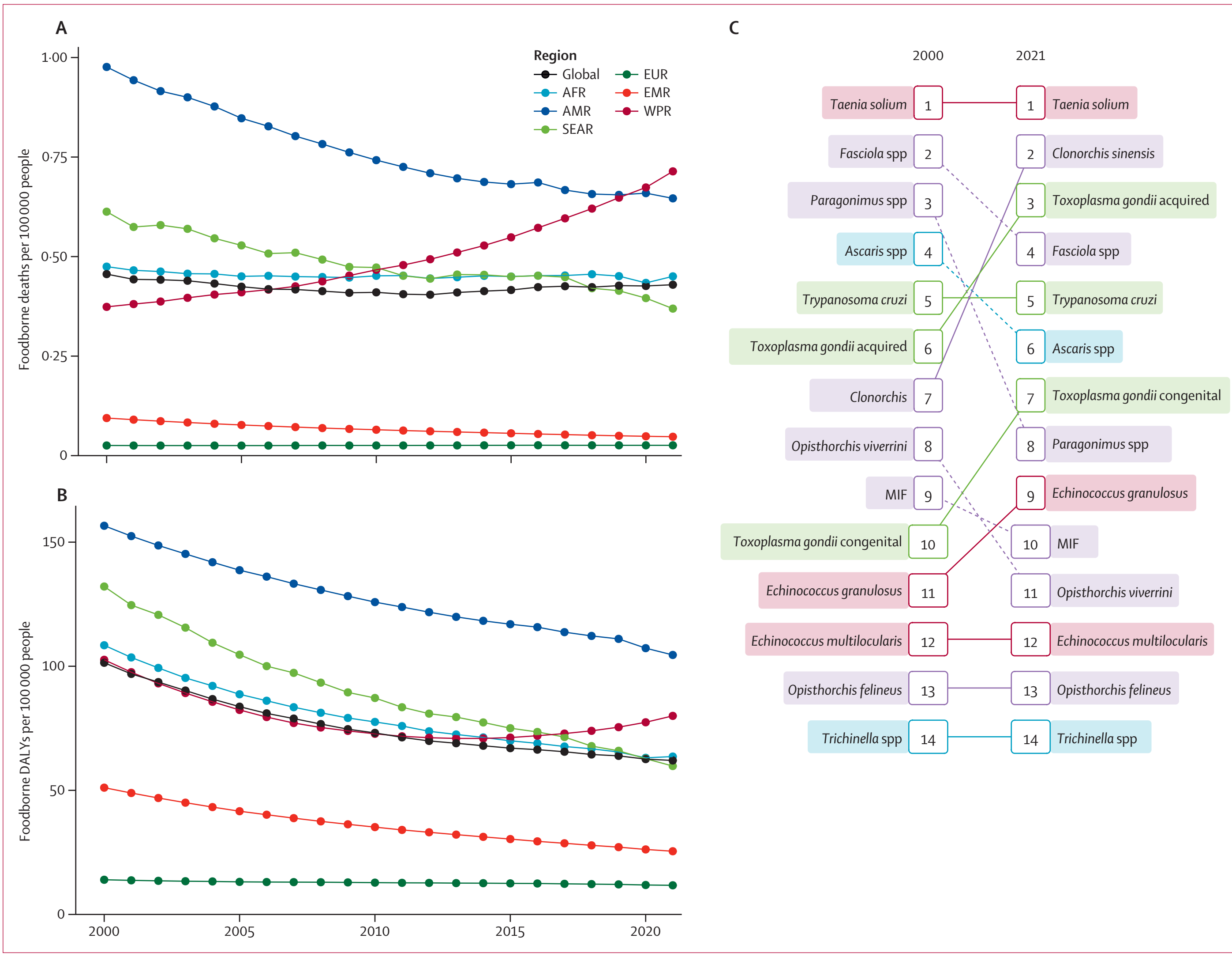


Figure 3: **Time trends in foodborne DALYs from invasive parasites between 2000 and 2021**

(A) Changes in mortality rate due to foodborne transmission of invasive parasites from 2000 until 2021 by WHO region. (B) Changes in rate of foodborne DALYs due to invasive parasites from 2000 until 2021 by WHO region. (C) Ranking of parasites with highest foodborne public health impact (DALY score) globally in 2000 and 2021. DALY=disability-adjusted life-year. AFR=Africa region. AMR=region of the Americas. EMR=Eastern Mediterranean region. EUR=European region. MIF=minute intestinal flukes. SEAR=South-East Asia region. WPR=Western Pacific region.

distributed and imposes a widespread burden. These data provide an updated baseline against which impacts of targeted, disease-specific interventions can be evaluated, informing future control and prevention strategies.

Contributors

LJR, PRT, BD, KHK, BS, and YM contributed to the conceptualisation of the study. PRT, BD, CDB, LV, KF, GFN, HC, CMB, and AR contributed to data curation. BD, CDB, LV, KF, GFN, and PRT contributed to formal analysis. YM contributed to funding acquisition. LJR, PRT, BD, KHK, BS, YM, HC, CMB, AR, SMP, GFN, and CR contributed to study investigation. LJR, PRT, BD, KHK, BS, CDB, LV, KF, GFN, MEK, and LM-G contributed to study methodology. LJR, PRT, BD, CR, YM, and RJL contributed to project administration. BD, CDB, LV, KF, GFN, SEM, MD, and CR contributed resources. BD, CDB, LV, KF, and GFN contributed to software use. LJR, PRT, RJL, BD, YM, and CR supervised the study. LJR, PRT, and YM contributed to validation of results. BD, CDB, and LV contributed to visualisation of data. LJR and PRT wrote the original draft. LJR, PRT, BD, KHK, BS, LV, KF, GFN, HC, CMB, AR, SEM, SMP, CR, MEK, LM-G, RJL, and MD contributed to writing—review and editing. LJR, PRT, BD, and YM directly accessed and verified all underlying data reported in the manuscript.

Declaration of interests

All members of FERG had the opportunity to attend up to two meetings, with expenses covered by WHO.

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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 in Devleesschauwer and colleagues.[4] The analysis code will be accessible via GitHub (https://github.com/fbdburden).

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