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REVIEW

Burden of foodborne disease in low-income and middle-income countries and opportunities for scaling food safety interventions

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Abstract
Foodborne diseases (FBD) are an important externality of agriculture and food systems, but only since 2015 have they risen up the development agenda. In the first part of this Review, I discuss the multiple burdens of FBD and how they relate to food systems with a focus on low-income and middle-income countries (LMIC), particularly African nations. The health burden of FBD is comparable with that of malaria, and over 90% falls on people in LMIC, with an economic burden of more than US$100 million per year. FBD have many other, less well-estimated effects on nutrition, gender, equity, and the environment. FBD are becoming increasingly prevalent in LMIC and many outbreaks are attributable to nutritious, fresh foods purchased from informal markets. In the second part of the paper, I consider options for improved management of FBD at scale in LMIC. I summarize previous investments in Africa, finding that they have often been poorly directed and evaluated. Finally, on the basis of a systematic literature review, I make recommendations for an integrated framework to evaluate food safety interventions in LMIC, including a typology for interventions and five factors critical for success. Incorporating these factors into food safety interventions will ensure that they are scalable and sustainable.

Keywords Foodborne disease · Food safety · Low-income and middle-income countries · Informal markets · Food systems

1 Introduction

Foodborne diseases (FBD) are an important externality of agriculture and food systems, and are defined as 'illnesses caused by food that is unsafe, because it is contaminated or naturally contains hazards'. A hazard is anything in food that could impair human health, whether or not it actually does. By contrast, a risk is a combination of the negative impacts of a hazard and the likelihood of the occurrence of negative impacts: it captures actual harm to human health. The Codex Alimentarius (Codex Alimentarius, 2021) — the main global food safety authority — considers 'food' to include bottled and packaged water, as well as other drinks. FBD have long been a concern in high-income countries (HIC) where many infectious diseases that are still common in low-income and middle-income countries (LMIC) have been controlled or eradicated. However, FBD have only become a development priority in since 2015, hence the absence of FBD from the United Nations Sustainable Development Goals. This recent increase in the prominence of FBD can largely be attributed to the publication of the first *Global Burden of Foodborne Disease Report* (WHO, 2015), which indicated that FBD carry a health burden comparable to malaria, HIV/AIDS, or tuberculosis — the so-called 'big three' — thus seriously compromising human health in LMIC. With growing recognition of the health burden of FBD, interest has also risen in understanding the dynamics and trends of these diseases, their relevance to food systems and, perhaps most importantly, their management at scale. In this Review, in addition to presenting the currently available information on these issues, I will recommend an integrated framework for evaluating food safety interventions in LMIC based on a study on previous investments in food safety and a systematic literature review. This framework includes a typology (or way of categorising) interventions

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and five critical success factors that, if not met, indicate that the intervention is unlikely to be scalable or sustainable.

2 Multiple burdens of foodborne disease

2.1 Metrics for health burden

Health burden can be measured in various ways. A common measure is incidence, that is, the number of new cases over a specified period of time. Prevalence is the proportion of people in a population who have a particular disease or attribute at a specified point in time (or over a specified period of time). Another important feature of disease is severity. Many common FBD, such as diarrhoea caused by norovirus, are very rarely fatal. However, other FBD, such as liver cancer caused by aflatoxins, have very high mortality. Chemical hazards often cause chronic disease. Linking disease outcomes with long-term ingestion of chemicals can be difficult and can lead to under-estimation of the health burden associated with chemicals.

Using different measures of health outcomes leads to different ranks in terms of magnitude, and drawing comparisons between FBD become challenging. To overcome this problem, the World Health Organization (WHO) developed a metric called the 'disability-adjusted life year' (DALY), which combines both the amount of disease and how severe it is (that is, the morbidity and the mortality). One DALY can be thought of as the loss of the equivalent of 1 year of full health.

2.2 Evidence for the health burden of FBD in LMIC

Little empirical information is available on the burden of FBD in LMIC. The main sources of information are official reports, epidemiological surveys, risk assessments, and health burden assessments. Official reports are unreliable due to under-reporting at every level (Grace, 2015). Epidemiological studies in several countries have demonstrated that FBD cause considerable morbidity and mortality, but these studies are often conducted at a subnational scale and typically include only one foodborne hazard, or a subset of hazards. This is in contrast to HIC where the health burden of FBD in HIC where well-resourced agencies report high quality data on FBD regularly (CDC, 2019; EFSA & ECDC, 2022).

Quantitative risk assessments are widely used in HIC to predict the likelihood and impact of FBD based on the level of hazards in food consumed, the quantity consumed, and the susceptibility of those consuming the food. A limited number of quantitative microbial and chemical risk assessments from developing countries have been published, but most indicate a high level of FBD. For example, around 13% of people suffer from pork-borne salmonellosis each year in Vietnam (Dang-Xuan et al., 2017) and around 1% of children are exposed to zoonotic milk-borne *Cryptosporidium* spp. annually in Nairobi, Kenya (Grace et al., 2012a).

Some FBD have been included in *Global Burden of Disease Assessments* produced by the WHO and the Institute for Health Metrics and Evaluation. These reports indicate high burdens for the diseases included, such as cysticercosis caused by the tapeworm *Taenia solium* in pork. The impact of FBD can be estimated using a variety of methods including literature review, expert opinion, and Bayesian imputation. However, the only study to focus solely and comprehensively on the global health burden of FBD was conducted by the WHO Foodborne Disease Epidemiology Reference Group (FERG). This paper, which represents the work of more than 60 experts over a period of 10 years, can be considered the most definitive and comprehensive guide to the health burden of FBD (Havelaar et al., 2015).

The FERG used three metrics: incidence, deaths and DALYs lost. The first part of the study considered 31 biological and chemical hazards for which experts judged sufficient data were available to make global estimates. Results are presented for the baseline year 2010, and as rates per 100,000 people to facilitate comparison between WHO geographical regions. Disaggregating the results by sex was not possible, owing to data limitations, and only two age categories were defined (children aged under 5 years and all other individuals aged 5 years or older). The FERG found that hazards accounted for around 420,000 deaths in LMIC, imposing a burden of around 33 million DALY lost each year (Havelaar et al., 2015). This estimate is likely to be conservative. Children aged under 5 years were disproportionately affected. This group makes up 9% of the world's population, yet they experience 38% of all FBD, represent 30% of deaths related to FBD, and bear 40% of global DALY lost from FBD (Havelaar et al., 2015). Africa and South-East Asia had the highest incidence of FBD and the highest mortality and DALY lost across all age groups. People living in the poorest areas of the world comprise 41% of the world's population, experience 53% of all FBD, represent 75% of deaths related to FBD, and bear 72% of global DALY lost from FBD. In all, over 90% of the burden of FBD falls on LMIC (Havelaar et al., pers. com.).

The second part of the FERG study, focusing on four foodborne heavy metals (arsenic, cadmium, lead, and methylmercury), was published as a separate report (Gibb et al., 2019). This investigation suggested a global burden of more than 1 million diseases, over 56,000 deaths, and more than 9 million DALY lost a result of these four hazards. This estimate is likely to be less conservative than for the first part of the study. A different methodology was used for this

second investigation, meaning that results can only approximately be aggregated with the first part of the study. However, the combined health burden of all FBD is estimated to be around 42 million DALY lost per year. For comparison, the estimated global burden of tuberculosis and malaria in 2010 was 40 million and 66 million DALY lost, respectively (Institute for Health Metrics and Evaluation, 2021).

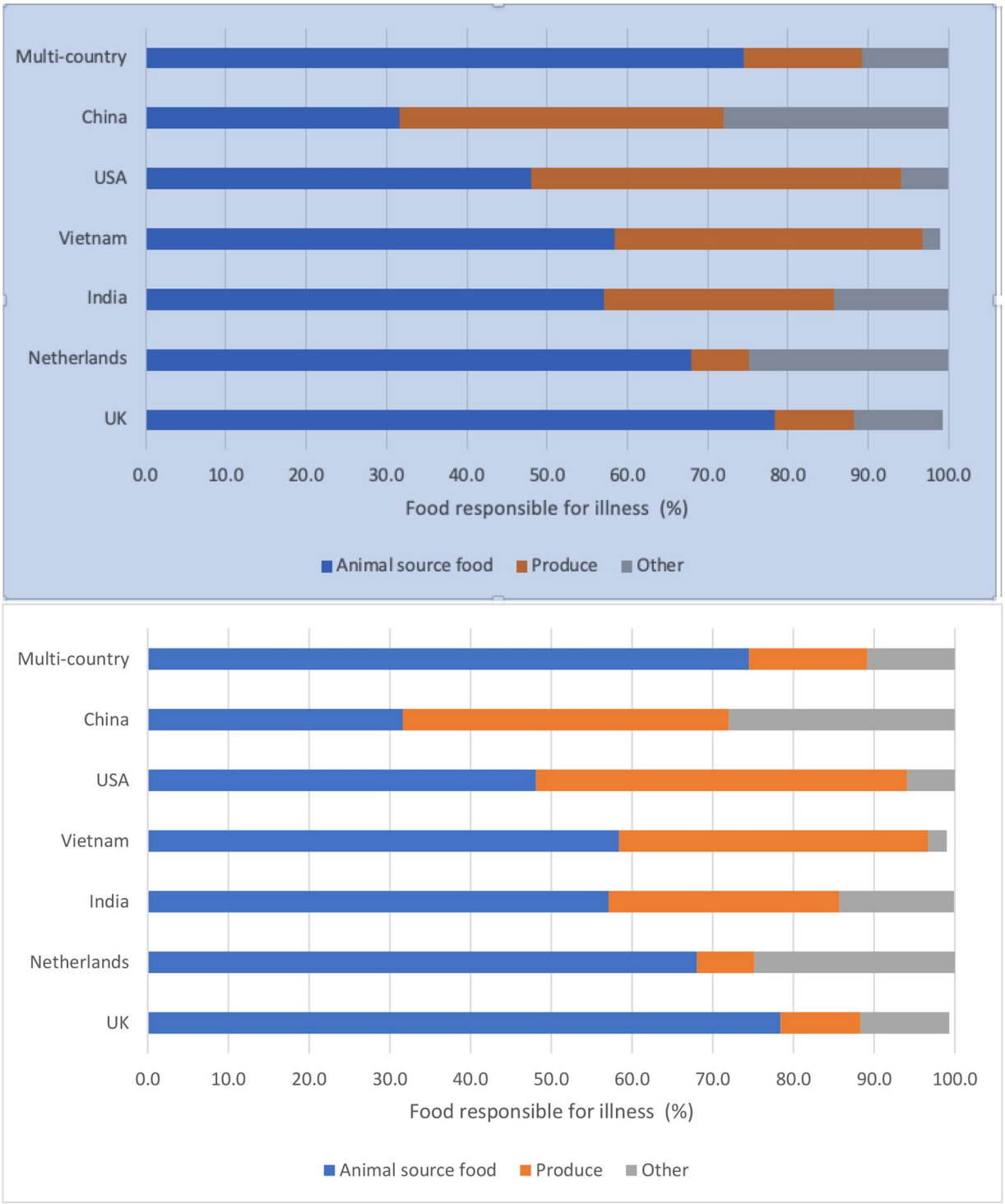

Fig. 1 The proportion of foodborne disease by food source in various countries. Data from Grieg & Ravel (2009) (multicounty), Sang et al. (2014) (China), Painter et al. (2013) (USA), World Bank (2017) (Vietnam), Sudershan et al. (2014) (India), Mangan et al. (2015) (Netherlands), and Tam et al. (2012) (UK)

2.3 Food sources of FBD in LMIC

Very little information exists on the foods that are the source of FBD in LMIC. In HIC, most FBD result from consuming animal products (those derived from livestock or aquatic animals) and contaminated fresh produce (fruits and vegetables). In LMIC, less animal products and fresh produce are consumed, but these foods are mainly sold fresh in informal markets and are often heavily contaminated. The limited data from LMIC on reported FBD by food source show a similar pattern to the data from HIC (Fig. 1) (Painter et al., 2013; Sudershan et al., 2014; Mangen et al., 2015; Tam et al., 2012; Sang et al., 2014). Meat consumption is a strong predictor of mortality from FBD. In a cross-country study, for every additional metric ton of meat consumed per 100 people, mortality from FBD increased by 6% (Hanson et al., 2012). However, this correlation does not necessarily imply causation. A paper published in 2019 that focused on only a subset of hazards, suggested that animal products might be the source of around one-third of FBD (Li et al., 2019), but this figure is likely to be an underestimate.

In HIC, the proportion of outbreaks of FBD attributed to fresh produce has increased in since the 1980s (Lynch et al., 2009). Although less information is available from LMIC, similar trends are to be expected, as the drivers are similar and include greater consumption of fresh produce, agricultural intensification, increasing length and complexity of value chains, globalization, greater recognition of diseases linked to fresh produce, emergence of new FBD, increasing tendency to eat fresh produce without cooking, and the limited effect of washing in removing pathogens (Burnett & Beuchat, 2001). Use of raw manure on crops, sewage and contaminated water for irrigation and washing, and excessive use of pesticides are particularly common in LMIC and are an important source of FBD.

Major chemical hazards that are well managed in HIC are still problematic in LMIC. Therefore, making direct extrapolations from data gathered in HIC is difficult. For example, most cases of exposure to aflatoxin are caused by consumption of maize, groundnuts, and sorghum. In HIC, the burden of FBD from aflatoxins is negligible, but in many LMIC it is a priority public health problem. If the association between aflatoxins and stunting is proven (Grace et al., 2015), the importance of this pathogen will be even greater. No credible, comprehensive, quantified evidence on the impact of agricultural chemicals in food on human health in LMIC currently exists (Käferstein, 1997; Prüss-Ustün et al., 2011), but if solid evidence is developed that substantiates fears regarding chemicals in food then impact on health is likely to be substantial.

Food consumption is determined by culture, religion, values, and beliefs. Often, the most nutritious and high-societal value foods also carry the highest risk for FBD. Animal source foods are highly nutritious, yet also disproportionately incriminated in FBD (Li et al., 2019). In terms of cultural valuses and practices, in Ethiopia, raw meat is consumed (Seleshe et al., 2014) and in Kampala, Uganda, people eat raw eggs in the belief that they cure illness (Nasinyama et al., 2010). Pastoralists in West Africa believe that raw milk does not cause illness (Roesel & Grace, 2014) and, in Vietnam, widespread consumption of raw or undercooked blood, meat, and fish leads to several zoonoses (Carrique-Mas & Bryant, 2013).

2.4 Trends in FBD in LMIC

Monitoring trends for FBD in LMIC is difficult owing to the lack of accurate reporting. In high-income regions with good reporting, such as North America and Europe, there has been no overall marked decline in the burden of FBD in the first decades of the 21st century (Grace, 2015). However, control of specific pathogens has been achieved in some areas.Investments in food safety over the past 20 years are argued to have had limited impact; not because these strategies are ineffective, but because of other factors that increase risk, such as globalization, changes in eating habits, and changes in farming practices. Given the strong association between agricultural intensification and increase in FBD, sharp rises in FBD are likely in countries where intensification is most rapid and least governed.

In a study from the World Bank Group, a food safety "life cycle" is proposed, whereby food safety can be expected to worsen as countries develop, before improving as they reach HIC levels of economic development (Fig. 2) (Jaffee et al., 2019). As countries develop, a shift occurs from short and simple value chains where most people know where their food comes from, to long and complex chains with little traceability or trust. Moreover, with increasing urbanization and incomes, the consumption of fresh produce and animal products (the foods associated with the highest risk of FBD) also increases. In addition, production starts to intensify, which can result in the increased use of chemicals, production in polluted areas and, in the case of livestock, more crowding and disease.

2.5 The economic burden of FBD in LMIC

Economic valuation of health benefits is now an established tool for identifying the highest priorities for public health investments. Although methods of valuation have recognized limitations, they can provide insights into the economic cost of disease and the potential value of reducing the burden. Understanding the basis for such estimates is important, as they can be misinterpreted. For example,

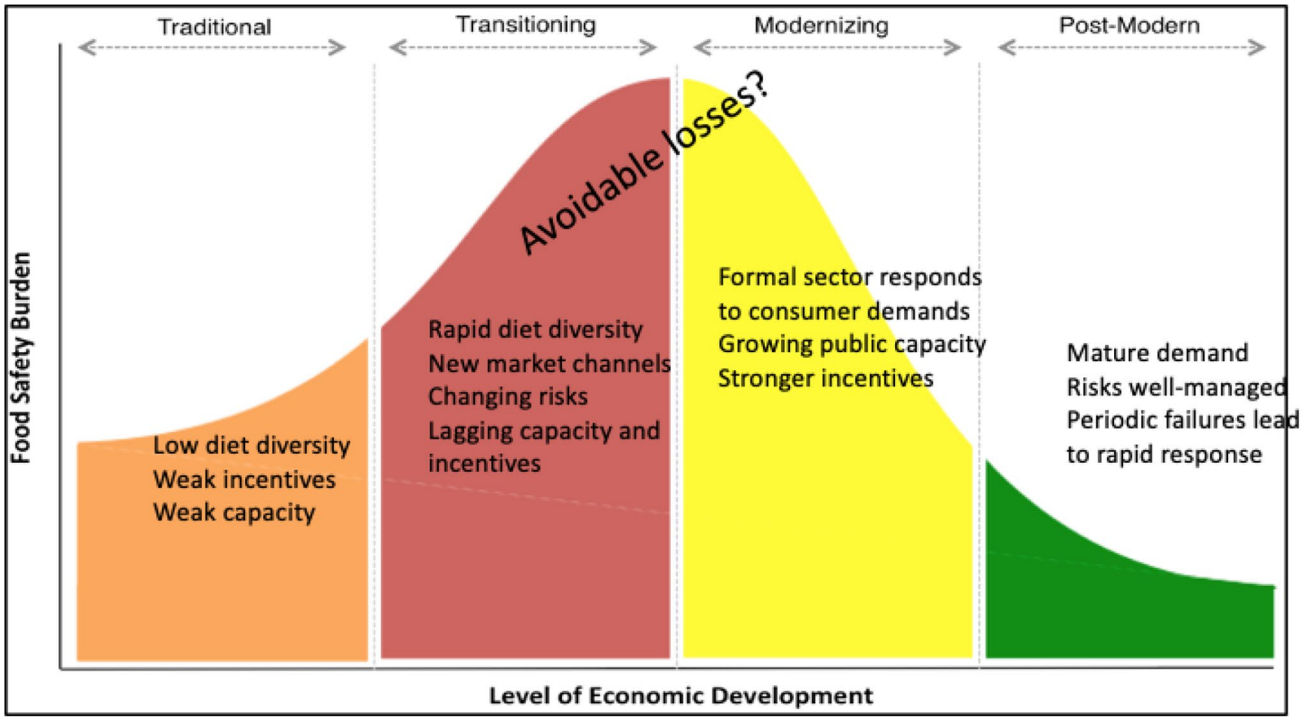

Fig. 2 The food safety life cycle. Reproduced from Jaffee et al., 2019

credible estimates of the economic burden of FBD in the USA vary from $14 billion to $77 billion, owing to differences in methodology and pathogen coverage (Hoffmann & Anekwe, 2013).

A review by the World Bank Group of health economic methods provides a useful overview of the issues (Narain & Sall, 2016), which are briefly summarized here. Valuation of health benefits starts with estimation of DALY lost, followed by loss of life, which typically accounts for the biggest share of health valuation estimates. Loss of life can be valued in two ways. Firstly, the foregone output from the life lost (what a person would have produced if the premature death had not occurred). Secondly, the willingness to pay (WTP) to avoid death, that is the value of statistical life (VSL), inferred in various ways from behavior or surveys. The WTP approach typically yields much higher estimates than the foregone-output approach, because the WTP to avoid death is typically higher than income.

In addition to DALY lost and loss of life, there are direct and indirect costs associated with illness. Direct financial costs include transport costs to receive treatment, medical expenses paid by the patient, wages lost, and the cost of public health provision. Indirect costs include productivity lost through employees being unable to work and the monetized value of forgone household chores. The number of studies on these costs in LMIC is limited.

Other costs associated with FBD are borne by the food sector economy. These costs include domestic and exported product rejections and recalls, and markets lost owing to the inability to meet food safety standards. In LMIC, however, unsafe food is rarely recalled and food that is rejected from one market can usually find a buyer in another. HIC countries that import food from LMIC, tend to be more demanding but, even so, the losses do not seem to be extremely high. Certainly, imported foods have been linked to outbreaks of FBD. For example, in the USA, there are well-documented cases of FBD associated with cheese from unpasteurized milk, mainly imported from Latin America (Centers for Disease Control, 2012). However, the number of cases linked to imported food remains low. Between 2005 and 2010, 39 outbreaks of disease were traced to imported foods in the USA, 45% of which came from Asia. This figure represents just 0.7% of the 5,500 total outbreaks of FBD in the USA in this period (Gould, 2013).

In considering the economic burden of FBD, the World Bank Group has estimated that lost human capital (productivity) is by far the greatest cost associated with FBD (Fig. 3) (Jaffee et al., 2019). The economic cost of FBD in LMIC has been estimated at over US$100 billion per year (Jaffee et al., 2019). These costs are heaviest in larger, middle-income countries such as South Africa, Nigeria and Egypt, but are also substantial elsewhere. In relative terms, the economic burden of FBD is higher in African countries than among other LMIC, because the per capita burden of FBD is higher in African countries.

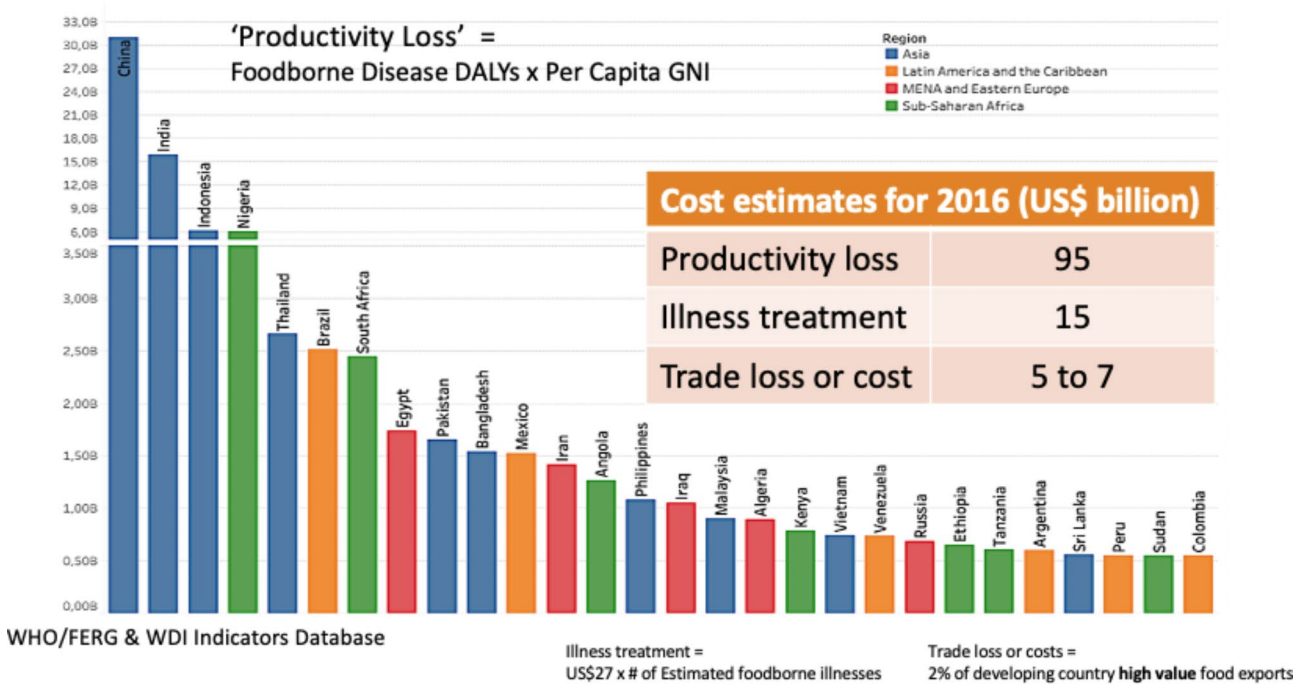

Fig. 3 The economic cost of foodborne diseases in LMIC. Reproduced from Jaffee et al., 2019. DALY, disability-adjusted life years; FERG, Foodborne Disease Epidemiology Reference Group; GNI, gross national income; LMIC, low-income and middle-income countries; MENA, Middle East and North Africa; WDI, world development indicators; WHO, World Health Organization

2.6 Other burdens of FBD in LMIC

When we look beyond health burden, it becomes clear how embedded food safety is in food systems. From the information summarized in this Review so far, FBD can be seen to have important effects on poverty and equity as well as implications for development issues, such as nutrition, gender, and emerging infectious diseases.

2.6.1 Nutrition

Stunting, or extreme shortness (very low height-for-age), is caused by a combination of long-term (chronic) poor dietary intake in terms of quality as well as quantity of food and repeated episodes of infectious disease. Both wasting (very low weight-for-age) and stunting are associated with increased mortality as well as poor health and long-term development outcomes. FBD and hazards can contribute to stunting and wasting through additional pathways, outlined below.

Diarrhoea is associated with malnutrition, but a causal link is hard to demonstrate. A study conducted in nine countries showed that 25% of cases of stunting could be attributed to experiencing more than four episodes of diarrhoea before the age of 24 months (Checkley et al., 2008). In another study from Ghana, a strong peak in the incidence of diarrhoea was found after the introduction of supplementary foods, and weaning foods often had high levels of aflatoxin and fumonisin contamination(Kumi et al., 2014). Aflatoxins could directly contribute to stunting and high levels of this toxin have been associated with poor growth in several contexts but, although plausible, causality is as yet unproven (Leroy, 2013).

Ingestion of animal faeces in food or from the environment could contribute to environmental enteric dysfunction (George et al., 2015). In children, this incompletely defined syndrome of inflammation, reduced absorption, and barrier function of the small intestine could contribute to stunting and wasting. Illness of adults within a family can reduce the money available for food purchase and time available for childcare, with a knock-on effect for the growth and health of children.

In LMIC, there is often a trade-off between food safety and availability. Informal, traditional markets are the major source of the most nutritious, but high-risk, fresh foods such as eggs, green leafy vegetables, and fish (Grace, 2015). Measures intended to improve the safety of food can have

the unintended consequence of reducing its availability. For example, in Kenya, the cost of pasteurized milk is double that of raw milk and, therefore, beyond the means of many poor families. A study on aflatoxin in Kenya found that if existing standards were strictly enforced, enormous amounts of staple foods would have to be destroyed, which would be economically and practically infeasible (Sirma et al., 2018).

2.6.2 Gender

Little research has been conducted on the intersection between gender and food safety, but FBD can have important implications for women. Firstly, food safety has a direct impact on women's health. Pregnant and lactating women are particularly vulnerable to FBD because of alterations in their immune system. In addition, some FBD cause foetal abnormalities, abortion, and stillbirths and some chemical hazards can be transmitted to the newborn through breast milk.

Secondly, culture affects the relative consumption of high-risk foods by men and women. In Nigeria and Somalia, women have been reported to consume more low-value offal and men more high-value muscle meat (Masese-Mwirigi & Waweru, 2010). Consumption of offal has been found to be a risk factor for diarrhoea (Stafford et al., 2008; Grace et al., 2012b). In Africa, men generally have greater access to meat because they predominate in bars that serve meat and alcohol (Roesel & Grace, 2014). The risk of FBD is higher in these venues than for food prepared in the home. A similar pattern is seen with fish consumption in China, Vietnam, and Korea, where men have more frequent eating opportunities at restaurants than women and have a significantly higher rate of clonorchiasis (from the fish-borne liver fluke *Clonorchis sinensis*) (Han et al., 2013).

Thirdly, food safety has implications for women's livelihoods. Women have an important (even dominant) role in many traditional food value chains. However, as chains modernize, partly driven by food safety concerns, women are often excluded, lose their source of income and have to seek alternatives, which might be less lucrative and more dangerous (e.g., selling food at bust stands) (Grace, 2015).

Finally, women are risk managers in the realms of food consumption, preparation, processing, selling and, to a lesser extent, production. However, they are often disadvantaged by reduced access to support and services such as education and extension. These factors highlight the importance of gender analysis when assessing and designing interventions to improve food environments by enhancing food safety.

2.6.3 Emerging infectious diseases

Emerging infectious diseases are those that have newly appeared in a population or are rapidly increasing in incidence or geographic range or changing host. Many emerging infectious diseases are associated with food value chains, particularly those for wildmeat or bushmeat.

In March 2020, the global outbreak of the SARS-CoV-2 virus, which causes the disease COVID-19, was declared a pandemic by the WHO (2020). To date, COVID-19 has killed over a million people and has cost the global economy billions of dollars. Both COVID-19 and an earlier disease caused by a coronavirus (sudden acute respiratory syndrome; SARS) have been associated with traditional, informal markets or fresh produce markets (sometimes called 'wet markets') in China. These markets sell fresh meat, fish, and other perishable agricultural produce. Some of these informal markets sell live poultry and other domesticated animals, live aquatic products (fish and shellfish), and live or dead wild animals. The products are sourced from different locations, and many are transported long distances. SARS was associated with civets sold at informal markets in China, and the origin of the SARS-CoV-2 outbreak has been associated with a traditional food market in Wuhan, China where wildlife was purported to be sold. The consensus is that informal markets can be epidemiologically high-risk, particularly those with poor hygiene and where live domesticated animals or live or dead wild animals are sold. However, expert opinion differs as to whether live animal markets should be regulated more strictly, gradually upgraded with buy-in from vendors, or banned completely to reduce the risk of disease transmission.

Notably, strict regulation of food has proven difficult in governance-poor contexts. Informal, traditional fresh produce markets have many benefits for local populations, including low prices, ease of access, availability of preferred fresh and traditional foods, income-earning opportunities for women, worker independence, and attractions for tourists (Naguib et al., 2021). However, these benefits need to be weighed against the wider advantages to humanity of preventing disease outbreaks and global pandemics. Moreover, attempting to ban foods for which demand exists, drives sales and consumption underground making them more difficult to manage.

3 Scaling food safety improvements in LMIC

3.1 Previous investments in food safety: the case of sub-Saharan Africa

The Global Food Safety Partnership (GFSP) is a public–private initiative, hosted by the World Bank Group, dedicated to supporting and promoting global cooperation for food safety capacity building (The Global Food Safety Partnership, 2021). The GFSP assessed of nearly a decade's worth of donor investment in food safety in sub-Saharan Africa (SSA) (The Global Food Safety Partnership, 2019). More than 360 food-safety focused projects were identified and analyzed across several areas including budget, duration, and orientation. The main findings from the report are outlined below.

Firstly, current donor investment in food safety in SSA is substantially focused on access to regional and overseas export markets, with emphasis on oversight by national control systems to facilitate trade. However, little is being done to reduce FBD in African consumers. The current focus reflects the economic importance of food exports to African governments, the role of African governments in overseeing exports, and the focus of European and other donors on the safety of food that they import from SSA. Analysis by the WHO underscores the importance of improving food safety as an African health challenge, particularly in the subsistence and informal market sectors which are the main source of food for hundreds of millions of Africans.

Secondly, much donor investment involves training and laboratory activities that are not linked to a holistic strategy. The investments typically do not address the microbiological hazards that impose a substantial health and development burden in SSA. Standards and guidance from the Codex Alimentarius recognize that achieving food safety requires well-planned, risk-based efforts from farm-to-table that link private-sector responsibility with government oversight and support (Codex Alimentarius, 2021). These principles can be adapted and applied to capacity investments in SSA to improve food safety for both domestic and export markets.

Thirdly, the burden of FBD in SSA and input from a wide range of experts and stakeholders argue strongly for donors and national governments to consider a new strategic approach to capacity building. Increased focus and investment in public health and food safety is needed, together with greater emphasis on harnessing consumer awareness and market forces to drive progress. This recommendation does not imply reducing investment in export-oriented capacity building, which remains an important element of agriculture-led development strategies.

Fourthly, there is no evidence of sustainability (I use sustainability in the sense of continue after the project ends) or scalability of investments in food safety in domestic markets. This is partly due to the few investments in domestic markets, and partly due inadequate short term evaluation and generally lack of long term evaluation. But also the nature of investments (e.g., in building laboratories without providing for running costs, or supporting 'silver bullet' solutions in the absence of any business plan or indication value chain actors would pay for the intervention) make them unlikely to be scalable or sustainable.

3.2 Interventions to improve food safety: an evidence-based approach

3.2.1 Framework

However, even if regulation is enabling and consumers are able to exert demand for food safety, food value chain actors will still need to change their behavior and ideally have access to better tools and technologies to respond to consumer demand. A systematic literature review was conducted to understand the interventions that could improve food safety. The review focused on Africa, but the plan is to extend the analysis to Asia and update the findings. The methodology followed the PRISMA guidelines for systematic literature review (Page et al., 2021). In brief, a syntax was developed and tested for to see if the expected kind of publications could be found. The keywords in the syntax related to FBD, interventions, evaluation methods and geography[1]. Then using the syntax, CabDirect and PubMed was searched, and hits downloaded to Excel. Search strategies were developed using the population, intervention, comparison and outcome (PICO) format using Medical Subject Headings (MeSH), truncation symbols, Boolean search operators to robust the search strategy. The inclusion criteria were published between 2000 and 2017; studies in English; includes an intervention aimed at improving food safety; includes evaluation on hazards or health impacts (the outcome studied should be either effect on health or on hazard occurrence); study conducted in Africa. Exclusion criteria were not related to food-borne hazards; studies conducted only in laboratories; studies only focusing on prevalence or risk factor analysis. The initial search identified 3,470 titles. These were screened by two independent reviewers and 498 abstracts identified as relevant which in turn were screened by two independent reviewers and in case of disagreement a

[1] foodborne OR "food safety" OR "safety label" OR "food hygiene" OR "food-borne" OR "food borne" OR "kitchen hygiene" OR "street food" OR abattoir OR slaughter* OR "willing* to pay" NOT "organic" NOT "indigenous" NOT "GMO" NOT "exotic") AND ("cluster random" OR Random OR "clinical trial" OR intervention OR trial OR experiment OR impact OR evaluation OR effect OR control* OR manag* OR improve OR achiev* along with African countries named individually and Africa.

third reviewer screened, and the majority decision taken. As a result, 84 papers were identified, and full papers retrieved for all. After reading 17 were eliminated because they were duplications (1 paper), reviews (2 papers) or not relevant to the study questions (14 papers). This left 67 papers included in the review. The results are available in a working paper (Grace et al., 2018), but are summarized here. From the systematic review, a typology was developed that set out the types of intervention used along the value chain and at population level to improve food safety. Table 1 shows an estimate of the relative importance of each intervention in LMIC. In addition to these value chain interventions, a smaller number of interventions were conducted at population level. For example, incorporating food safety into health programs (such as mother-and-child care or treatment of HIV) or medical interventions (such as vaccination for cholera).

The interventions covered in the reviewed papers were dominated by technologies, including antibacterial wiping cloths, biocontrol of aflatoxins, and vinegar sprays for decontaminating carcases. The next most-common type of intervention was training and information. These strategies varied from 1-day training for street-food vendors to 2-year training for government medical and veterinary officers. Interventions around new processes included hazard analysis critical control points, food safety management systems, good agricultural practice), food labelling, and willingness to pay for quality-assured products. Regulations were the next most-common type of intervention, followed by new organizational arrangements such as institutionalizing mycotoxin testing. Interventions involving infrastructure, such as laboratory funding to test for aflatoxin, were the least common in the papers reviewed.

A minority of interventions aimed to reduce FBD, but were not directed at the food value chain. Five interventions integrated food safety with other health programs, two were medical interventions (a vaccination and a toxin binder), one initiative aimed to improve hygiene in school children, one intervention was a household cleaning technology, and another assessed the impact of dietary diversity on reducing exposure and vulnerability to aflatoxins and cyanide. Most interventions focused on specific types of hazards. Most frequently microbial hazards, followed by mycotoxins, then pesticides, and finally chemical hazards (cyanide and cadmium). Among the studies retrieved, very few focused on multiple categories of hazard.

The systematic review showed that the interventions with the highest levels investment (for example, provision of infrastructure, strengthening of national control systems) are among the least evaluated. In addition, the export sector, formal processing, and institutional catering are over-investigated relative to their influence on health burden. The hazards studied are more aligned to the FBD than are donor investments, although the lack of any interventions specific to nematodes is an important gap in research.

3.2.2 Design, outcomes, and impact

Few of the studies included in the systematic review used a randomized, controlled trial (RCT) design, which is the gold-standard for determining whether a community-level intervention has impact. Most of the studies had an experimental design, which is suitable for assessing whether a technology is effective (for example, whether irradiation reduces bioactive amines in sausages). Several WTP studies were assessed, most of which used conjoint valuation, a method that very prone to overestimating WTP. One WTP study used an auction with endowed money, which is considered a better method of assessment. In another study, revealed behaviour was investigated (where participants have to use their own money to purchase 'improved' vegetables), which is the most accurate way of assessing WTP.

Most papers included in the systematic review had only one type of outcome, but around one-third reported on two types of outcome and a small minority on three types. The most-commonly measured outcome was change in knowledge, attitudes, and/or practices (KAP), which are poor indicators of impact. The second most-common outcome was presence or level of hazards in food. This outcome is more objective and gives an indication of health impact. However, it is not a direct health outcome as hazards can be high, yet risk to human health low and vice versa. Less than 10% of papers measured a direct health outcome, such as reduction in the incidence of liver cancer. Only one paper had an

Table 1 Typology of food safety interventions identified in a systematic literature review

Along the value chain	Technologies	Training & information	New processes	Organizational arrangements	Regulation	Infrastructure
Farmer	+++	+++	+	+++	+	++++
Processor & transporter	+++	+++	+++	++	++	+++
Retailer	+	++	+	++	++	+++
Consumer	+	+++	+	+	+	+++
Government		+++	++	++	+++	

From Grace et al., 2018. The number of + indicate the qualitative estimate of the level interventions in Africa. This estimate is not based solely on the systematic review, which focused on published papers, but also includes expert opinion.

outcome related to livelihood, and no papers had economic, social, environmental, or gender-related outcomes. This finding indicates that food safety interventions published in journals still reflect a siloed rather than a systems approach.

Around half the studies included in the systematic review claimed success or partial success (significant change in the beneficial outcomes measured), which suggests high (perhaps suspiciously high) levels of intervention success. However, more well-designed interventions than poorly designed interventions (as determined by the author using systematic criteria) were completely or partially unsuccessful. 14% of these failed partially or completely. This finding was somewhat surprising, as our hypothesis was that studies of poorly designed interventions would have a higher level of claimed success.

3.2.3 Five factors critical for scalbility

Despite the apparently promising level of success, detailed reading of the papers revealed factors for food safety interventions that are poorly addressed in the literature. Five factors that are critical for scalble food safety interventions were identified — efficacy, an enabling environment, economic viability, incentives, and equity — which should be incorporated into future studies.

1. Efficacy: Promising interventions might not be effective in practice. Interventions that succeed in small, badly conducted studies are often unsuccessful when properly evaluated. To show efficacy, a robust study design is needed. RCT are the gold-standard for assessing an intervention. For example, early anecdotal evidence suggested that microbial hand towels reduced contamination in households in western Kenya. However, a large RCT found no effect on health outcomes (Slayton et al., 2016). RCT are rarely used in evaluating interventions to prevent FBD: they are expensive and methodologically complex. Efficacy must also be interpreted in light of the outcome measured. An intervention that is effective in improving KAP might have no effect on lowering the prevalence of hazards, and an intervention that reduces hazards might have no effect on health. Measuring efficacy is essential because food safety interventions have the potential to make matters worse. For example, a study in abattoirs in Nigeria found that carcases were more contaminated after washing, because water was not clean (Bello et al., 2011). Similarly, pot-chlorinators did not achieve WHO-recommended chlorine levels in well water during a cholera outbreak and conveyed a false sense of security to local residents, some of whom stopped chlorinating their household water (Cavallaro et al., 2011).
2. An enabling environment: Such an environment is essential if interventions are to be sustained. Unfortunately, most studies only assess the outcome of interventions in the short-term; therefore, how long the change persists in the food system is unknown. An enabling environment has two components — at the micro-level it entails buy-in from leadership or local authorities and a culture shift among users (sometimes called a 'food safety culture') and at the macro-level it involves the development and enforcement of policies, standards, and regulations. The benefits of an enabling environment can be seen in comparing bean exporters in Kenya and pepper exporters in Uganda. Kenyan exporters had higher compliance with standards and regulations than Ugandan exporters, which was attributed to a better legal framework, more power with suppliers, quality assurance departments, and intensive support from importers (Nanyunja et al., 2016). By contrast, street vendors often experience a disabling environment; they can be subjected to harassment from authorities and forced to pay bribes (Rahman, 2019; Adama, 2021).
3. Economic viability: Interventions that are very costly have little chance of scaling to mass markets in LMIC. However, few evaluations of interventions to prevent FBD address the issue of cost. One solution is to reduce the cost of the intervention, while maintaining effectiveness. For example, a 1-day workshop for street food vendors based on the 'Five Keys' in Ghana was effective in improving KAP. On the other hand, the Nigeria Field Epidemiology and Laboratory Training Program was established in October 2008 and had provided in-depth, high-level training to 207 residents as of 2014. However, financial sustainability is in doubt (Nguku et al., 2014). Another option is to identify stakeholders willing to subsidize interventions. In Ghana, a training sponsorship was solicited from companies in the food industry, such as Unilever and Nestle, which was also an opportunity for these companies to launch their products (Tortoe et al., 2012).

Some food safety interventions are almost cost-free. Many SSA countries require a medical certificate for food handlers, but without health justification and the practice is not recommended (National Disease Surveillance Center, 2002). According to the South African health authorities, there is no scientific indication for the routine medical examination of food handlers in the prevention of FBD, whether on recruitment or otherwise. However, the unnecessary requirement for a health certificate has become both a burden and excuse for illicit payments in many countries. In Kenya, a health certificate must be purchased, but no medical examination is carried out. This requirement merely

adds to the cost of business for vendors who are already living in poverty. In Ghana, vendors were coerced by the metropolitan assembly to visit a contracted medical service provider in a mass health screening exercise. Queues were long, the process was slow, fees were arbitrary, and some examinations were not covered by receipts (Apaassongo et al., 2016).

4. Incentives: Although training can result in short-term benefits, long-term change requires incentives, particularly if there is a considerable gap between knowledge and health or hygienic behaviors (Fishbein & Ajzen, 2009). Knowledge alone does not lead to use of safer practices (Wilcock et al., 2004). However, very few food safety interventions include incentives. This omission is illustrated by a study from Libya, in which private eating establishments were found to have better hygiene than government-controlled establishments. "Staff in these institutions is aware of the high penalty of losing their jobs by being instantly dismissed if they do not follow such practices, whereas with government most workers are fairly assured that they have their jobs secured regardless of whatever situation" (Abogrean & Abugrain, 2013).

All the WTP studies included in the systematic review (Grace et al., 2018) showed that consumers were willing to pay for safe food products. However, a detailed study by the International Food Policy Research Institute revealed that setting up market-based incentives in LMIC is complicated. In several cases, producers were not prepared to invest in food safety processes even for a premium and consumers were not willing to pay a premium for food safety (Hoffmann et al., 2019).

Incentives go beyond punishment and financial reward. Societal or cultural norms can also provide incentives or disincentives. For example, Griffith et al. considered that the type of food-safety culture existing within a business could explain why food handlers choose not to implement known food safety practices and why training, although important, might not change practices (Griffith et al., 2010).

5. Equity: Most food safety interventions target changes in KAP or the level of hazard. However, the possibility exists that food safety interventions will have unintended and unwanted consequences. Only one of the studies included in the systematic review assessed the effect of a food safety intervention on livelihoods, and one other explicitly considered the effects on food accessibility (Mwangi, 2010). In this study, street-food and fast-food outlets in Nairobi were compared. Although street-food outlets had poorer hygiene than fast-food venues, the food sold was cheaper and the patrons poorer (Mwangi, 2010). This finding implies that actions to penalize street-food vendors could reduce food access. Many food safety interventions focus on upgrading value chains, which is well known to result in the exclusion of women and people living in poverty (Kristjanson et al., 2010).

4 Conclusions

Food safety interventions have been largely ignored, due to lack of evidence on the multiple burdens of FBD. This is rapidly changing as evidence emerges on the high health and economic impacts of FBD in LMICs. Moreover, FBD has multiple, complex interactions with other development objectives such as gender equity, stunting, and emerging infectious diseases. A study from Africa shows investments in food safety have been small in proportion to these burdens and few were directed to the mass domestic markets (mostly informal) where the great majority of these burdens fall. Moreover, those that were directed to domestic markets were unlikely to be scalable.

The track record for food safety interventions published in the literature and generally conducted by researchers is more encouraging. Most evaluated interventions comprising technologies, training and information, new processes, and WTP for food safety had generally good results. However, major investments in infrastructure, national control systems, and organizational innovation have not been well evaluated. Moreover, the interventions evaluated did not account for environmental or economic feasibility, incentives, or equity. There was no evidence that any of the interventions had been scaled although some had potential for scalbility. However, analysis of the strengths and weaknesses of the published studies suggested five factors essential for scalbility: efficacy, economic viability, an enabling environment, incentives, and equity.

Ultimately, to achieve food safety at scale, foundational investments will be needed in people, infrastructure, and institutions. Addressing these issues will require sustained attention from technical agencies and government ministries as well as donors. Broader interventions will be required to improve access to quality public-health services, clean water, sanitation, and improved agricultural productivity. In short, the commitment needs to be commensurate to the scale of the problem. As was the case in other parts of the world, improvements in food safety in LMIC are ultimately likely to be driven by consumers with improved awareness exercising their demands for food safety and eliciting

responses from public sector and food suppliers. Recognizing that prospect is a good place to start.

Action Track 1 of the United Nations Food Systems Summit 2021 aims to ensure access to safe and nutritious food for all (United Nations, 2021). One of the three themes of this summit was food safety, which is both an indicator of the increasing emphasis given to food safety and an opportunity for the world to unite around 'game changers' that offer radically different and better ways of ensuring safe food for all.

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