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Foodborne zoonoses control in low- and middle-income countries: Identifying aspects of interventions relevant to traditional markets which act as hurdles when mitigating disease transmission

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Globally, foodborne zoonoses are responsible for approximately one third of all foodborne disease burden and this picture is likely to worsen if consumption of animal source foods continues to rise with insufficient attention to risk mitigation. Traditional markets represent highly important nodes that can be targeted for risk mitigation; in this series of case studies, we discuss food safety interventions relevant to this nexus. We illustrate that to improve food safety within traditional markets it is essential to consider some of the motivations and incentives of the stakeholders involved and the cultural, social, and economic context in which interventions are undertaken, highlighting barriers, enablers future interventions should aim to avoid, embrace. We also conclude that a holistic approach to foodborne zoonoses control will require the institutionalization of One Health across food systems of which traditional markets are part.

KEYWORDS

foodborne zoonoses, traditional markets, LMICs, food safety, interventions, One Health

1. Introduction

Consumption of animal source food (ASF) is rapidly increasing especially in low- and middle-income countries (LMIC), driven by population growth, urbanization, and increased income (De Balogh et al., 2013; Abebe et al., 2020). ASFs supply calories, along with multiple bioavailable nutrients, lacking in plant-based diets, such as Vitamin B12 (Watanabe, 2007), providing the nutrients required for healthy human development and growth (Adesogan et al., 2020). ASFs contain high quantities of protein and more

bioavailable nutrients including vitamin A, folic acid, vitamin D3, iron, and zinc, than many plant-based foods. Simultaneous consumption of animal and plant-sourced foods can synergistically enhance overall nutritional bioavailability and improve health outcomes (Adesogan et al., 2020). Livestock value chains also have numerous other roles in livelihoods, culture, and human wellbeing (Randolph et al., 2007; Alders et al., 2021). ASFs, however, are also closely associated with foodborne disease, harboring numerous bacterial, viral, and parasitic foodborne hazards (Li et al., 2019).

The One Health concept acknowledges the interconnectedness of the health of humans, animals, and the environment, and advocates for multi-disciplinary collaboration and the engagement of multiple sectors (multi-sectoral) for the enhancement of health across these three domains. Food safety, especially the control of foodborne zoonoses (FBZ), sits at the nexus of the human and veterinary spheres and as such is an exemplar of a “One Health” challenge, in which multi-sectoral and multi-disciplinary collaboration is imperative for their control. The environment here may relate both to the health of the physical environment in which food systems operate as well as a healthy enabling institutional and governance environment in which the food system actors operate. One Health interventions implemented to date have focused more on surveillance and disease control in the animal host, with little consideration of other One Health issues. We believe, however, that a One Health lens can be applied to interventions at multiple nodes along the food-system, and acknowledging the need for multi-disciplinary collaboration is critical in ensuring this is achieved.

The majority of ASF products in LMICs are sold through traditional markets, where many vendors congregate with official recognition and governance structure, or through informal street vendors (Smit, 2016; Grwambi, 2020), with the proportion of food sold through modern formal retail (supermarkets and convenience chain stores) remaining low, even in large cities (Kang'ethe et al., 2020). This is especially the case for perishable foods such as ASF. Traditional markets are important hubs of trade and commerce; they supply the growing ASF demand to urban populations and are a source of employment for small-scale livestock owners and all those who ensure the products are delivered and sold through these markets (Roesel and Grace, 2014), including women and youth. Infrastructure in many of these markets is poor and this makes food safety issues within them a matter of concern (Grwambi, 2020). Traditional markets are often located close to where low-income earners live, especially those in urban areas, and are characterized by no or irregular provision of electricity, lack of piped water, poor drainage and sanitation, poorly built structures and floors, all of which increase the risk for food contamination and foodborne diseases (Resnick, 2017). Some of these markets operate outside in open air, either partially or entirely (King et al., 2000; Muyanja et al., 2011).

It should be kept in mind that traditional markets play a vital role in fragile food systems in LMIC (Béné, 2020), as they are important for the food security and livelihoods of many of the most vulnerable populations, and as such merit protection and support through integrated safe food approaches. Despite high foodborne disease burdens, caution against demonizing traditional markets just because they belong to an unregulated sector must be observed (Chukwuocha et al., 2009). Firstly, informal market food is often safe for consumption and foodborne hazards, which are very common in traditional markets, do not necessarily always translate into foodborne risks at the point of consumption (Roesel and Grace, 2014). Secondly, supermarket food, commonly believed to be safer than informal market food, is sometimes no better (and sometimes worse) at meeting standards than food sold in the informal sector (Grace, 2015).

In addition to the risks related to the traditional markets in which ASF are sold, the inherent nature of ASF has the potential to increase the risk to consumers from specific foodborne zoonotic hazards. Vertebrate animal species are natural reservoirs for many zoonotic pathogens, which can be transmitted through food (Abebe et al., 2020), as well as non-zoonotic pathogens resulting from contamination. The human health burden of FBZ increases as consumption of food of animal origin increases (Carrique-Mas and Bryant, 2013). The burden from just 13 zoonoses in ASF is estimated to be 168 (137–219) DALYs lost per 100,000 of the population, or ~35% of all foodborne disease burden (Li et al., 2019) with three hazards found to be responsible for 70% of this burden: non-typhoidal *Salmonella* spp., *Taenia solium*, and *Campylobacter* spp., and Africa is the continent with the highest burden of FBZ (Li et al., 2019). As the analysis took into account only 13 FBZ and did not consider several other pathogens commonly found in or contaminating ASF such as *Listeria*, *Clostridium*, *Yersinia* spp., *Coxiella burnetti*, or *Echinococcus*, it under-estimates the actual burden of this important subset of food safety hazards. Country-level studies have hinted at under-estimation, as 78 and 71% of foodborne disease burden in the UK and India is attributed to ASF (Grace, 2015). It can be argued, therefore, that consumers of ASF in LMIC face a double-edged sword scenario: while they stand to gain nutritional benefits from high-quality animal-sourced protein, they also run the risk of becoming infected with foodborne zoonoses, with negative health consequences. Table 1 outlines the health burden associated with some of the main ASF zoonotic pathogens in LMIC. Consumers of non-ASF may also be at risk of the same diseases, for example, vegetables can become cross-contaminated by zoonotic pathogens when they get irrigated with contaminated water or through poor vendor storage and hygiene practices (Desiree, 2019; Schwan et al., 2021).

In higher-income countries (HIC), an effective method used to mitigate risks associated with FBZ is a “farm to fork” system of surveillance, allowing full traceability and transparency along

TABLE 1 Key foodborne zoonoses of particular relevance to LMICs in Africa and Asia.

Foodborne zoonotic pathogen	Global burden (DALYs/100,000) with 95% uncertainty interval attributable to ASF*	Animal source food and approximate % of burden attributable to ASF*	Details on transmission
<i>Campylobacter</i> spp.	27 (19–40)	Poultry, Beef, Pork, Small ruminant meat, Dairy (90%)	Recognized as the leading cause of bacterial foodborne diarrheal disease. Infections with <i>Campylobacter</i> spp. are commensals of many vertebrate species, but infections are most commonly associated with poultry meat. Other sources of infection is consumption of water contaminated with animal feces (Hall et al., 2004)
Non-typhoidal salmonella enterica	49 (30–76)	All ASFs (80%)	Fecal pathogens of animals which can cross-contaminate ASF at many points of the value chain. Cause a generally self-limiting gastroenteritis with complications in the young, old, and immunocompromised (Roesel and Grace, 2014)
<i>Brucella</i> spp.	2 (0.6041)	Dairy, Beef, Pork, Small ruminant meat, (95%)	Predominately transmitted to humans through unpasteurised milk or through direct contact with infected animals. Human infections lead to an undulant fever, joint pain, and weakness (Li et al., 2019)
<i>Toxoplasma gondii</i>	9 (6–14)	Beef, Pork, Small ruminant meat, Poultry, Dairy, eggs (70–80%)	One of the most ubiquitous zoonoses. Humans become infected through consumption of cysts from undercooked meat or through contact with food and water contaminated by the sporulated oocysts from cats, the definitive host. Toxoplasmosis is generally sub-clinical, but adverse outcomes can arise in the fetuses of pregnant women and in the old and immune-compromised (Roesel and Grace, 2014)
<i>Taenia solium</i>	41 (31–52)	Pork (100%)	The parasitic zoonoses <i>T. solium</i> has pigs as its intermediate host. Consumption of undercooked pork meat leads to infection with the definitive stage of the tapeworm (Taeniosis) yet subsequent fecal-oral transmission can result in an aberrant intermediate stage infection in humans, resulting in neurocysticercosis, a leading cause of epilepsy in endemic areas (Khan et al., 2017)
<i>Mycobacterium bovis</i>	9 (7–33)	Dairy (100%)	<i>M. bovis</i> is transmitted to humans from cattle predominately via unpasteurised milk. Symptoms in humans are indistinguishable from those of <i>M. tuberculosis</i> . The highest burden of zoonotic TB is assumed to be borne by Africa given the prevalence in cattle and lack of pasteurization for the majority of milk consumed (Barlow et al., 2015)
Fishborne trematodes	13 (10–15)	Finfish (100%)	Metacercariae are harbored in the muscles of fish which are then consumed by humans and can cause chronic liver disease, pancreatitis and cholangitis in some people. These trematodes are common across South East Asia (Carrique-Mas and Bryant, 2013)
<i>Paragonimus</i> spp.	15 (11–21)	Shellfish (100%)	Humans acquire this zoonotic parasite through the consumption of raw/undercooked shellfish. The immature flukes migrate to the lungs where they are responsible for pulmonary signs linked to inflammation, through aberrant migrations including to the CNS can occur. The parasite is most commonly distributed across Asia where cultural practices relating to the consumption of raw shellfish propagate the life-cycle (Grace, 2015)

*Li et al. (2019).

the supply chain (Jaffee et al., 2018). Unfortunately, such systems, which would identify how and where ASFs become contaminated, have thus far proven too costly in LMIC (Thomas et al., 2020) and may not be feasible in what is largely an informal sector. At present, hygiene-improving interventions addressing infrastructure, resources, and knowledge of the multiple actors along the ASF supply chain, necessary for successful food safety (Aiyar and Pingali, 2020), are scarce. Given the significant role that traditional markets have in food security and food safety (Roesel and Grace, 2014), and the growing consumption of

ASF (Grace et al., 2012b), investigating how FBZ transmission risk changes and evolves before, at, and after the informal market nexus, is increasingly becoming important, from a public health perspective.

In this review of selected case studies the traditional market is presented as the interface where a vendor and a producer of an ASF producer meet the consumer (a key moment in understanding transmission pathways for ASF-borne diseases). Approaches at local, regional, and governmental and multi-sectoral levels, sourced from literature previously identified

through two bodies of work (Grace et al., 2018; Global Alliance for Improved Nutrition, 2021) and supplemented by a non-systematic literature search focusing on the infrastructure of informal markets, their vendors, consumers and their governance are reviewed. The aim is to gain a better understanding of how interventions to reduce FBZ and other foodborne pathogens, have been applied specifically at the traditional market level, and to highlight barriers or enablers to successful implementation.

2. Interventions focused on infrastructure

The working environment of ASF vendors in traditional markets is often responsible for major breaches in food safety, vendors operate within challenging occupational settings, often without electricity, clean potable water, waste disposal, and sanitation facilities (Grwambi, 2020). The lack of refrigeration provides opportunities for cross-contamination for highly perishable ASF (Muyanja et al., 2011), especially when leftover raw materials are retained for the next day's use without appropriate storage facilities (Alimi, 2016). Vendors use open-air, crude structures such as push carts, wooden display tables, or chop bars, to display goods, thus facilitating contamination and transmission of foodborne pathogens (Alimi, 2016). Poor market infrastructure, specifically inadequate sanitation and water supply is linked to increased foodborne disease burden. In a study in Uganda, lack of public sanitary facilities within an informal market was linked to poor personal hygiene among meat vendors (Muyanja et al., 2011), predisposing both the vendors and their food products, to foodborne pathogens. Lack of running water forced milk vendors in a Tanzanian market to wash their utensils in basins designed for hand washing, thus increasing the risk of food contamination (Kilango, 2011). In Vietnam, meat workers reportedly used unclean water to wash utensils and this increased opportunities for cross-contamination of meat products (Thi Nguyen et al., 2019).

Given this context, it is assumed that infrastructural development is a highly influential mechanism for improving food safety, yet despite substantial investment in infrastructural development, these are often the interventions least often evaluated. Lack of evaluation is partly because infrastructure investments are regarded as a development rather than a research activity and hence do not lead to scientific evaluations published in journals. Examples of such investments are: building/upgrading market infrastructure, building abattoirs, building dairy chilling plants, sewage, and waste disposal, building/upgrading laboratories, electrification, improvement of roads, and other transport. It is often assumed that such interventions can only produce benefits, an assumption that makes research evaluations less common. However, as the following case studies show, investments in modern

infrastructure may result in under-utilized equipment lying dormant, or worse still, have unintended negative consequences on food safety.

In Uganda, more than 90% of milk is sold in the informal sector without treatment. A development project installed 3 dairies in Gulu district, two of which had cooling tanks, to improve milk quality. A study of the milk value chain observed that of these cooling tanks only one was used, the other was never used as the dairy staff considered it too expensive and slow, consumers generally wanted to purchase milk immediately upon delivery without waiting for the cooling process, therefore such equipment demonstrated a poor return on capital investment (Rock et al., 2016).

Abattoirs are a major point of contamination as animals are often slaughtered and skinned on the floor which is covered in feces allowing cross contamination. A study in one of the largest abattoirs in Nigeria, built in 1986 with poor maintenance history, found that 98% of meat failed to meet standards for total aerobic bacterial counts (indicators of potential presence of pathogenic organisms) (Thi Nguyen et al., 2019). A participatory, peer-to-peer, low-cost intervention that took the form of an interactive training workshop for Butchers Associations' representatives was found to reduce unsafe meat by 15% (Grace et al., 2012a). Despite this successful intervention, in 2014 the government initiated a public-private partnership to build a new modern abattoir, citing unhygienic practices. However, this abattoir was far from customers and butchers found the fees charged unacceptable. They returned to the previous abattoir which did not benefit from meat inspection. Authorities tried to remove them by force resulting in riots, nine people were shot dead in the street and a police station was burnt to the ground. Meat in the old abattoir was less safe than before the relatively successful intervention (Grace et al., 2019).

Similarly, street vendors in Zambia who were moved into new and hygienic premises were soon found to have returned to their former market location; the improved market, despite having better environmental conditions, meant less accessibility to customers and higher transaction costs for vendors (Ndhlovu, 2011). In Mozambique, as in most of Africa, women usually own, are responsible for, and slaughter chickens. However, only men are employed in the modern slaughterhouses highlighting how when food systems modernize, women are displaced from their traditional roles (Roesel and Grace, 2014), an important consideration when developing inclusive food safety interventions.

Infrastructural development is by its nature expensive and difficult to test under formal experimental conditions. The examples above, however, illustrate the need to consider unexpected and unintended consequences of infrastructural investments aiming to improve food safety. We would highly recommend investors, be they public or private sector, to first

ensure that the needs and concerns of the end-users are fully considered and invest time and effort in managing the change and adoption process by ensuring stakeholders are prepared, supported, and equipped and by reducing the friction involved in adopting new ways of working (Thaler and Sunstein, 2008).

3. Interventions targeting vendors of animal source foods in traditional markets

Vendors are important players in the etiology of FBZ outbreaks (Grwambi, 2020). How vendors prepare and handle food can lead to cross-contamination and promote the transmission of foodborne zoonosis (Alimi, 2016). One study in an informal market in Vietnam, showed how *Salmonella enterica*, a bacterium from cattle and poultry, had contaminated multiple food products across the market due to the poor sanitation practices among the market vendors, unaware of the impact of their actions (Schwan et al., 2021). Understanding and improving vendor awareness regarding FBZ has been one area of focus for interventions.

Studies have demonstrated a widespread lack of knowledge in LMIC settings, among vendors of ASF, leading to the perpetuation of unsafe practices (Chukwuocha et al., 2009; Insfran-Rivarola et al., 2015; Lindahl et al., 2015). Although echinococcosis—a FBZ caused by *Echinococcus granulosus*—is endemic in some areas of Morocco, butchers and meat vendors, unaware that dogs play a role in the transmission, continue to dispose of offal where these animals have access to it (Thys et al., 2019). They strongly believe that their actions do not, in any way, contribute to the disease problem in the community. Similarly, in Pakistan, butchers are identified as being at high risk for echinococcosis, yet few knew the transmission pathway for the disease, an important predisposing factor for the infection (Khan et al., 2017). In many African countries, it is not uncommon to see meat retailers turning carcasses destined for human consumption into sitting chairs or resting platforms with little or no concern over the potential effects of their actions (contamination of the meat or themselves indirectly contracting infections from the carcasses) (Okoli et al., 2005). There is evidence that interventions that have addressed low knowledge levels have reduced foodborne disease transmission risks, training of meat vendors in Nigeria and milk vendors in India saw a significant reduction in coliform bacterium, indicators of fecal contamination (and in turn of the potential presence of pathogenic organisms), in meat and milk post-intervention (Grace et al., 2012a; Lindahl et al., 2018a) and a hygiene educational intervention showed increased hand washing among food handlers in Malaysia, in a 6 weeks post-intervention follow-up study (Nh et al., 2018).

The premise that the provision of information will lead directly to a change in attitude and, consequently, a change in

behavior or practice can be successful in the short term, however, its long-term sustainability is questionable (Insfran-Rivarola et al., 2015). In Nigeria, a follow-up study 9 years after the training intervention saw coliform bacterial load (an indicator of potential food safety risk) in meat creep back up to previously high levels again (Grace et al., 2019). In India, milk sold by producers and vendors 3 years post the training intervention was highly contaminated with *E. coli* (Lindahl et al., 2018a). It appears, therefore, that knowledge-focused interventions can create temporary improvements in food safety, but time-limited educational efforts may only partly improve long-term food safety practices of food vendors (Singh et al., 2016). This suggests the need for both repeated educational efforts over the long-term and that other aspects of vendor beliefs and behaviors within the market context must be considered when designing interventions.

Several studies illustrate how interventions to mitigate FBZ among ASF vendors must consider local beliefs and values regarding zoonotic disease transmission pathways and that knowledge alone does not translate in to practices (Zanin et al., 2017). One Kenyan study highlights how cultural and religious practices influence informal market vendors' perceptions to food safety risks, disease transmission, and ultimately their willingness to adopt biosecurity measures: some vendors, when asked, believed that disease outbreaks were a divine punishment (Nyokabi et al., 2018), a perception that can greatly impact adoption of health interventions. A study among pastoralists in Mali found they believed milk was naturally a pure and wholesome substance and so could not, by definition, contain harmful substances. This belief, alongside a fear that soap would taint the milk, led to a reluctance to wash milk containers with anything but water (Roesel and Grace, 2014). Naturally, any food safety intervention in these contexts would first have to develop a strategy to overcome such beliefs.

As well as addressing vendors' current knowledge of food safety and their underlying beliefs and values, we should also consider the context within which they work and their ability to comply adequately with food safety protocols. In Kenya, when milk vendors were asked why they failed to wear the mandatory personal protective equipment (PPE), which the Kenya government requires them to wear, they said the PPE was cumbersome, reduced their productivity, and did not generate any tangible benefits (Nyokabi et al., 2018), illustrating the need for interventions to be feasible for the actors, within the context in which they work.

Limitations to sustained adoption of hygiene practices in infrastructure-constrained settings reflect a still-developing understanding of the factors that influence these practices (Dreibelbis et al., 2013). We know that interventions used to reduce FBZ transmission risks are likely to fail if engagement with local, key actors is lacking (Grace, 2015). It is therefore imperative that we address knowledge gaps, local values,

and beliefs shared by ASF vendors in specific communities, whilst also addressing vendors' capacity to undertake a desired behavior without undue burden, if interventions are to succeed.

4. Interventions targeting consumers of animal source foods in traditional markets

Consumers across traditional markets in LMIC comprise heterogeneous groups with varying demographic characteristics (Ajayi and Salaudeen, 2014; Abebe et al., 2020). Despite this heterogeneity, most consumers of products from traditional markets state that they care about food safety (Grace, 2015), although specific knowledge on hazards and protective measures are often lacking as demonstrated through a 2017 review on consumer demand for food safety in LMIC (Ortega and Tschirley, 2017). A dichotomy between consumer knowledge of a risk and their capacity to mitigate that risk has been demonstrated, for example, pork consumers in South Africa, were aware that *T. solium* cysticercosis could be harmful but lacked the knowledge on how to identify *T. solium* cysts in pork, they also lacked sufficient knowledge regarding butchery certification processes including disease control, slaughter, and food preparation (Sithole et al., 2020). In Nigeria, consumers at an informal market claimed to be knowledgeable and aware of hazards and food pathogens which caused health risks, yet still engaged in risky eating habits; they did not wash their hands prior to eating consumed products made from raw milk, drank untreated water from boreholes and consumed *suya*, a beef product prepared under unhygienic conditions and linked to many foodborne disease outbreaks in Nigeria (Ajayi and Salaudeen, 2014) and a scoping review of studies conducted in Ethiopia also highlighted the lack of translation from consumer knowledge and attitudes to food-safety and their food-safety practices (Parikh et al., 2022). Attitudes and behaviors, therefore, are highly influenced by customs and beliefs, and knowledge of disease risks does not always curb local customs or eating traditions. From the examples given, it is possible to foresee how consumers may wrongly provide the impression that they know and observe basic food safety practices, masking the need for interventions. Therefore, similar to the case of vendors, interventions aimed at consumers of products from traditional markets will require a prior consideration of local beliefs and awareness about FBZ, but how these can be translated to practices to better mitigate FBZ remains a challenge (Ajayi and Salaudeen, 2014; Umar et al., 2019).

Despite sub-optimal practices, the increasing awareness of consumers of food-safety issues does present a valuable entry-point for interventions to reduce FBZ, through heightened consumer demand for safe food and through improving the food-safety practices of consumers (Riaz et al., 2016). Shifts in consumer purchasing behavior because of food safety concerns

have been observed. As much as 40% of consumers reported switching to alternative meats in the wake of animal disease epidemics (Roesel and Grace, 2014), for example moving to poultry meat away from pork after a swine flu outbreak in Asia (Shao et al., 2011). Willingness to Pay (WTP) studies seek to determine the value to consumers of a particular attribute of a commodity demonstrated through their revealed or stated willingness to pay for a particular product. They have been used as a tool to gain insights into the value consumers place on safe food (Alimi and Workneh, 2016). The WTP literature in LMIC, particularly in sub-Saharan Africa is still scarce (Ortega and Tschirley, 2017) yet a growing body of work demonstrates an increasing consumer demand for safer food products, particularly in urban settings (Jabbar et al., 2010; Ifft et al., 2012; Tran et al., 2022).

Several studies demonstrating consumer demand for safe food indicate the potential benefits of a certification scheme as a signal of safety to the consumer (Owusu-Sekyere et al., 2014; Tran et al., 2022). Such an example was seen in India, where growing concern among consumers about the purity and quality of milk marketed by informal milk vendors and the possible health risks it posed, paved the way for the introduction of a successful milk certification programme (Lindahl et al., 2018b). Currently, official certification in traditional markets is scarce, and often not trusted by consumers (Roesel and Grace, 2014): the generation of trust, and an awareness of consumers' food control risk perception, are two key attributes that must be considered in successful implementation (Akinwehinmi et al., 2021; Tran et al., 2022). There is also a need for certification schemes to be based on appropriate standards, however, in many LMICs such standards for food quality and safety are either non-existent or exist defined by public health norms in developed countries, with no real relevance for traditional markets in resource-poor settings (Jabbar et al., 2010).

The ability of consumers to pay the premium which they state to place on food safety is another key barrier to the successful leverage of consumer demand to improve food safety. What a consumer may want but what they actually can access may differ. Therefore, despite their stated willingness to pay more for safer products, consumers can find themselves in a vulnerable situation where they rely heavily on the hygiene practices of vendors (Akinbode et al., 2011) and other market forces, prohibiting their access to safe products (Thi Nguyen et al., 2019), and for certain demographics, food safety is not an attribute which influences their purchasing decisions (Asiegbu et al., 2016). There is certainly a research gap on food-safety interventions focussing on leveraging consumer demand, through certification schemes or other mechanisms. These interventions must, however, be designed in line with contextually relevant standards, with concomitant trust-building so that the certification is accepted by consumers and in line with consumers' ability, as well as willingness, to pay.

Importantly such schemes will only flourish if consumers are equipped with relevant and accurate knowledge about food-safety risks.

Although low food-safety knowledge and practices have been demonstrated in LMIC consumers, targeted food-safety education interventions directed at these consumers are few. A 2016 systematic literature review identified 246 studies on consumer-focused interventions, of which just 22 were from Asia, six from Central/South America, and the Caribbean and no studies identified from the African continent (Sivaramalingam et al., 2015).

However, it is interesting to note that inadequate knowledge of food safety is not only restricted to consumers of traditional markets in LMIC. For example, a survey of 1,008 German consumers demonstrated that only 11.5% knew how to protect themselves from infection with *Campylobacter* spp., an organism that is the most reported causative agent of foodborne bacterial infection in Germany (Henke et al., 2020).

In a similar way to educational interventions directed toward vendors as discussed above, short-term efficacy of consumer-focused interventions to improve food-safety knowledge has been demonstrated, predominately through un-controlled, before-after trials (Young et al., 2015), with changes in the incidence of foodborne illness and microbial contamination being infrequently monitored. Randomized controlled trials (RCTs) of educational interventions for food safety are still relatively scarce and short follow-up periods reduce our ability to judge long-term efficacy. Even within HIC, RCTs are relatively rare with only 79 studies identified in a 2015 systematic review and meta-analysis, with heterogeneous outcomes leading to a weak evidence base (Young et al., 2015). A 6-week follow up of an RCT for mothers of young children in Nepal which used a behavioral-centered approach to its' intervention demonstrated an increase in target behaviors (Gautam et al., 2017). Longer-term studies of educational interventions are rare, though a computer-based educational tool for *T. solium* "The Vicious Worm" has been evaluated after a period of 1-year and students were found to have retained higher than baseline knowledge through this period (Hobbs et al., 2019) and a 2-year follow up of community-based training for food-safety in Vietnam also demonstrated an improvement in the majority of target behaviors through the period (Takanashi et al., 2013).

It is important that educational interventions focussed on consumers consider the relevant contextual factors including beliefs and values and the capacity of consumers to enact change, as we discussed in relation to vendors. The gap between knowledge and practice as identified in several studies (Parikh et al., 2022), should be explicitly considered and educational interventions which aim to increase knowledge without creating an enabling environment for change may find success elusive. If consumers are to be agents of change, both through their own practices and through their demand for safe products, there is

a need to establish their trust in the food systems that serve them. This brings into play the question of governance and if interventions to improve governance of these markets can improve consumers' access to safer food.

5. Interventions focused on governance

5.1. Local governance

ASFs flow through informal market chains with much diversity among the many actors involved and poor official regulation and governance throughout the market chain (Roesel and Grace, 2014). While opportunities to improve food safety in traditional markets through restructuring of governance exist, their feasibility and effectiveness are not well-understood (Grace, 2015). For vendors in traditional markets, attempts to regulate through a "command and control" method does not appear to improve food safety (Johnson et al., 2015). In Ghana, one-third of meat vendors obtained meat from unlicensed sources ignoring the government certification requirements and in spite of being harassed by authorities (King et al., 2000). In high-income countries, risk-based approaches are becoming popular and are now a recognized standard for food-safety governance in many areas, where sufficient data is available to inform the probable risks to exposed populations (Grace et al., 2012a; Barlow et al., 2015). In LMIC settings, where traditional markets dominate, risk analysis is not widely used mainly because of human and financial resource constraints and the paucity of reliable data (Fahrion et al., 2014). To make risk-based approaches more commonplace in traditional markets, several challenges firstly need to be addressed; lack of pre-existing information on diverse structures and practices, difficulties of working with informal sector participants due to poor relations with local government officials, and lack of local laboratory capacity (Grace et al., 2008).

Food safety interventions in traditional markets which try to enforce specific practices rather than principles can impact negatively on food safety (Johnson et al., 2015). For example, washing hands could pose a health risk if the water is not clean and if soap is not used (Roesel and Grace, 2014). Therefore, attempts to set mandatory safety standards at traditional markets alone can be unsuccessful in mitigating foodborne zoonoses, and the banning or criminalizing of vendors of ASF, on the basis of poor food safety, can have far-reaching negative implications for health and nutrition overall (Johnson et al., 2015). A "light touch" governance approach has shown to yield better results, an example being the voluntary training schemes for milk suppliers and traders in Kenya which saw a marked improvement in milk safety (Blackmore et al., 2015). When hard-line approaches are taken, with violent crackdowns on informal market vendors, there may not only be serious consequences for food security

(Resnick, 2017), but also loss of life (Grace et al., 2019). A draconian food safety policy can make things worse (Grace, 2015). Interventions to regulate traditional markets will require public policies that are inclusive and consider everybody along the food chain if the health of vendors and consumers is to be protected (Alimi and Workneh, 2016) and in a similar way to the implementation of infrastructural investments, legislative change should consider society at large and may require careful monitoring and evaluation to identify and mitigate unintended consequences.

Across many of Africa's urban food markets, a vibrant set of market vendor associations have emerged in recent years (Resnick, 2017). Understanding the social structures between and among these vendor groups or associations can identify opportunities for interventions to mitigate FBZ. Informal food safety standards "rules in use" can differ among groups and subgroups of traders, as seen among butchers' associations in Nigeria, with better hygiene standards among female butchers compared to their male counterparts (Grace et al., 2012a). Such subgroups within the marketplace could act as champions of good food safety standards, future research should endeavor to understand the social dynamics within the marketplace and how this could leverage improved food safety standards.

5.2. National governance

Decision-makers at the policy level need to be convinced of the benefits of improving food safety in traditional markets (Fahrion et al., 2014), this will require more empirical evidence on the cost-effectiveness of food safety interventions (Hall et al., 2004). The use of standardized metrics and formal assessment of the health and economic burden of foodborne zoonoses can advocate for their relative importance and improve resource allocation (Grace, 2015). In LMIC, however, accessing data for these parameters is challenging (Thomas et al., 2020). Data forming a business case for interventions that improve food safety at the informal market level should be made available for policy decision-makers. These may take the form of cost-effectiveness data (the cost per unit of "health," often a Disability Adjusted Life Year or Quality Adjusted Life Year) or cost-benefit analysis (Thomas et al., 2020), where the cost of interventions to improve food safety, such as training meat retailers in traditional markets may be far cheaper than the health care costs linked to the diarrhea suffered by those who eat unsafe meat, as seen in a Nigerian study (Grace et al., 2012b). A surveillance system would need to be developed to capture the required data, and monitor these to assess the interventions.

While mitigating foodborne zoonoses and improving food safety should be a long-term goal of improved governance of traditional markets, a consequence of improving governance is that as standards ratchet upward, there is a risk that poor producers and value chain actors will be displaced from rapidly

growing domestic markets (Resnick, 2017). This has already occurred in export markets where smaller farmers are forced to drop out, as they lack the human and financial capital needed to participate in highly demanding markets (Grace, 2015). Costly farm-to-table tracking systems effective in HIC, may not be an option within traditional markets in LMIC settings. Instead, locally orchestrated, vertically integrated systems may have merit in reducing food safety risks and in providing small-scale farmers with increased access to markets, locally, and internationally (Hall et al., 2004).

Training on developing businesses and facilitating the establishment of contracts between farmers and markets to improve food safety and gain certification may counteract growing pressure on small-scale producers, retailers, and distributors (Grwambi, 2020). Governments need to promote accreditation programs for food safety including offering training to promote traceability, record-keeping, and sharing of information along the value chain (Jaffee et al., 2018). Long-term investments in food safety can have significant positive development impacts. Countries with agri-food sectors that have a limited capacity to manage food safety might find themselves excluded from lucrative export markets or face periodic yet costly rejections of products; improving agri-food exports contributes to sustainable economic development and poverty reduction (Jaffee et al., 2018).

5.3. One health governance

Addressing challenges at the human, animal, environment interface through multi-disciplinary, collaborative approaches, requires institutions and policies which enable an integrated form of governance not traditionally observed in our highly specialized, siloed institutions. In animal, human and environment health at the national and international levels there is a predominance of vertical, programmatic-based approaches to individual challenges without acknowledgment of the complex systems in which they occur. A radical restructuring of global health governance mechanisms has been suggested to optimize the policy-development-setting-evaluation cycle through enhanced multi-sectoral learning, systems thinking, use of multi-criteria analysis frameworks, data sharing frameworks, and appropriate institutional structures for co-ordinated action (Hitziger et al., 2018). For food-safety governance, collaboration and coordination mechanisms are required between the health, veterinary, and environmental sectors including formal data-sharing agreements, mechanisms for inter-sectoral communication which escape the highly hierarchical protocols often existing within government institutions, and for intervention implementation inter-sectoral budgetary sharing agreements may be required. Such factors were recognized by health and veterinary surveillance officers in Western Kenya as being key enablers for integrated surveillance and response

to zoonoses; including foodborne zoonoses (Thomas et al., 2021). Recent declarations, including from the G7 and the G20, regarding the need for a One Health approach specifically targeting pandemic prevention & preparedness, should provide a platform under which global One Health governance will be strengthened (G20 High Level Independent Panel, 2021; G7, 2021). The inter-sectoral policies and institutional structures developed within the realm of pandemic prevention and preparedness will also provide collaborative platforms relevant to all One Health challenges including food safety.

6. Improving food safety intervention design through an understanding of context and use of participatory methods

Contextual consideration is potentially missing in some interventional design, through the increased acknowledgment of the need to develop multi-disciplinary teams with a strong representation from the social sciences, will continue to enhance intervention design, implementation, and evaluation (Ngwili et al., 2021; Di Prima et al., 2022). Qualitative studies drawing on ethnographic methodologies are an important yet underutilized method when it comes to fully understand the behavioral context within which interventions are designed (Bardosh et al., 2014; Crandall et al., 2016; Nordhagen et al., 2022), and such studies can be supplemented by contextual analysis through systematic literature reviews (Nordhagen et al., 2022), structured surveys, or direct observations (Lee et al., 2022). Ethnographic methods can also be applied to understand why interventions fail to yield improvements, such as in the case of understanding community norms and beliefs on latrine use in light of a disappointing uptake of a community led total sanitation program in Zambia aiming to reduce exposure to *T. solium* (Bulaya et al., 2015; Thys et al., 2015).

To successfully draw upon the knowledge of the target community for interventional design, implementation, and evaluation various methodological frameworks are available that explicitly require stakeholder participation. One method which has proved effective in understanding social structures and in the development of a shared sense of ownership of interventions among vendors and improving the safety of ASF is Participatory Learning and Action. Participatory Learning provides a tool to navigate the complex dynamics among vendors and their supply chains in traditional markets (Nyokabi et al., 2018). In Nigeria, interactive training workshops were held for Butchers Associations' representatives, who were then responsible to pass on information and training to their groups, in addition, a gender analysis identifying tasks differentiation by gender was carried out. The findings present gender and group membership as important food safety determinants and both

as promising entry points for interventions to improve food safety (Grace et al., 2012a). The Nigerian Participatory Learning intervention underpins how food safety has both gender equity and empowerment implications which warrant consideration in future interventions.

Another participatory model utilized with success for the control of FBZ has been the PRECEDE-PROCEED model (Porter, 2016), a nine-phase planning model facilitating the design of health promotion interventions in a contextually relevant way. The model requires that communities participate both in the definition of the problem and in the development and implementation of solutions. The PRECEDE-PROCEED model has been used to develop control strategies for *T. solium* in Tanzania, Nepal, and Burkina Faso which include the education of pork consumers who access their pork through traditional markets (Carabin et al., 2018). In Tanzania and Burkina Faso, the approach was implemented within the context of a Randomized Controlled Trial, and the resulting educational intervention was demonstrated to significantly reduce the consumption of infected pork by 20% in Tanzania, whilst the cumulative incidence of active human cysticercosis was demonstrated to be reducing in Burkina Faso. Utilizing participatory frameworks such as these in an attempt to create interventions that acknowledge context and provide empowerment to the stakeholders involved is an important step to achieving tangible and sustainable improvements in food safety.

7. Traditional markets and the emergence of diseases of zoonotic origin

Traditional food markets, in addition to contributing to the potential transmission of FBZ and other pathogens, may also play an important role in the emergence—as well as prevention—of FBZ emergence. The multi-factorial drivers of zoonotic spill-over is a particularly striking example of wicked problems at the human, animal, environment interface for which One Health concepts are needed. The emergence of the SARS-CoV2 virus, suspected to be from an unknown animal source in or around the vicinity of the Wuhan Seafood Market in late 2019 is just the latest, and most dramatic, example of a disease emergence event of zoonotic origin. It follows the relatively recent emergence of Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), Nipah virus, “Swine Flu,” and the Highly Pathogenic Avian Influenza (H5N1) (Thomas et al., 2020). Although not a foodborne zoonosis, COVID-19 demonstrated the challenges in preventing and controlling such pathogen spill-over and spread worldwide and the lack of preparedness to tackle the pandemic. The One Health approach has been highlighted by many as a much-needed paradigm shift

to prevent such occurrences in the future (Amuasi et al., 2020), understanding the causes, as well as consequences, of such events can avoid the “ripple effect” and disruption of local food systems in LMIC, brought about when movement restrictions are implemented (Béné, 2020; Mutua et al., 2021).

Several factors can drive the emergence of new zoonotic pathogens and the re-emergence of endemic zoonoses. Epidemics like Ebola and HIV were driven by poverty and food insecurity, where an increase in demand for wild animals for consumption and related trade led to increased contact between wild animals and humans (Roe et al., 2020). Climate change can increase foodborne disease risks by causing novel vectors and pathogens to move into temperate regions, or by temperature-associated changes in contamination levels (Grace, 2015; Aiyar and Pingali, 2020). Ecosystem degradation due to rapid urbanization, intensification of animal production, modernization of food marketing systems as well as changes in food consumption habits have increased human exposure to animal pathogens (Carrique-Mas and Bryant, 2013). Intensification of bovine and dairy production in Vietnam, for instance, has increased the prevalence of bovine tuberculosis and brucellosis (Carrique-Mas and Bryant, 2013). As urban populations grow, livestock enterprises tend to expand, and whilst intensive units may be found in peri-urban locations and those rural locations relatively close to urban and conurbation areas to facilitate supply to markets, urban livestock keeping is also present in many LMIC cities increasing mixing of people, livestock, other domestic animals and wildlife, and creating a fertile ground for zoonotic disease transmission (Gilbert et al., 2020). Furthermore, the lack of food-safety standards enforcement in traditional markets, where improper management of animals, overcrowding, inadequate hygiene, and improper disposal of feces and carcasses routinely occur, can cause markets to become infectious disease hot spots (Aiyar and Pingali, 2020). Human behavior; consumer purchasing practices and preferences, as well as low perception of disease risk on behalf of vendors, has impacted on avian influenza transmission rates (Kuo et al., 2011), showing how traditional markets are hotspots for zoonoses transmission in general, not just FBZ.

This consumer demand for bush meat and other “exotic” foods has also increased the risk of human exposure to animal pathogens (Roesel and Grace, 2014). In countries like China, Myanmar, Vietnam, and Thailand, the social status, prestige, and gastronomic exclusivity deriving from *ye wei* (literally “wild taste”) is the main driver of the demand for wild meat, particularly among the wealthiest and those aspiring to be, with the consequence of increasing sale of wildlife meats in markets (Volpato et al., 2020). Interventions that address the problem by banning wet markets, wildlife trade, and wildlife farming, without driving down

the demand for wild meat, may not succeed as they risk driving the illegal trade underground (Roe et al., 2020). Also, research shows that bans on wildlife markets often, and wrongly include calls for bans on “wet” markets, but the two are not the same thing, and wet markets (synonymous with “fresh” markets) can be a critical underpinning of traditional food systems (Volpato et al., 2020). Therefore, the complex interplay of social, economic, and cultural reasons behind the increasing pressure on the sale of wildlife must be taken into consideration, in efforts to address the challenge. If not, interventions that try to control or regulate these markets or practices could potentially lead to undue pressure on fragile food systems and indeed undermine human rights and harm sustainable development (Roe et al., 2020).

Another area of intervention key in mitigating foodborne disease emergence is the development of integrated surveillance systems based on a One Health approach, integrating data from the human, animal, and environment sectors (Bordier et al., 2018; Thomas et al., 2020). Research on the self-regulating systems that local communities put in place to avoid overexploitation of specific resources, as well as political ecological research on how governance systems at different levels impact ASF supply chains (Volpato et al., 2020), are other areas where interventions to mitigate FBZ emergence could be developed. Overall, taking proactive steps to incorporate One Health expertise along with food safety interventions may reduce the risks of the emergence of new diseases (Aiyar and Pingali, 2020) as it brings in perspectives that single disciplines or single sectors may ignore.

The race to investigate the pathogenesis and epidemiology of COVID-19 has seen governments and funding agencies allocate substantial resources to fund COVID-19-related research proposals with unusual swiftness (Prudêncio and Costa, 2020). Such international collaborations and funding were not always apparent; previously the emergence in China of two emerging zoonoses, severe acute respiratory syndrome (SARS) and H5N1 avian influenza virus, failed to get the attention of the international community to address the lack of surveillance systems associated with handling and consuming ASF (Shao et al., 2011). While further scientific inquiry to ascertain the zoonotic origin of COVID-19 is required, integrated wildlife, livestock, and human surveillance and response may contribute to preventing future zoonoses outbreaks (Zinsstag et al., 2020). Major challenges still exist concerning the reorientation of market incentives and food safety standards, yet in the light of COVID-19 consumers are increasingly aware of the broader effects of current food systems (Thomas et al., 2020). A possible silver lining to this pandemic may be that policymakers will work harder to reshape global food systems to support better health for all.

8. Conclusion

The sale and consumption of ASFs within traditional markets represents a potentially risky activity, yet traditional markets provide a vital source of nutrition for much of the world's population and most foods available are safe. The potential link between the emergence of COVID-19 and the Wuhan Seafood market has put traditional markets in the spotlight and interventions, both at the traditional market nexus and within the wider food system are certainly required to mitigate potential risks to communities that markets serve. This review highlights several areas in which market-based interventions may be of value, but also some key challenges in implementing these interventions.

Improving the knowledge of vendors and consumers on food safety is important, yet an understanding of the motivations and incentives behind stakeholder behavior and the physical and social determinants of food safety must be considered to drive long-term improvements. A one-size-fits-all approach for consumers and vendors will not work. Site-specific cultural, social, and economic factors make tailored intervention design a necessity. Governance of traditional markets is complex and draconian measures to regulate them have been demonstrated not to work. Interventions that focus on marketplace regulation need to take a grassroots approach that considers the actions and values of all traditional market stakeholders; such values must be considered when introducing mandatory changes.

It is unlikely that interventions that concentrate on a single subset of actors or one single stage in the value chain will have a lasting and sustainable impact. Rather, utilizing the ethos of One Health, implementing multi-disciplinary collaborations for the enhancement of human, animal, and environment health, the interventions discussed in this review under the auspices of 'vendors, consumers, and governance' should be considered as a toolkit from which to select multiple approaches that can work synergistically, to enhance food safety in traditional markets. The market-based approaches identified here should also be supported by veterinary input in the pre-market value-chain to improve the health of livestock "at source" as well as by post-market interventions focused on consumer practices within the home.

Fostering teams of clinicians, veterinarians, environmental health specialists, microbiologists, nutritionists, ethnographers, anthropologists, policy analysts, behavior change, and communication specialists to work together to solve "wicked problems" is an exemplar of One Health in action. This approach has gained increasing traction considering the recent COVID-19 pandemic. While there are logistical and economic challenges to implementing a One Health approach,

it should remain an optimistic goal for those working in food systems development.

Author contributions

ELe, FM, DG, ELA, and LT made substantial contributions to conception and writing of the review. All authors read and approved the final draft of the manuscript.

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Conflict of interest

ELA was employed by Global Alliance for Improved Nutrition (GAIN).

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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