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The U.S. Government's Global Hunger & Food Security Initiative

EatSafe: Evidence and Action Towards Safe, Nutritious Food

Assessing Food Safety Interventions Relevant to Foodborne Zoonoses in Low- and Middle-Income Countries

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This EatSafe report presents evidence that will help engage and empower consumers and market actors to better obtain safe nutritious food. It will be used to design and test consumer-cantered food safety interventions in informal markets through the EatSafe program.

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ACRONYMS

Below is a list of all acronyms and abbreviations used in the report:

AIDS	Acquired Immunodeficiency Syndrome
AMR	Antimicrobial resistance
AMU	Antimicrobial usage
ASF	Animal source food
BSE	Bovine spongiform encephalopathy
CDC	Centre for Disease Control and Prevention
DALY	Disability-Adjusted Life Years
EU	European Union
FBD	Foodborne disease
FBZ	Foodborne zoonoses
GAP	Good Agricultural Practices
HACCP	Hazard Analysis & Critical Control Point
HIC	Higher Income Country
H5N1	Highly Pathogenic Asian Avian Influenza A Virus
KAP	Knowledge Attitude Practices
LMIC	Low- and middle-income countries
OHZDP	One Health Zoonotic Disease Prioritization
PPE	Personal Protective Equipment
SARS	Severe acute respiratory syndrome
ToC	Theory of Change
UK	United Kingdom
US	United States
WTP	Willingness to pay
WHO	World Health Organisation

EXECUTIVE SUMMARY

Foodborne diseases associated with zoonotic pathogens can be transmitted to humans primarily, but not exclusively through animal source foods (ASF). It is estimated that 75% of all emerging diseases are zoonotic in origin. Globally, foodborne zoonoses are associated with approximately one third of the foodborne disease burden, though this is likely an underestimation. Some regions, particularly Africa, have a higher attribution of disease burden to foodborne zoonoses. As the population, urbanization, and expendable incomes of low- and middle-income countries (LMIC) increase, the demand for ASF is also projected to rise, bringing with it the risk of foodborne zoonoses. If the consumption of ASF continues to increase without adequate attention to risk mitigation strategies, the burden of foodborne zoonoses is likely to worsen.

The majority of ASF in LMIC are sold in informal markets, which represent highly important nodes that can be targeted for risk mitigation. The nature of zoonoses, however, requires that, where possible, a 'farm to fork' approach is adopted; an approach guided by robust risk assessment techniques to address risk in the most effective and cost-effective way. A holistic vision of foodborne zoonoses control requires multi-sectoral collaboration, within surveillance, response, and prevention functions. The nature of pathogen transmission between human and animal hosts and make collecting data on their prevalence, distribution and risk factors a common goal between the human health and veterinary science communities.

This report highlights the multiple and complex factors involved in mitigating foodborne zoonoses in ASF sold at informal markets in resource-poor settings. Many of those factors may also be relevant to pathogens in non-ASF. The evidence discussed here is meant to inform the design of interventions to potentially be tested in phase two of the EatSafe project, as well as the design of other food safety programs. Given that most food safety interventions (ASF and non-ASF) require a "farm to fork" approach, this report discusses interventions implemented at the market and consumer level, as well as at the farm and processing stages. In addition, factors that previous interventions have identified as inhibitory or enabling to effective food safety strategies, such as cultural settings, governance policies, or infrastructure, are highlighted and recommendations for intervention design discussed.

The case studies reviewed here highlight several lessons to consider when designing interventions to mitigate foodborne zoonoses in food markets. For instance, accounting for the local socio-economic and cultural context and how it shapes attitudes and behaviours is key to intervention effectiveness. While one-off education and training interventions have had short-term success, evidence is lacking for long-term interventions. Also, knowledge alone does not usually result in changed behaviours. Appropriate equipment and infrastructure, as well as other factors, are often necessary to enable a new practice. Participatory approaches can be effective, at least in part, because they account for and leverage key behaviour drivers. Establishing draconian standards, on the other hand, has often failed. Overall, strategies to control zoonotic and non-zoonotic pathogens at food

marketplaces exist and are generally similar. However, the role of other critical control points throughout the supply chain is particularly important for the control of zoonoses and should be considered for the effective application of food safety interventions.

1. INTRODUCTION

Vertebrate animal species are natural reservoirs for many pathogens of animal origin that cause human infections (zoonoses). Zoonotic pathogens can be transmitted through ASF, and secondarily via non-ASF that become contaminated during their production process (1). The importance of these pathogens is hugely significant; 75% of all emerging diseases are zoonotic in origin (11), which puts consumers of ASF at increased risk.

Consumption of animal source food (ASF) is rapidly increasing, especially in low- middle-income countries (LMIC) where consumers are increasing consumption of higher-protein diets (1). Rapid population growth, urbanization, and increased income drives demand for ASF, resulting in an intensification of livestock production (2). ASF supply several bioavailable nutrients lacking in plant-based diets, providing the nutrients required for healthy human development and growth (3). Especially important is Vitamin B12 which is not naturally available in plant foods unless these have been fortified (4). The majority of ASF products in LMICs are sold through informal markets (5), with the proportion of food sold through retail (supermarkets and convenience chain stores) remaining low, even in cities (6).

Informal markets are important hubs of trade and commerce. They supply the growing ASF demand among urban populations and are a source of employment for small scale livestock producers and others involved in the transport and sale of animal source food (7), including women and youth. Informal markets play an essential cultural, social, economic, and nutritional role in communities across LMIC. Consumers of ASF sold in informal markets nevertheless face a double-edged sword scenario: while standing to gain from the nutritional benefits of high-quality, animal sourced protein and micronutrient-rich diets, they also are at risk of foodborne zoonoses.

Infrastructure in many informal markets is poor, which is an important factor in raising concern about food safety issues (5). Informal markets are often located close to low-income urban housing settlements where irregular electricity supply, poor drainage, and a lack of sanitation increases the risk of food contamination and foodborne diseases (8). Some of the markets operate outdoors in the open air, either partially or entirely. Vendors in informal markets operate without electricity, clean potable water, or proper waste disposal and sanitation facilities - all factors that increase the risk of foodborne pathogen occurrence or transmission (9, 10).

In food marketplaces, foodborne zoonotic hazards can be introduced through ASF, adding to the risks related to the hygienic conditions of informal markets where ASF are sold. ASF also provide a good environment for zoonotic and non-zoonotic pathogens to survive and grow. Pathogens that could not survive in sugar, salt, or dried grains may remain viable in the moist, nutrient rich matrix provided by ASF. While consumers of ASF may be at particular risk from foodborne pathogens of zoonotic origin, consumers of non ASF may also be at risk, since vegetables sold at these markets can become cross-contaminated by zoonotic pathogens, for example by being irrigated with contaminated water or through poor vendor storage and hygiene practices (12).

The human health burden associated with foodborne illness from ASF is estimated to be 168 (137-219) DALY lost per 100,000 individuals, or approximately 35% of the estimated foodborne disease burden (13). Three biological hazards are responsible for 70% of the foodborne zoonoses burden: non-typhoidal *Salmonella* spp., *Taenia solium*, and *Campylobacter* spp., with the highest burden found in Africa (13). However, this analysis (13) included only 13 foodborne zoonoses, and hence may have underestimated the burden of this important sub-set of food safety hazards. Notably it does not include all foodborne zoonoses, or non-zoonotic pathogens commonly found in ASF. Country-level studies have hinted at this under-estimation, with 78% and 71% of foodborne disease in the UK and India being attributed to ASF (1). The burden of common foodborne zoonoses of relevance to Africa and Asia, and the ASF most commonly associated with each pathogen, are outlined in Table 1.

Table 1. Foodborne Zoonoses of Particular Relevance to LMIC in Africa and Asia

Foodborne Zoonoses	Global burden attributable to pathogen, in DALY/100,000 (95% uncertainty interval), and % attributable to ASF*	Animal source food associated with transmission of pathogen	Details on transmission
Campylobacter spp.	27 (19-40) 90% ASF	Poultry, Beef, Pork, Small ruminant meat, Dairy	Recognized as a leading cause of bacterial foodborne diarrheal disease. *Campylobacter* spp. is commensal of many vertebrate species, but human infections are most commonly associated with poultry meat. Another source of infection is consumption of water contaminated with animal faeces (16).
Non-Typhoidal *Salmonella enterica*	49 (30-76) 80% ASF	All ASFs	Faecal pathogens of animals which can cross-contaminate ASF at many points in the supply chain. Causes a generally self-limiting gastroenteritis with complications in the young, old, and immunocompromised.
Brucella spp.	2 (0.6041) 95% ASF	Dairy, Beef, Pork, Small ruminant meat,	Predominately transmitted to humans through unpasteurized milk or through direct contact with infected animals. Human infections lead to an undulant fever, joint pain, and weakness (17).
Toxoplasma gondii	9 (6-14) 70-80% ASF	Beef, Pork, Small ruminant meat, Poultry, Dairy, Eggs	One of the most ubiquitous zoonoses. Humans become infected through consumption of cysts in 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 fetuses and in the old and immunocompromised.

Taenia solium	41 (31-52) 100% ASF	Pork	Pigs are the intermediate host for the parasitic zoonoses *T. solium*. Consumption of undercooked pork meat leads to infection with the definitive stage of the tapeworm (Taeniosis). 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.
Mycobacterium bovis	9 (7-33) 100% ASF	Dairy	*M. bovis* is transmitted to humans from cattle predominately via unpasteurized milk. Symptoms in humans are indistinguishable from those of *M. tuberculosis.* The highest burden of zoonotic tuberculosis (TB) is assumed to be borne by Africa given the prevalence in cattle and lack of pasteurization for the majority of milk consumed (18).
Fish borne trematodes	13 (10-15) 100% ASF	Finfish	Metecercaiae are harboured 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 (14).
Paragonimus spp.	15 (11-21) 100% ASF	Shellfish	Humans acquire this zoonotic parasite through the consumption of raw/undercooked shellfish. Immature flukes migrate to the lungs where they are responsible for pulmonary signs linked to inflammation; aberrant migrations including to the central nervous system can occur. The parasite is most commonly distributed across Asia where cultural practices relating to the consumption of raw shellfish sustain its life-cycle (19).

* (13)

An effective method used in in higher income countries (HIC) to mitigate foodborne zoonoses is a “farm to fork” system of surveillance using food supply chain information to allow full traceability and transparency in the supply chain (20). Unfortunately, such systems, which could help identify how and where animal source foods become contaminated, prove too costly in LMIC (15) and are not feasible in systems that are largely traditional and more informal. At present, hygiene improving interventions are lacking to address the infrastructure, resources, and knowledge of the multiple actors along the ASF supply chain necessary for successful food safety (21). Given the significant role that traditional markets have in food security and food safety (7), and the growing consumption of ASF (22), it is increasingly important to investigate how foodborne zoonoses transmission risk evolves along the supply chain before, at, and after the informal market nexus.

This report is focused on understanding how interventions applied at traditional markets impact foodborne zoonoses. Interventions associated with foodborne zoonoses in informal markets are gaining traction for two main reasons: the increase in demand for ASF from these markets (1) and the resulting burden of foodborne disease attributed to ASF in LMIC (23). Despite high foodborne disease burdens attributed to ASF sold in informal markets, informal markets should not come under undue scrutiny because they belong to an unregulated sector (24). Firstly, informal market food is often safe for consumption and food hazards, which are very common in informal markets, do not necessarily translate into foodborne illness (7). 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 (25). Informal markets play a vital role in fragile food systems in LMIC (26); they are important for food security and livelihoods and as such merit protection and support through integrated safe food approaches.

Evidence gathered in this report highlights barriers and bridges to interventions associated with foodborne zoonoses in LMIC. The informal market will be presented as the interface where vendor and animal sourced food producer meets consumer, a key moment in understanding transmission pathways for foodborne zoonoses. Approaches at a governmental and intersectoral level, such as a One Health approach and its relevance to integrated surveillance and other strategies, will be reviewed. Given how foodborne zoonotic pathogens have developed efficient and effective strategies to exploit food as a vehicle for transmission from animals to humans (27), special consideration will be given to the drivers of foodborne zoonoses at the informal market interface; as well as the socioeconomic and cultural considerations that successful interventions must consider in mitigating risk.

2. OBJECTIVES

A non-systematic literature review, including drawing on the literature identified in EatSafe activity 1.12, was conducted to identify specific aspects of food safety interventions relevant to foodborne zoonoses in LMIC across Africa and Asia, with a focus on lessons learned from recent projects.

This review aims to synthesize evidence to the EatSafe audience, setting out why, where, and how interventions linked to informal markets have succeeded, or failed, to mitigate pathogens of animal and human-associated health risks and their transmission through food. Specifically, this review is intended for technical experts who design evidence-based interventions, and for program managers who need to prioritize investments based on potential impacts of an intervention.

The review specifically provides guidance to the design of EatSafe and other food safety interventions in informal markets in LMIC by addressing three key questions:

- Which interventions to support food safety within LMIC informal markets (focused on food vendor and consumers level) have relevance to foodborne zoonoses?
- Are there food safety interventions specific to foodborne zoonoses outside of market setting which should be considered?
- Are there interventions within informal markets which may mitigate the risk of future emergence of zoonotic disease transmission ?

The scope of the literature review includes:

- literature identified previously as part of EatSafe Global Activity 1.12,
- targeted database searches, namely Google Scholar, focusing on foodborne zoonoses interventions in informal markets in Africa and Asia,
- interventions in informal market settings, ASF production, and consumer food handling practices,
- changes in infrastructure and governance, and
- relevant interventions in HIC

3. FINDINGS

3.1 Food Safety Interventions targeting foodborne zoonoses implemented in informal market settings

Across Africa and Asia, large volumes of meat, milk, eggs, and fish are sold through informal markets. These markets play an important role in livelihood strategies and food security, particularly among the poorest members of society (28). There are, however, risks of foodborne zoonoses associated with the consumption of ASF from informal markets. Disease knowledge, cultural practices, and perception of risk of both vendors and consumers are all important factors that have been the focus of past food safety interventions.

3.1.1 Market Interventions focusing on vendor KAPs

Market operators can play an important role in the transmission or control of FBZ outbreaks (5). Foodborne pathogens may be already present in a food when it arrives at the market, or it may be transferred to the food by vendors either directly or by cross contamination (29). For example, a study in an informal market in Vietnam showed how *Salmonella enterica*, a bacterium often carried by cattle and poultry, had contaminated multiple food products of non-ASF origin across the market due to poor vendor sanitation practices (12). The ways and means by which vendors may transfer pathogens as they prepare and handle food at markets is common to most zoonotic and non-zoonotic pathogens, and to both ASF and non-ASF (30). These practices are influenced both by the knowledge, beliefs, and values of the food handlers as well as the physical market infrastructure they are working within.

Vendor Awareness

Understanding and improving vendor awareness regarding foodborne zoonoses is one area where research has been undertaken. In LMIC settings surveys have been used widely to survey the knowledge, attitude, and practices (KAP) of food handlers (31, 32). These surveys show that vendors of ASF lack knowledge about disease transmission (24, 33). Interventions addressing this lack of knowledge have been associated with a reduction in foodborne disease transmission. Training on hygiene and business skills among meat vendors in Nigeria and milk vendors in India saw a significant reduction in coliform bacteria, which are indicators of faecal contamination, in meat and milk post intervention (22, 34). A hygiene educational intervention showed increased hand washing among food handlers in Malaysia 6 weeks post intervention (35).

Interventions involving the provision of information, training, and skills-building will lead directly to a change in attitude and, consequently, a change in behaviour or practice can be successful in the short term (31). However, if not repeated, its long-term sustainability is questionable. Follow-up studies 9 years later saw coliform bacterial load creep back up to high levels again in meat and milk sold by vendors in both the Nigerian and Indian study (34, 36). KAP interventions do create temporary improvements in food safety, but education alone (especially one-off education initiatives) can only partly improve food safety practices of food vendors (37); other factors linked to behaviour change must be considered. For example, in meat plants in HIC, interventions aimed at improved food safety among meat handlers found that both the "behavioral setting" and the cognitive processes associated by the meat handler with that behavior must be changed for training interventions to succeed (38).

Training

In LMIC, rigorous, long-term impact assessments of food handler training interventions often fall outside the scope of studies, which tend to be more exploratory in design (39), hence failing to identify factors associated with long-term training success. One example of a long-term evaluation method based on the Theory of Change (ToC) approach, designed to define long-term goals and then map backward to identify necessary preconditions, showed that

more evidence is needed to validate hypothesized causal relationships between vendor training interventions and food safety outcomes among meat and milk vendors in informal markets in African and Indian settings (40). While there is evidence that educational interventions among vendors of informal markets is beneficial, mechanisms enabling long-term impact assessment need to be incorporated into the study design.

In Kenya, culturally accepted and religious practices influence informal market vendors perceptions of food safety risks and disease transmission, and ultimately their willingness to adopt biosecurity measures. For example, some vendors believe that disease outbreaks are a divine punishment (41). Vendor values and beliefs must be considered, as approaches used to reduce foodborne zoonoses usually fail if engagement with key actors is lacking (25). Informal milk vendors in Mali, for example, refused efforts to wash milk containers with soap (7), as their belief that soap taints the taste of milk trumped their concerns over pathogenic milk borne bacteria.

The underlying level of knowledge on disease transmission and high-risk practices is important to understand in order identify areas where educational interventions may be of use. In areas of Morocco where the foodborne zoonotic disease echinococcosis, caused by the parasite *Echinococcus granulosus,* is endemic, butchers and meat vendors continue to dispose of offal where street dogs roam. They do not consider their actions as contributing to cystic echinococcosis in the community and are unaware of the role of dogs in the complicated life cycle of *Echinococcus granulosus* (42). Similarly, in Pakistan, butchers are identified as being at high risk for echinococcosis, yet few reported knowledge of the disease and therefore are unlikely to take mitigating actions (43). In many African countries, it is not uncommon to see meat retailers turning carcasses destined for human consumption into sitting chairs or resting platforms without concern for potential contamination, either of the meat or of themselves from the carcasses (44). These studies illustrate how any interventions to mitigate foodborne zoonoses among animal sourced food vendors, must consider both local cultural beliefs and the current level of knowledge regarding zoonotic disease transmission pathways.

Vendor settings

Vendors in informal markets operate within challenging occupational settings, often without electricity, clean potable water, or proper waste disposal and other sanitation facilities (5). Often market vendors use leftover perishable raw materials for next-day preparation without appropriate storage facilities (45). Lack of refrigeration, proper containers, and equipment and clean water needed to effectively wash reusable tools provides opportunities for cross-contamination particularly for highly perishable ASF (10). Vendors use open air, crude structures such as push carts, wooden display tables, or chop bars to display goods, which can facilitate transmission of foodborne pathogens from one food to another, by direct contact or via surfaces (30). In Uganda, a study linked the lack of public sanitary facilities within a market setting to poor personal hygiene among meat food vendors (10), predisposing them and their food products to possible foodborne pathogens. Meat workers in Vietnam were observed to use poor cleaning practices when washing utensils, increasing the opportunities for cross-contamination of meat products (46). Without running water, milk vendors in a

Tanzanian market wash utensil in basins designed for hand washing, thus increasing the risk of food contamination (47). In India, pork sold in open stalls sampled morning and evening of the same day showed rapid growth levels of *Salmonella* spp., toxigenic *E. coli* and *Listeria* spp., all causative agent of foodborne zoonoses (48). Interventions aimed at reducing the time to market for meat have been recommended to reduce pathogen transmission risk (7). However, actions that identify poor market infrastructure or technologies as the sole cause of poor hygiene practices by vendors, without due regard to cultural beliefs and practises, fail to mitigate foodborne zoonoses.

Interventions to upgrade or build new marketplaces with proper sanitation and lighting for informal vendors, attempting to reduce transmission of foodborne pathogens (zoonotic and non-zoonotic alike), often do not work (8). Interventions to upgrade market infrastructure must first gain insights into the needs, concerns, and demands of vendors if risks associated with foodborne zoonoses are to be reduced. It is much easier to install infrastructure than to maintain it. A recent study in Nigeria (unpublished) found many markets had water supply towers but few were operating. Coliform bacterial levels on meat sold in a marketplace in Ibadan in Nigeria increased despite the building of a modern abattoir for butchers. While the modern abattoir had objectively better facilities, no market survey had been carried out to establish demand for it among butchers; its location and higher usage costs meant butchers reverted to the original market facility which had no access to running water (36). In Kenya, when milk vendors were asked why they failed to wear the mandatory PPE required by the Kenyan government, they described the PPE as cumbersome, reducing their productivity, and not generating any tangible benefits (41). The same study found that food safety practices should be feasible, inexpensive, and not time-consuming for vendors. Street vendors in Zambia who were moved into new and hygienic premises were soon found to return to their former market location; the improved market, despite having better environmental conditions, meant less accessibility to customers and higher transaction costs for vendors (49). Limitations to sustained adoption of hygiene practices in infrastructure-constrained settings reflect a still-developing understanding of the factors that influence these practices (50). While issues related to the interactions between technology and behaviour are common to all foodborne hazards, impacts can be amplified for inherently perishable food products such as animal source foods.

One method that has proven effective in understanding social structures among vendors and improving the safety of animal sourced food is Participatory Learning and Action. Participatory Learning provides a tool to navigate the complex dynamics among vendors and their supply chains in informal markets (41). 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, an analysis identifying task differentiation by gender was carried out; findings identified both gender and membership in a trade association as important food safety determinants, and hence as promising entry points for interventions to improve food safety (51). This participatory learning and action intervention in Nigeria also highlights how food safety has gender equity implications that should be considered in future interventions.

3.1.2 Market Interventions focusing on consumer KAPs

As an increasing number of consumers purchase foods of animal origin from informal markets in LMIC, consumers themselves have an increasingly important role to play in the safety of the food they consume; their purchasing habits and food handling practices are an important node for food safety interventions.

Consumers across informal markets in LMIC span a broad range of demographic characteristics (1). Despite the heterogeneity of consumers, most consumers of informal markets express concern about food safety (25). Also, consumer purchasing behaviour has been observed, in some occasions, to change due to food safety concerns. For example, 40% of surveyed consumers reported switching to alternative meats in the wake of animal disease epidemics (7), and were observed to preferentially purchase poultry and avoid pork after a swine flu outbreak in Asia (27). This growing awareness among consumers together with improved consumer knowledge, attitudes, and practices can reduce the burden of foodborne zoonoses (52). However, while consumers will change purchasing behaviour in the face of publicised animal disease outbreaks, there is much less evidence that poor consumers will pay a premium for food credibly branded as safe (53).

Consumer Awareness

Awareness does not necessarily equate to behavior change. In India, growing concern among consumers about the purity and quality of milk marketed by informal milk vendors and the possible health risk posed by it, paved the way for the introduction of a successful milk certification program (40). However, attitudes and behaviours differ across countries and regions. Informal market consumers in Nigeria, despite claiming to be knowledgeable and aware of hazards and pathogens in foods that may cause health risks, still engaged in risky eating habits such as lack of hand washing prior to eating; high consumption of raw milk products, beverages made with raw milk or with untreated water from boreholes; and high consumption of *suya*, a beef product prepared under unhygienic conditions and linked to many foodborne disease outbreaks in Nigeria (54). In Thailand, a public health food safety campaign aimed at increasing consumer awareness of disease risks caused by *Streptococcus suis*, which is associated with the tradition of consuming raw pork,, found a positive reduction in disease incidence two years after intervention. However, on the third year, disease incidence increased, suggesting that deep-rooted cultural behaviours prevailed, and continuous public health information campaigns tailored to local cultural settings may be needed to sustainably mitigate foodborne zoonoses (64). These findings highlight that a one-size-fits-all approach for consumers in different cultural settings will not work, and also that knowledge alone may not be associated with behaviour change.

Translating consumer knowledge and awareness of foodborne zoonoses into practices to mitigate risk is challenging (29, 54). In one study in South Africa, pork consumers were aware that *T. solium* cysticercosis could be harmful but they lacked knowledge on how to identify *T. solium* cysts in pork. They also lacked sufficient awareness that a butchery certification related to disease control, slaughter, and food preparation had been put in place by the public

health department, and would therefore continue purchasing meat from uncertified premises that may not have adopted appropriate hygiene practices (55). Consumers are often either unaware of the presence of foodborne zoonotic pathogens or unaware of the necessary steps to mitigate transmission risks. This is not unique to LMIC. *Campylobacter* is the most reported causative agent of foodborne bacterial infection in Germany, with contaminated chicken meat identified as the most important source of infection; yet in a survey of 1008 consumers only 11.5% knew how to protect themselves from *Campylobacter* infection (56). This highlights how inadequate knowledge on the causes of foodborne zoonoses and the actions which may mitigate their risks is not restricted to LMIC consumers and exists even where safe food media campaigns are in place (57).

The rise of social media as an alternative platform for sharing food safety risk information has brought a significant change in how risk communication occurs among food consumers in LMIC (58). Mass media and social media have played the role of "risk amplifiers" among food consumers in Vietnam (59), with social media platforms influencing consumers judgment and purchasing behaviour following dairy industry scandals in China (60). Examples of planned food safety interventions relevant to foodborne zoonoses using social media platforms in informal LMIC markets where not identified in this report. Nevertheless, given the power of such platforms for sharing food safety risk information, they could prove to be a strategic tool in future intervention designs to improve information accuracy and trust among consumers.

Consumer Willingness to Pay

Willingness to Pay (WTP) surveys have been used in informal markets as a tool to gain insights into consumers' willingness to pay a premium for safe food (45). In Vietnam, a consumer WTP intervention identified gender, household income, and the severity of a hazard as positive determinants of consumers demands for "safe" pork from informal markets (46). The same study identified consumer perception of "safe" pork as pork that is packed and labelled, distributed from hygienic selling points, and certified by certificate bodies. However, in most LMIC the official certification of products sold in informal markets is problematic and scarce (7). What consumers may want but what they actually access can differ (expressed versus revealed demand). Standards for food quality and safety are either non-existent or exist as defined by public health norms in developed countries, with no real relevance for informal markets (61). In these circumstances, consumers will seek out branded food products only if they trust the specific branding program and the training and certification activities on which they are based (7). But even when consumers are willing to pay more for branded animal sourced foods, certification may not always guarantee food safety and hygiene (31), with other market forces restricting consumer access to safe products (46). Consumers, despite being willing to pay for safer products, are often left in a vulnerable situation and rely heavily on the hygiene practices of vendors and other market actors in mitigating risks to their health (62). When used as part of a consumer food safety intervention, understanding the willingness to pay (either stated or revealed preference) will reflect consumer values regarding safe food but by itself will offer limited insight into foodborne zoonoses mitigation strategies.

Consumer behaviours and practices

Epidemiological data indicate that improper food preparation practices in consumers' homes is responsible for a substantial proportion of foodborne disease (52). Most foodborne diseases are preventable with proper food handling, and foodborne zoonoses are for the most part no different (25). Applying the WHO's five keys to safer food could theoretically mitigate the risk of exposure to many foodborne zoonoses by keeping food clean; separating raw and cooked foods; cooking food thoroughly; keeping food at safe temperatures; and using safe water and raw materials (63). In Bangladesh, an educational intervention based on the WHO's 5 keys and targeted at female food handlers showed improvements in food handling practices, increased washing of utensils with soap, and overall improved 'kitchen cleanliness' post intervention (52). Nevertheless, large-scale education targeted to the in-home food preparation environment tends to be costly (48) and often fails in reducing foodborne disease burden (14). Why such actions fail requires a deeper understanding of consumers customs and practices relating to food preparation as well as their perception of risk within the kitchen setting and how it contributes to foodborne zoonoses transmission.

Public health education also presumes access to a minimum level of appropriate infrastructure, such as clean spaces to store and prepare food, access to clean water and soap, and access to an appropriate heat source for cooking. In some communities, particularly those served by informal markets, these needs may not always be met. It is therefore not only important that educational campaigns are contextually relevant, but that they are undertaken in parallel to wider socio-economic development activities to ensure everyone has the capacity to prepare safe food. In high-income countries it has also proven difficult to change behaviour in households, so emphasis has shifted to ensure food is safe when it enters the house.

3.1.3 General approaches to guide market interventions

Holistic approaches to risk management in informal markets can prove cost-effective (15), allowing for potential synergies through behavioral changes in both vendors and consumers.

Risk-based approach

In informal markets, both vendors and consumers must perceive that their current behaviour endangers their health, and that taking action has a strong likelihood of reducing foodborne zoonoses risks (65). Sections 3.1.1 and 3.1.2 of this report highlight the lack of knowledge regarding foodborne zoonoses among vendors and consumers and how their values and traditional belief can be barriers to their perception of risk from foodborne pathogens. A risk-based approach, i.e. explicitly prioritizing and designing interventions based on their estimated potential to reduce risk, has been recommended for informal markets (66). Importantly, the terms hazard (the intrinsic potential to cause harm) and risk (the probability of harm occurring at a given exposure) must be distinguished, something the public and even professionals often confuse (67). After all, vendor or consumer interventions focusing on controlling the level of foodborne zoonotic hazard, may not result in a satisfactory reduction

in the risks to human health should issues of cross-contamination not be considered (66). Conversely, high levels of hazard in raw products may not equate to high risk to consumers if appropriate mitigation strategies are in place. In East Africa for example, the number of zoonotic hazards in milk responsible for diseases such as brucellosis, tuberculosis, listeriosis, salmonellosis, and others has been found to be extremely high, but due to commonplace practices by vendors and consumers such as boiling milk prior to consumption, the risk of these hazards to human health is dramatically reduced (7).

In high-income countries, the use of risk-based approaches brought new insights and are now standard for food-safety issues (68). In the EU, where *Campylobacter* disease is the most frequently reported bacterial foodborne zoonosis, the prevalence of this pathogen in poultry is often high. Hazard-based control is not realistic because banning the supply and sale of fresh chicken is not a societally acceptable option. A risk-based microbiological criteria approach, where a predefined number of samples are taken from batches of poultry meat for microbial concentration analysis allows risk managers to decide on the most appropriate course of action for each batch based upon its risk profile, possibly balancing residual risk against economic consequences and practical feasibility (67). In LMIC settings, however, risk analysis is not widely used in informal markets because of human and financial resource constraints (48). To make risk-based approaches more common place in informal markets, several considerations need to be addressed, such as lack of pre-existing information on diverse structures and practices, difficulties of working with informal sector participants due to poor relations with officials, and lack of laboratory capacity (66). Examples from the literature describing interventions which encompass these challenges are lacking.

Risk-based methods can identify the true players in disease transmission; food products or disease transmission pathways originally perceived as risky may in fact not be when a risk-based method is used. An example is the case of *Cryptosporidium parvum* in Kenya. This zoonosis, whose main reservoir is cattle, was found to pose most risk to consumers from eating fresh vegetables, cross-contaminated at some point in the supply chain, and not from consuming milk or being in direct contact with cattle, as previously assumed (68). Similarly, food safety interventions which recommend specific practices rather than principles can negatively impact food safety (40), thus highlighting the need to address infrastructural weaknesses as well as change in behaviour. For example, washing hands could pose a health risk if the water is not clean and if soap is not used (7) Faced with high levels of hazards in informal markets but little understanding of the risks, a risk-based approach is recommended (68) to help quantify risk and identify appropriate mitigation strategies for foodborne zoonoses.

Use of HACCP

The use of the Hazard Analysis and Critical Control Points (HACCP) approach, an effective and economically efficient method of food safety control based on a qualitative risk assessment, is one aspect of a risk-based approach that has proven effective in reducing contamination of home-cooked weaning food in peri-urban Mali and Bangladesh (69). In Bangladesh, this approach, through examination of infant food processing steps, enabled the identification of the critical control points in infant weaning food preparation essential to food safety (cooking,

reheating, and cooling), thus facilitating appropriate targeting of educational messages to mothers when preparing food for their infants (69). In India, a HACCP approach was used in the pork supply chain to identify nodes where mitigation of the potential risk from foodborne zoonotic hazards could be implemented by vendors (48). Therefore, the HACCP approach allows for a starting point where foodborne hazards and their related risks can be identified, before designing effective preventive mechanisms for vendors or consumers.

3.2 Interventions of relevance to foodborne zoonoses at other stages of the supply chain

Contamination of food may occur at any stage in the process from production to consumption ('farm to fork' or 'stable to table') (70). Markets are one stage where pathogen control is possible, but the relative effectiveness of market-focused interventions needs to be put in the broader context of what level of control is possible at other supply chain stages. Understanding how food safety is influenced by the roles played by multiple stakeholders along this "farm to fork" supply chain is needed; previous food safety campaigns which neglected the role of actors in food processing, packaging, and distribution have been ineffective (36). Since contamination of ASF can result from environmental pollution, including water, soil, or animal feed contaminants (70), and these foods can in turn contaminate other non-ASF in the pathway to markets (15), a broader view of interventions beyond the marketplace is necessary. To fully mitigate the risk of foodborne zoonoses, factors "before" and "above" informal markets (i.e. upstream in the supply chain, or overarching aspects at play throughout the supply chain) must be considered. Therefore, in this section interventions that target foodborne zoonoses transmission pathways from "farm to fork" will be reviewed.

3.2.1 Interventions targeting KAPs of livestock farmers and producers

As vertebrate animal species are natural reservoirs for many zoonotic pathogens, and ASF can pose high health risks due to such pathogens, it is logical that controls at farm level should be considered to prevent unsafe food from entering the supply chain. This is especially the case for parasitic risks that enter the food chain at the farm level and populate in the live animal. It is important to note that other potential hazards carried by ASF also include natural toxins, adulterants, and other chemical contaminants such as animal drug and pesticide residues (1).

Insufficient knowledge and a lack of understanding about foodborne zoonoses among producers in the agricultural sector is a barrier to food safety in LMIC (71). In India, brucellosis is endemic and can spread to humans from animals through consumption of raw milk or milk products and through direct or indirect contact with aborted materials from infected animals, yet few farmers know about it or its zoonotic importance (72). One study among Indian small ruminant farmers showed how lack of knowledge of brucellosis was significantly associated with brucellosis prevalence in farmers, underpinning the critical link between farmer awareness and human infection risk (30). However, knowledge of zoonoses is not the only barrier. Even if farmers know how to identify a livestock disease of zoonotic potential, there

are disincentives for farmers to do so, such as stigmatization by their peers, financial losses from market exclusion, or culling without compensation (2). This can result in animals sick and unfit for human consumption entering the food chain. Cattle farmers in Senegal also were unaware of brucellosis as a disease or its transmission pathways, with 95% of farmers reporting to drink milk without prior heat treatment (73). Sheep and goat famers in Morocco, who are at a high risk of the parasitical zoonoses echinococcosis, practice home slaughter and feed offal to dogs, both factors associated with increased prevalence the *Echinococcus granulosus* tapeworm (42). Lack of knowledge combined with traditional belief systems and practices put farmers' health, and that of potential consumers, at risk.

Training farmers to improve their knowledge.

Training interventions can be effective in improving farmer knowledge and farm hygiene levels, especially if combined with incentives (25). An example of this was a study carried out among dairy farmers in India, where initial KAP surveys showed low levels of awareness about milk-borne zoonoses but post training follow-ups showed improved farmer knowledge and milk safety standards. An additional benefit was that messages from the training were observed to have been disseminated among the wider community (34). Other KAP studies among Indian dairy farmers found that small dairy farms had worse food safety standards than their larger counterparts (74), indicating opportunities for interventions to improve practices. A review of Indian farming systems identified farmers with a low education and economic standing as those most in need of education to reduce the health and economic impacts of zoonotic diseases (75). Identifying subgroups or cohorts of farmers who are more at risk or have more to learn in mitigating foodborne zoonoses could aid in the design of targeted educational interventions.

Ownership and personal responsibility for a problem are important influences of farmer behaviour and should be considered when adopting any training approach. In Uganda, a participatory training was used where pig farmers were encouraged to explore the problem of African Swine Fever in relation to their activity, and how their livelihoods could be affected if not addressed. The training created a feeling of ownership of the entire process and gained an insight into pig farmers KAP on good biosecurity practice and readiness to implement these practices in relation to African Swine Fever. An important outcome of the study was that knowledge is not the binding constraint to the uptake of biosecurity interventions (76). To improve understanding of why pig farmers still maintain poor biosecurity in relation to a particular foodborne zoonosis, the same approach could be applied to the control of cysticercosis, caused by the porcine tapeworm *Taenia solium* endemic across much of sub-Saharan Africa (77).,

HACCP on farm

A Hazard Analysis and Critical Control Point (HACCP) approach at the farm level can allow for poor sanitation, hygiene, biosecurity, quarantine, cleaning, and disinfection practices by farmers to be identified and modified where needed (78). Milk and dairy products, raw meats, and fresh fruit and vegetables produced in an environment contaminated by the intestinal protozoan parasite *Cryptosporidium parvum* pose a health risk to humans, with livestock

faeces identified as an important vehicle of transmission within herds, farms, the water supply, the fresh food chain, and the wider environment (79). Outbreaks of cryptosporidiosis, due to *C. parvum*, are linked to cockroaches, flies, mice, and rats introducing *C. parvum* oocyst into food and water (79). Good farm hygiene and rodent control is needed to reduce the risk of potential entry routes for this foodborne zoonoses. On-farm HACCP could identify likely opportunities for environmental contamination by this parasite and indicate measures, such as the correct storage and/or treatment of animal waste, to limit parasitical transmission to the farm environment and food chain (79).

Farmers' willingness to participate in good agricultural practices can be problematic and is often incentivized in HIC by government controls and certification (80), with these incentives either absent or flawed in LMIC. In Thailand for example, implementation of mandatory Good Agricultural Practices (GAP) among commercial poultry layer farms was done without any prior consulting with poultry farmers or other stakeholders related to egg production (81) and adoption has been inconsistent. The farmers' KAP scores were shown to be positively correlated with the adoption of GAP in Thailand, indicating that increased education may be needed in non-complying farms as compulsory adoption is rolled-out (81). Motivating farmers to adopt good agricultural practices will remain a challenge unless they perceive a benefit, either social or economic, to such interventions and when adoption is facilitated by both educational and infrastructural interventions.

Another approach to reducing foodborne zoonoses at the farm level is through the use of vaccines. Vaccination interventions can reduce the prevalence of zoonoses in livestock, which can reduce risks to human health (79). Vaccines have been developed to reduce the shedding from farm animals of zoonotic pathogens. Examples include vaccines for enterohaemorrhagic *Escherichia* coli in cattle and *Salmonella enteritidis* in chickens (82). A highly effective vaccine is available to protect pigs against infection with *T. solium* cysticercosis, with resultant reduction in infection risk to humans (83).

Large-scale zoonoses vaccination campaigns may be exciting, but there are many real-world practicalities and logistical challenges involved in such control measures. First, in livestock species, the cost of a vaccine is an important consideration, and farmers must see a positive cost-benefit ratio for vaccination of their herd if long term and wider vaccination use is to be successful (82). Second, many zoonotic pathogens circulate between livestock and wildlife. Spill-over of pathogens to wildlife hosts can by driven by growing immunity among livestock, as evidenced by poor brucellosis vaccination efficacy in cattle as wildlife species created new disease reservoirs, thus preventing disease eradication (86). Finally, poor veterinary infrastructure in LMIC and a lack of veterinary personnel to oversee vaccination campaigns complicates vaccination programs. (82).

Use of Antibiotics and AMR

Antibiotics are an intervention used to treat sick animals, to provide prophylactic protection, or as growth promoters in animals destined for human consumption. Targeted antibiotic

treatment in the animal, e.g. in a chicken flock, can reduce zoonotic pathogen levels so that the risk of infection to animals and humans is better controlled. . However, the development and spread of antimicrobial resistance (AMR), commonly but not exclusively in the form of resistant microbial strains, can exacerbate the FBD burden. Regulations on antibiotic usage (AMU) and the presence of antibiotic residues are in place in HIC (87). Such controls are absent in LMIC, resulting in the unregulated usage of antibiotics in livestock and creating a foodborne toxicological hazard to humans (87). Farmers' knowledge of antimicrobial usage in terms of withdrawal periods and the risks associated with AMR potential is low across various livestock systems in LMIC (88). A KAP study of poultry farmers in Cameroon showed poor knowledge about the risks of human exposure to antibiotic residues in food (89). In Vietnam, pork farmers seemed aware of the risk of antibiotic resistance based on observed poor outcomes after antibiotic use in animals (90). In the absence of food screening and sampling, improving farmer knowledge on the prudent use of antimicrobials will be an important to reducing AMR in food animals and antimicrobial residues in ASF. Educational interventions that focus on the economic benefits of correct antibiotic usage are likely to generate traction among farmers, thereby reducing the growth of AMR. Antimicrobial prescribing practices are poorly understood, with little or no studies conducted regarding the usage of antibiotics in veterinary medicine or the role of physicians and pharmacists in AMR control (91). AMR interventions that target farmers only, despite their vital role in antibiotic stewardship, may fail to understand the diverse influence which lead to antibiotic residues in ASF. Consideration of the cultural and technical challenges and competing interests in each country, as well as the sustainability of funding for successful AMR programmes (15), is needed.

3.2.2 Intervention approaches involving governance

Local Governance

Informal supply chains usually lack official regulation and governance throughout (7). While opportunities to improve food safety in informal markets through a restructuring of governance exist, their feasibility and effectiveness is not well understood (25). What governance approach is most effective depends on the local context. For vendors in informal markets, attempts to regulate through a 'command and control' method do not appear to improve food safety (40). In Ghana one third of meat vendors acquired meat from unlicensed sources despite government certification requirements and oversight by government officials (9). Setting safety standards at the market level alone has been unsuccessful in mitigating foodborne zoonoses; banning or criminalizing vendors of animal sourced food on the basis on poor food safety can have negative implications for health and nutrition overall (40). A light touch governance approach may yield better results. For example, the voluntary training schemes for milk suppliers and traders in Kenya have demonstrated a marked improvement in milk safety (92). When hard-line approaches are taken, with strict enforcement on informal market vendors, consequences can be serious not only for food security (8), but also in extreme cases due to violence (36). Draconian food safety policy can make things worse (25).

Interventions to regulate informal markets will require appropriate public policies that consider everybody along the chain if the health of vendors and consumers is to be protected (45).

Across many of Africa's urban food markets, a vibrant set of informal sector workers' associations have emerged in recent years (8). Understanding the social structures between and among these vendor groups or associations can help identify opportunities for interventions. 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 (51). Such subgroups within the marketplace could act as champions of good food safety standards, and future research should endeavor to understand the social dynamics within the marketplace and how this could leverage improved food safety standards.

National governance

Policy makers need to be convinced of the benefits of improving food safety in the informal sector (48). This will require more empirical evidence on the cost-effectiveness of food safety interventions (93). The use of standardized metrics and formal assessment of the health and economic burden of foodborne zoonoses can document their relative importance and improve resource allocation (36). However, in LMIC, accessing this data is challenging (94). Data supporting food safety interventions at informal markets 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 (94), where the cost of food safety interventions, such as training meat retailers in informal markets, may be less expensive than the health care costs linked to the diarrhoea suffered by those who eat unsafe meat, as seen in a Nigerian study (51).

While mitigating foodborne zoonoses and improving food safety should be a long-term policy goal at the informal market level, a consequence to improving governance is that as standards increase there is a risk that poor producers and value chain actors will be displaced from rapidly growing domestic markets (8). This has already occurred in export markets where smaller farmers tend to drop out, as they lack the human and financial capital needed to participate in highly demanding markets (25). Costly farm to table tracking systems effective in HIC may not be an option within informal markets in resource poor settings. Instead, locally orchestrated, vertically integrated systems may be more effective in reducing food safety risks and in providing small-scale farmers with increased access to markets, locally and internationally (93).

Training on developing businesses and establishing contracts between farmers and markets to improve the safety of food and gain certification may counteract growing pressure on small scale producers, retailers, and distributors to meet higher standards (5, 40). Governments need to promote accreditation programs for food safety; including training to promote traceability, record-keeping, and sharing information along the value chain (20). 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 (20).

Inter-sectoral One Health intervention approaches

A One Health approach, i.e. multi-sectoral collaborations in which the health of humans, animals, and the environment are improved for the benefit of all, has been strongly advocated for the control of many foodborne zoonoses and other 'wicked' problems (94, 95). Antimicrobial resistance, for example, affects the health of humans, animals, and the environment and mitigation approaches must involve all relevant sectors (96). Models for integrated systems, where multiple sectors work together for improved surveillance of antimicrobial resistance in farm animals, food and humans exist in HIC such as Denmark (94). However, public sector legislative and budgetary changes made in these countries to support such programs may not translate easily to LMIC. Previous collaborative efforts between the human and veterinary sectors regarding disease surveillance in developing countries have often failed (25). Implementing coordinated zoonoses surveillance in LMIC is challenging (87) given the collaboration among various institutions and agencies with human health, animal health, ecosystems, agriculture and food safety mandates needed to contribute to effective surveillance systems (2). Timely and open reporting and information-sharing among all those involved at the human–animal–ecosystems interface is crucial to enhance health and ensure overall food security (2). To achieve this, strategic, country-lead plans with a One Health approach meeting human, animal, and environmental health challenges are needed (97).

A One Health approach can enhance the performance and cost-effectiveness of surveillance systems and response to disease events, as compared to more conventional approaches (95). Such cost-saving incentives could be used to improve engagement among public and private actors and accelerate the adoption of integrated surveillance systems for foodborne zoonoses. An integrated West Nile virus surveillance program in mosquitos, wild birds, horses, and humans in Italy demonstrated financial savings produced by closer cooperation between the human and animal health sectors (98). Timely and open disease reporting is clearly linked to financial gains as seen in the case of a bovine spongiform encephalitis (BSE) outbreak in the UK and Canada. A timely response to the outbreak in Canada enabled Canada to avert 88% of the costs which the UK incurred in its sub-optimal effort to control the outbreak (99).

One Health approaches have been championed in the control of several foodborne zoonoses, including *T. solium,* the pork tapeworm and a leading aetiology of epilepsy in endemic countries. An intervention in Laos, which targeted both the porcine and human hosts of this parasite, a production-limiting disease in pigs (classical swine fever), and soil- transmitted helminth infections in people, was shown to be cost-effective from a societal perspective (100). Future interventions showcasing the cost effectiveness of integrated surveillance specific for foodborne zoonoses could facilitate quicker adoption by all stakeholders involved.

3.3 Considerations relevant to food safety interventions to mitigate the emergence of diseases of zoonotic origin

The suspected emergence of the SARS-CoV2 virus from an unknown animal source in or around the vicinity of the Wuhan Seafood Market in late 2019 is the latest, and most dramatic, example of the potential emergence of zoonotic disease in human populations. If proven true, the COVID-19 pandemic is one of the most visible examples of zoonotic spill-over in recent history, and it follows the relatively recent emergence of Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), Nipah virus, 'Swine Flu', and Highly Pathogenic Avian Influenza (H5N1) (94). Though not technically a foodborne zoonosis as it is not transmitted to people via food, COVID's origin and spread from its source in an informal wet market clearly show that similar foodborne risks could be amplified through such settings. Its "ripple effect," and disruption on local food systems in LMIC, demonstrates the challenge in preventing and controlling such pathogen spill-over worldwide (26).

In recent years foodborne zoonotic pathogens have developed efficient and effective mechanisms to exploit food as a vehicle for transmission from animals to humans (27). Understanding the drivers of foodborne disease emergence at market level is necessary to develop control strategies. As urban populations grow, livestock enterprises tend to locate close by to facilitate supply to markets, increasing interactions among people, livestock, other domestic animals and wildlife, and creating a fertile ground for zoonotic disease transmission (15). Epidemics like Ebola and HIV were driven by poverty and food insecurity, and an increase in demand for wild animals for consumption and trade increased contact between these animals and humans (101).

Climate change also increases foodborne disease by bringing novel vectors and pathogens into temperate regions or by temperature-associated changes in contamination levels (21, 25). Ecosystem degradation due to rapid urbanization, intensification of animal production, modernization of food marketing systems as well as changes in food consumption habits have had major impacts on human exposure to animal pathogens and the overall risk of zoonotic disease transmission (14). Some of these factors drive the emergence of new zoonotic pathogens and some drive re-emergence of endemic zoonoses. Intensification of farming systems, for example, can impact new pathogen emergence as well as "old"; for example, intensive bovine and dairy production has increased bovine prevalence of tuberculosis and brucellosis in Vietnam (14).

Poor adherence to food-safety standards has allowed wet markets, where improper storage of animals, overcrowding, inadequate hygiene, and improper disposal of faeces and carcasses occur, to become infectious disease hot spots (21). 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 wealthy and those aspiring to be, resulting in the increased sale of wildlife meats in markets (102). This consumer demand for bush meat and other "exotic" foods, has increased the risk of human exposure to animal pathogens (7). Interventions to prohibit the sale of such products by banning wet markets, wildlife trade, and wildlife farming, without

discouraging the demand for wild meat, will risk driving the trade underground (101). Also, research shows that bans on wildlife markets often 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 informal food systems that deliver healthy nutrition (102).Therefore, the complex interplay of social, economic, and cultural factors influencing the sale of wildlife must be taken into consideration. If not, interventions to control or regulate these markets or practices could jeopardize fragile food systems, undermine human rights, and harm sustainable development (101).

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 (102), are some areas that can inform interventions to mitigate foodborne zoonoses emergence. Examples of such systems include voluntary, community-based systems to govern the use of common-pool resources such as water or fisheries, as studied by the Nobel-prize winner Emily Ostrum (103).

Another area of intervention key in mitigating foodborne disease emergence is a One Health approach to integrated surveillance systems (see Section 3.2.2). Taking proactive steps to incorporating One Health expertise along with food safety interventions could reduce the risks of emergence of new diseases (21). Disease surveillance systems which allow for the integration of data from the human, animal, and environment sectors are an important aspect of early warning for novel emergence events (94). While surveillance is not the focus of the EatSafe program, the need for and benefits of One Health knowledge integration, which also play out in informal supply chains, should be kept in mind.

The race to investigate the pathogenesis and the epidemiology of COVID-19 has seen governments and funding agencies allocate substantial resources to fund COVID-19 related research with unusual swiftness (104). Such international collaboration and funding were not always apparent. Previously, the emergence in China of two foodborne zoonosis (severe acute respiratory syndrome (SARS) and H5N1 avian influenza) failed to get the attention of the international community, thereby limiting opportunities to enhance disease surveillance systems that could provide risk assessments for the preparation and consumption of animal sourced food (27). Hindsight prompts consideration of whether the current pandemic could have been avoided if the wake-up calls given by the emergence of SARS and H5H1 had been acknowledged. While further scientific inquiry to ascertain the zoonotic origin of COVID-19 is required, integrated wildlife, livestock, and human disease surveillance-response may help prevent future zoonoses outbreaks (98). To this end, deficiencies in the availability of quantitative data on the burden of foodborne zoonoses must be addressed.

Overall, while major challenges still exist concerning the reorientation of market incentives and food safety standards, consumers are increasingly aware of the broader public health effects of current food systems (94). Possible upsides to this pandemic may be that the whole world is now aware of the significance of informal food markets and the interconnectivity of our global food-systems, and that policy makers may have increased motivation to reshape global food systems to better protect public health. As a result of this increased awareness, policy makers may have increased motivation to reshape global food systems to better

protect public health, and future foodborne zoonoses interventions targeted at informal markets may gain more support from national and international governments.

4. CONCLUSIONS

Foodborne zoonoses, transmitted directly through ASF, or through cross-contamination from animals or animal products to non-ASF, are a crucial focus for informal market-based food safety interventions in LMIC. The increasing consumption of ASF in LMIC alongside poor risk-mitigation practices is driving a high burden of foodborne disease from ASF in these regions. Knowledge, values, and beliefs associated with foodborne zoonoses among key informal market actors must be understood within their local context before intervention can be successfully implemented. This report highlights that knowledge regarding foodborne zoonoses among farmers, vendors, and the consumer is low.

Similarly to the evidence discussed in EatSafe's Activity 1.12 report "Food Safety Interventions in Africa and Asia: a Review of studies relevant to traditional markets in low-resource settings", this report concludes that knowledge alone is not the sole determinant to bring about change in hygiene and food safety practices. Training as a stand-alone tool is also insufficient to bring about long-term mitigation of foodborne zoonoses risk. Behavioural changes are multifaceted and need to be considered together with appropriate infrastructure to facilitate the adoption and maintenance of new practices. Long term impact assessment of training interventions among market actors is lacking in the current literature and needs to be addressed in future studies.

Both this report and the 1.12 report highlight the need for an enabling environment to support successful food safety interventions. Participatory Action and Learning methods are recommended to gain insights into the motivations and incentives behind stakeholder behaviour; what drives their adoption of interventions and what physical and social determinants of food safety must be considered to bring about long-term improvements. For example, successful participatory approaches involved understanding gender roles among butchers in Nigeria, traditional beliefs among Ghanaian fishermen, and biosecurity measure adoption by pig farmers in Uganda to control infectious disease.

At the informal market interface, interventions to improve food safety and mitigate foodborne zoonoses risks should adopt a risk-based approach. A risk-based approach can allow for a more targeted, cost-effective strategy to be put in place identifying human health risks rather than focusing purely on hazards in foods of animal origin. A hazard may be present in an animal, but the degree to which it poses a risk to the end consumer depends on the presence (or absence) of risk-mitigation steps between 'farm and fork'. Differences in consumer and producer motivations constitute a challenge to the adoption of risk-based food safety interventions. With HACCP, for example, consumers may readily recognize the benefit of adopting household controls, but livestock producers may require incentives. They need to

see a commercial benefit before implementing good agricultural practiced. This report highlights that a one-size-fits-all approach is unlikely to work across all informal market actors; understanding and leveraging what motivates each group is key to successful improvements.

Governance of informal markets is complex and strict measures to regulate them have been demonstrated not to work. Fragile food systems can be made more unstable by top-down pressure for improved food safety standards. Policy alone will not bring about change in food safety standards. Similarly, consumer willingness to pay for certified meat, eggs or milk may not translate into the improved food safety of a product. Certification programs should reflect the local context in which they are developed.

Interventions that focus on marketplace regulation should begin at the grass roots level where the actions and values of local market players are considered when introducing mandatory changes. If not, such changes will be short lived, as seen in this report's examples of butchers in Nigeria and Zambia. As evidenced by the female butchers in Nigeria referenced in section 3.2.2 (51), identifying vendor associations within informal markets, including the gender dynamics within these associations, could help improve governance at the local level.

Consumer food safety information has been widely disseminated through social media platforms in many countries; such tools, if accurately moderated could mobilize local consumer behaviour at informal markets, leading to opportunities for safer, consumer driven ASF purchasing.

A One Health approach is essential to effectively mitigate foodborne zoonoses, which by definition involve both humans and animals, and often the environment. This approach, which utilizes multi-sectoral collaboration to solve intrinsically complex problems, has facilitated vaccination of both humans and animals; improved understanding of the drivers of AMR; and facilitated integrated disease surveillance so that endemic zoonoses and novel, emerging zoonotic pathogens may be identified and responded to in a timely fashion. In reinforcement of findings in the I.12 report, a One Health approach is suggested by multiple authors as a flagstone from which a supportive environment can be created to improve food safety in informal markets. Implementing this approach presents logistical and economic challenges but should remain a goal for those working in food system development. Cost-benefit analyses in HICs have shown the advantages of the approach. Economic evaluations to support a business case for One Health are recommended to improve stakeholder engagement in LMICs.

The transmission of zoonotic pathogens from animals to humans is not new and has been a by-product of the socio-economic and cultural drivers leading to increased proximity of humans, domestic animals, and wildlife for some time. The SARS and Avian Influenza outbreaks from China highlighted how quickly pathogens of animal origin can infect humans. The drivers behind disease emergence must be intervened on, for prevention to be effective.

Recommendations for Intervention Design and Future Studies under EatSafe

EatSafe aims to generate evidence and knowledge to drive consumer demand for safe, nutritious food in informal market settings. Central to EatSafe's work is understanding (and potentially shaping) the motivations, attitudes, beliefs, and practices of consumers and food vendors. We recommend EatSafe consider the following lessons emerging from this document in the design of its interventions:

- There is no one-size-fits-all intervention that can be used as a blueprint for mitigating foodborne zoonoses in informal markets in LMICs. Understanding the site-specific cultural, social, and economic factors is needed to support tailored intervention designs.
- Actors at informal markets lack knowledge on foodborne zoonoses, their existence, transmission pathways, and health implications. Values and beliefs regarding safe food systems vary among actors and geographical regions and are much more resistant to change.
- Educational interventions can improve the knowledge of farmers, vendors, and consumers but knowledge alone does not bring about a reduction in foodborne zoonoses risk;
- Appropriate infrastructural improvements are also required to support the adoption and maintenance of improved food safety behaviours.
- Educational/awareness interventions to mitigate foodborne zoonoses should adopt a Participatory Action Learning approach; if this is neglected, key drivers of behaviour may be misunderstood or not reflected in the intervention design, leading to their possible failure.
- Initiatives should not be one-off, but should have a sustainability mechanism built in so knowledge and skills can be refreshed. Blended learning approaches show promise. Interventions must be simple, comprehensible, compelling, and affordable.
- Risk based approaches to understand foodborne zoonoses pathways and health impacts are recommended but challenging to undertake in LMICs where the necessary metrics for risk analysis are missing.
- Aspects of the HACCP tool can be useful to systematically identify areas where contamination of food by foodborne zoonotic pathogens occurs, allowing for targeted intervention design.
- Strict regulatory approaches for informal markets or wet markets do not work and make already fragile food systems even more unstable. Participatory and voluntary approaches have gained more traction among market vendors in improving food safety standards.
- A One Health approach is highly recommended to mitigate foodborne zoonoses transmission in informal markets. Such an approach would create a more supportive environment for interventions, as has already proved useful in areas such as integrated disease surveillance, human and animal vaccination campaigns, and the control of antimicrobial resistance.

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