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Emerging infectious zoonotic diseases: The neglected role of food animals

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ABSTRACT

This paper compares the relative frequency of zoonotic disease emergence associated with food animals versus emergence from other animal sources and explores differences in disease characteristics and drivers of emergence between the two sources. It draws on a published compilation of 202 Emerging Infectious Zoonotic Disease (EIZD) events for the period 1940–2004. Of the 202 zoonotic EID events in the dataset, 74 (36.6%) were associated with animals kept for food production, which acted as reservoir for the zoonotic pathogen in 64 events and as intermediate / amplifying host in 8 events. Significant differences exist both in the characteristics of the causal agents and the drivers of emergence of zoonotic diseases from food animals and non-food animals. However, the prevailing policy debate on prevention, detection and control of EIZDs largely focuses on diseases of non-food animal origin (wildlife), neglecting the role of food animals. Policies and investments that ensure appropriate veterinary public health measures along and within food animal value chains are essential to mitigate the global risk of EIZDs, particularly in developing regions where the livestock sector is experiencing rapid growth and structural transformation.

1. Introduction

Globally, the number of infectious disease outbreaks affecting humans has increased significantly since 1980 [26] and new virus species affecting humans are being discovered at an average rate of over 3 per year [37]. At least 60% of human emerging infectious diseases (EIDs) are zoonotic, i.e. stem from non-human hosts, and zoonotic pathogens are twice as likely to be associated with emerging diseases than non-zoonotic pathogens [15,27]. Zoonotic pathogens emerge either from wildlife or from domesticated animals. In a seminal paper on "Global trends in emerging infectious diseases" covering the period from 1940 to 2004, Jones et al. *[15]* estimated that 72% of zoonotic EIDs (EIZDs) originated in wildlife. Woolhouse & Gowtage-Sequeria [36] identified changes in land use and agricultural practices and changes in human demographics and society as the two categories of drivers most frequently associated with the (re)emergence of human infectious diseases. The ranking of drivers across different categories of pathogen showed poor concordance, with one of the most notable differences being the greater importance of land use change and agricultural practices for zoonotic than for non-zoonotic diseases. Indeed, the transformation of the natural landscape promotes encroachment into wildlife habitats, thereby creating opportunities for closer and more frequent interactions between humans, livestock, wildlife and vectors, while the intensification of livestock farming, associated with increased animal numbers and density, facilitates disease transmission when effective management and biosecurity measures are not in place [14].

In response to major outbreaks of EIZDs linked to wildlife, such as SARS and Ebola, a substantial amount of resources is being devoted to the identification of wildlife reservoirs and associated emergence hotspots. The US Agency for International Development, for instance, has spent around USD170 million over 8 years to conduct viral discovery in wildlife hosts [2]. This trend is likely to be reinforced by the recent emergence of COVID-19 [41]. The current narrative on preventing the next pandemic ([3,6,16,29,34]; US [30]) stresses the role of wildlife in the emergence of human infectious diseases, while it appears to underappreciate the role food animals may play, despite the recognition that a considerable share of human diseases of evolutionary and historical significance originated in livestock [35]. The pathogen pool of food animals is itself not static but also constantly undergoing evolutionary changes. In swine, for example, a systematic review of publications between 1985 and 2010, found 173 new pathogen variants from 91 species, of which 73 species had not been previously described in pigs. One third of these new species was zoonotic and discovery of zoonotic species was more likely to occur in low- and middle-income than in high-income countries [12].

EIZDs are best prevented by policies and investments targeting the

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main source(s) and driver(s) of emergence. To provide decision-makers with information for policy and investment design that minimize the risk of EIZDs, this note compares the relative frequency of zoonotic disease emergence associated with food animals versus emergence from other animal sources and explores pathogen characteristics and drivers of emergence between the two sources of EIZDs.

2. Methods

The compilation of 335 EID events over the period 1940 to 2004 by Jones et al. [15] provides the basis for the analysis. This dataset was chosen, despite reports of more EIZDs since 2004, because it provides the most comprehensive supplementary information for each EI(*Z*)D event and because other authors have used it for subsequent analyses (e.g. [1,22,24]).

Zoonotic EID events in the dataset are classified as potentially associated with food animals (large and small ruminants, pigs, poultry, camels) if the pathogen has been found in the latter and comprise those where (i) food animals are known reservoirs (e.g. *M. bovis, B. melitensis*) or (ii) where food animals acted as temporarily amplifying host (e.g. RVF in Egypt, Nipah in Malaysia). Horses, dogs and wild exotic species consumed as food, such as pangolins or nonhuman primates, are not considered as food animals for the purpose of this analysis. The dataset also includes information on pathogen characteristics (e.g. taxonomy, mode of transmission) and surmised driver of emergence (e.g. land use change, change in human susceptibility).

3. Results

Of the total of 335 EID events identified by Jones et al., 202 (60.3%) were regarded as zoonotic by the authors. Of these 202 zoonotic EID events, 128 (63.4%) were not associated with food animals (they involved wildlife, pets/recreational animals, environmental sources), while in 74 (36.6%) events the pathogen could be associated with animals kept for food production. In 85.5% (64/74) of food animal associated zoonotic EID events, food animals were a known reservoir for the associated pathogen, while in 10.8% (8 events) (Alkhurma, Banna, CCHF, HPAI H5N1, JE, Menangle, Nipah, and RVF virus) food animals acted as amplifiers and ‘bridge’ hosts (the role of food animals was not clear in two events, 2.7%). Pathogen type, mode of transmission, drug resistance and surmised driver of emergence for the non-food animal and food animal associated EIZDs are displayed in Table 1.

Table 1
Pathogen characteristics and surmised driver of non-food animal associated ($n = 128$) and food animal associated ($n = 74$) EIZDs as reported by [15]

Pathogen characteristics and surmised driver	Non-food animal associated EIZD		Food animal associated EIZD	
	N	%	N	%
Pathogen type				
Bacteria/rickettsia	52	40.6	52	70.3
Virus	48	37.5	10	13.5
Other	28	21.9	12	16.2
Transmission				
Vector	51	39.8	10	13.5
No vector	77	60.2	64	86.5
Drug resistance				
Yes	7	5.5	11	14.9
No	121	94.6	63	85.1
Driver				
Human susceptibility	31	24.2	7	9.5
Land use change	30	23.4	4	5.4
Ag industry change	13	10.2	18	24.3
Food industry change	1	0.8	26	35.1
International travel & commerce	13	10.2	7	9.5
Climate & weather	9	7.0	0	0.0
Other	31	24.2	12	16.2

Of the non-food animal associated EIZDs, 40.6% were caused by bacteria/rickettsia, 37.5% by viruses, and 21.9% by protozoa, fungi or helminths. For the food animal associated EIZD pathogens, the respective figures were 70.3% bacteria/rickettsia, 13.5% viruses and 16.2% protozoa, fungi or helminths. The differences in frequency of pathogen type between non-food animal and food animal associated EIZDs is statistically highly significant (Chi square: 18.2, $p < 0.001$).

A large share (39.8%) of the non-food animal associated EIZD pathogens were transmitted by arthropods while only 13.5% of the food animal associated pathogens were vector-borne (Chi square: 15.4, $p < 0.001$). Transmission by arthropods was far more prominent in events where food animals acted as ‘bridge’ (62.5%, 5/8) than in events where food animals acted as reservoir host (7.8%, 5/64).

Drug resistance was significantly more prevalent in EIZD pathogens associated with food animals than in those from non-food animals (14.9% vs 5.5%, Chi square: 5.1, $p = 0.023$). For comparison, 39.1% (52/133) of non-zoonotic EID pathogens in Jones et al.’s dataset were drug resistant.

For non-food animal associated EIZDs, changes in human susceptibility (e.g. HIV-AIDS, immunosuppressive therapy) were the most frequently identified driver for emergence (24.2%) followed by land use change (LUC) (23.4%). LUC was the most frequent surmised driver for vector-borne EIZDs (39.2%%) while changes in human susceptibility was the surmised principal driver (33.7%) for non-vector-borne EIZDs associated with non-food animal sources. For food animal associated EIZDs, the main drivers associated with emergence by Jones et al. [15] were food industry changes, 35.1% (26/74), and agricultural industry changes, 24.3% (18/74), while LUC was only linked to 5.4% (4/74) of food animal associated emergence events (three of these four were vector-borne).

4. Discussion and conclusion

Even though the dataset used is not up-to-date and new diseases have emerged since 2004, the data provides a sufficiently large sample from which to draw conclusions that are not likely to substantially change by including diseases that have emerged over the past 15 years. However, replicating this analysis on a dataset that also includes most recent emerging infectious zoonozes, such as H1N1 and MERS, would provide additional insights into the role of food and non-food animals in the emerge of EIZDs.

A high proportion, over 36%, of EIZD events (identified by [15]) were associated with food animals and food animals were a known reservoir for the respective pathogen in 31.7% (64/202) of EIZD events. This is not surprising as, historically, about half of humanity’s established temperate diseases have been acquired from domestic livestock, because of their high local abundance and frequent contact with humans [35]. A recent analysis of virus-mammal interactions concludes that domesticated species were the most central species (after humans) in the entire mammal–virus association network [31]. The 5 most central positions in the network of all virus species were occupied by *H. sapiens*, *B. taurus*, *S. scrofa*, *O. aries*, and *C. lupus* (in order of descending centrality), i.e. included 3 mammal species kept for food production. Overall, the proportion of zoonotic viruses carried by domestic species was 1.8 times higher than in wildlife (idem).

Even though past trends do not necessarily predict the future with accuracy, population growth, increasing disposable incomes and progressive urbanization are anticipated to lead to major changes in global food animal industries in the coming decades, with a possible increase in the number of zoonotic viruses emerging from livestock, particularly in the developing world. Projected growth in demand for meat and milk to 2050 (from 2015) is approximately five times higher in low/middle-income countries (LMICs) than in high-income countries (HICs), with sub-Saharan Africa (SSA) accounting for around one third of LMIC demand growth [7]. Concomitant to uneven global growth in demand for meat and milk, growth of livestock industries will be substantially higher in the 'global South' with livestock numbers predicted to more than double in sub-Saharan Africa (SSA) (Table 2).

The ongoing rapid expansion and intensification of livestock industries in LMICs without incorporation of the stringent biosecurity measures and animal health / veterinary oversight that have helped maintain the health and productivity of large herds in industrialized countries significantly enhances the likelihood of zoonotic disease emergence from food animals. Even HICs with high levels of veterinary oversight of animal industries have experienced important outbreaks of food animal associated EIZDs such as the BSE/vCJD crisis in the UK in the 1980s or the 2007 to 2010 Q fever epidemic in Holland, both linked to industry changes [18,33].

While the current attention on EIZDs associated with wildlife is warranted, policy makers cannot afford to ignore the role of food animals in EIZD dynamics, particularly as pathogen characteristics and the relative importance of surmised drivers of emergence differ significantly between food and non-food animal associated EIZDs. The main drivers of food animal associated EIZDs are changes in agricultural practices at farm level and transformations of the food industries along the livestock value chain, from transporting through processing to retailing [15]. These two drivers play a minor role in the emergence of EIZDs from non-food animals, which are primarily associated with land use changes and changes in human susceptibility. By promoting land use change, food animal production may indirectly contribute to the emergence of non-food animal associated EIZDs.

Policies and investments to address EIZDs have long relied on responsive measures that aim to reduce the impact of a disease after its emergence through improved capacity and speed of outbreak detection and emergency control measures [22]. In the last decade, proactive measures have gained prominence, including multisectoral collaboration ('one health'), pathogen discovery, behavioral change and improved biosecurity along the food animal value chain [2,25,32]. Pike et al. [22] find that proactive policies and investments need to be only minimally effective in reducing EID risk to be worth implementing.

Given the agricultural and food animal industries are (to a large extent regulated) human activities, designing and implementing policies to mitigate the risk of food animal associated EIZD should be 'simpler' and probably more cost-effective than mitigation of EIZD risks stemming from wildlife. The World Bank [38] estimates that improving farm biosecurity in 139 LMICs would require an annual expenditure of between USD76 and 136 million (7.7% of all animal health expenditures), which is dwarfed by the historical costs of EIZDs of about USD6.9 billion/year. LMICs should thus prioritize the implementation of a minimum set of veterinary public health (VPH) measures in food animal production – such as animal vaccination, cleaning and disinfection and farm and market inspection – to reduce global pandemic risk. This holds particularly true for SSA, which is not only expected to undergo the most extensive changes in its livestock industries but is also the region with the lowest economic and institutional capacity to deal with EIZDs. SSA has the lowest per capita income among all world regions (PPP $ 3500 per year); the lowest per-capita health expenditure (PPP $ 200 per year); and the second lowest Country Policy and Institutional Assessment (CPIA) quality of public administration rating, an index of the extent to which governments are able to implement policies [40]. Growing trade volumes, increased national and international travel and migration, and high rates of urbanization, often associated with large informal urban settlements, vastly increase the potential spread and consequences of EIZDs.

Table 2
Projected 2015–2050 growth in demand for meat and milk (million metric tons, MMT) and in livestock numbers (million head, MH) for high-income countries (HICs), low/middle income countries (LMICs) and sub-Saharan Africa (SSA) [7].

Growth 2015–2050	HICs		LMICs		SSA	
Demand	MMT	%	MMT	%	MMT	%
Meat	21.5	21.1	108.2	50.3	41.1	233.5
Milk	30.5	12.6	174.8	39.3	56.7	141.4
Livestock populations	MH	%	MH	%	MH	%
Cattle	−4.7	−1.9	586.2	56.2	364.7	113.3
Pigs	31.2	12.1	158.1	20.7	69.1	181.5
Sheep & goats	7.7	9.1	681.4	55.7	517.1	125.0
Poultry	1029.1	19.9	9109.0	47.9	5057.2	301.5

A positive note is that existing policies and legislations on veterinary public health in LMICs, including in SSA, often recommend the adoption of 'basic' standards along the animal food value chains [8,9]. Their implementation, however, remains scattered and piecemeal [17,19]. In most circumstances, lack of financial and human resources makes it challenging to ensure compliance with the existing veterinary public health legislation. For example, in two of the wealthier counties of Kenya, Kiambu and Nairobi City County, each public animal health officer is supposed to provide services to 1635 and 570 livestock farms, respectively, with an average annual budget of USD 2.1 and 3.1 per livestock farm [10]. Given such resource scarcity, LMICs governments should adopt a market-based approach to facilitate compliance with veterinary public health legislation and minimize the risk of EIZD events along the food animal value chain. Such an approach should primarily target mid- to large scale operators and include a research and an institutional pillar.

While in many cases there are positive private returns to investments in veterinary public health measures, small scale food animal operators usually have few incentives to make such investment because livestock is only one of their many income generating activities and rarely contribute the largest share to their livelihoods [20,21]. Conversely, mid to large scale livestock operators have established a business around animals and are often willing to take any investment that improves the profitability of their enterprise [17,39]. In addition, mid and large-scale food animal enterprises are those that are growing and transforming more rapidly in LMICs, which could create novel and emerging public health threats [4,5,13,14].

In order to effectively target mid to large-scale animal food operators, it is necessary to generate in-country evidence that the adoption of basic veterinary public health practices is likely to improve the profitability and long-term sustainability of businesses along the animal food value chain [11,23,28]. Undeniably, in many circumstances the adoption of simple practices – such as using disinfectants and separating sick from healthy animals – is low-cost and, by significantly reducing the risk of pathogen introduction and spread, improves profitability. This evidence would allow animal health staff on the ground to utilize a business approach when providing services to mid and large-size livestock operators. In particular, animal health officers should not only assist farmers and other value chain actors in preventing, detecting and controlling animal diseases from a technical perspective, but also in improving the profitability and sustainability of their business, which involves the adoption of a core set of veterinary public health measures. In other words, investments in veterinary public health measures should not be presented as risk-reduction practices but as business practices that can reduce the cost / improve the revenue of the enterprise.

Overall, unless existing policies and legislations on veterinary public health along the animal food industry are properly enforced, the current global, regional and national investments to minimize the risk of EIZDs from non-food animal, may generate little returns as over one third of EIZDs events are associated with animals kept for food production.

Authors' statement

MJO: conceptualization and preparing the first draft manuscript. MJO and UPC: writing reviews and editing. UPC: addressing the comments of reviewers and editors. Both authors approved the submitted version.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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