FAO/WHO Project Report

Improving Food Safety in Meat Value Chains in Kenya

SAMUEL KARIUKI,[1]* ROBERT ONSARE,[1] JOYCE MWITURIA,[1] RONALD NG'ETICH,[1] CYNTHIA NAFULA,[1] KENNETH KARIMI,[1] PURITY KARIMI,[1] FRIDAH NJERUH,[1] PATRICK IRUNGU[2] AND ERIC MITEMA[3]

[1]Centre for Microbiology Research, KEMRI, Nairobi, Kenya
[2]Dept. of Agriculture Economics, University of Nairobi, Nairobi, Kenya
[4]Dept. of Pharmacology, Toxicology and Public Health, University of Nairobi, Nairobi, Kenya
[3]Dept. Food Safety, Zoonoses & Foodborne Diseases, University of Nairobi, Nairobi, Kenya

ABSTRACT

Meat production contributes significantly to household food security and domestic and export income in Kenya; thus, managing the safety of meat is essential to protect public health and ensure market access and economic benefit for the country. The management of microbiological risks associated with meat should be based on scientific assessment of health risks, the identification of the critical points through the chain where microbiological contamination occurs and quantitatively increases and at which prevention and control measures can be most effectively applied to protect public health. This is a report of a collaborative study in Kenya aimed to provide risk managers with preliminary data on which to base a risk-based food safety program by undertaking value chain analyses, a microbiological survey of food production and human illness, observations and questionnaires and by bringing stakeholders together to share knowledge and develop management and policy directions. Foodborne bacterial zoonoses and antimicrobial resistance were key hazards for which risk management strategies were required through the value chain, taking into account the diversity of production, slaughter and retail practices and coupled with surveillance and monitoring of disease, food contamination, Antimicrobial Resistance (AMR) and antimicrobial usage.

INTRODUCTION

Meat is an important source of protein in the human diet and it is projected that world human meat consumption will rise with increasing populations and consumption per person will increase linked with increasing personal income *(8)*. However, while meat is a rich nutrient source it can also be a potential vehicle for the transmission of human foodborne illness *(6)*. The meatborne microbial hazards of importance, their prevalence, and the risks posed to public health have changed over time and at any point in time vary in different geographical and socio-economic settings. These changes and differences have been associated with emerging pathogens, changes in the primary production and processing of meat, the implementation of food safety risk management strategies, and changes in social and economic factors. Bacterial foodborne zoonoses are among the priority microbial meatborne hazards, and the carriage of antimicrobial resistance (AMR) by these bacteria or other bacterial flora of meat adds a further dimension to their importance. The Codex Alimentarius Commission (CAC) provides guidelines for the control of meatborne hazards *(6)* and foodborne AMR bacteria *(4)* that are based on a risk-based approach where control measures are applied at those points in the meat supply chain where they will have the greatest impact on lowering the final risk to the consumer *(5)*.

In Kenya meat production, including chicken, beef and pork, contributes significantly to household nutrition, community food security and income, and the national economy with growth projected to move with world trends *(11)*. Supply of safe meat is essential both for the protection of public health and for market access opportunities regionally and internationally. While there is a legislative framework governing the food supply that includes reference to food safety, past programs were not specifically based on public health risk reduction with supportive science and an evidence base as recommended now by the CAC *(5)*. The CAC risk management framework for governments is structured, beginning with preliminary activities such as identifying the food safety problems and establishing a risk profile *(5)*. In Kenya, there

*Author for correspondence: Phone: +254.202.718247; E-mail: skariuki@kemri.org; P.O. Box 43640-00100, Nairobi, Kenya

is an overall paucity of data available to risk managers to support these activities. There is a lack of quantitative data to assess hygiene and pathogen presence along the food continuum and risk factors. Equally, there is no effective system for integrated surveillance of human foodborne diseases or for monitoring foodborne pathogens and AMR, and no monitoring of antimicrobial usage in human and veterinary medicine.

Various *Salmonella enterica* serotypes and *Campylobacter* spp. are the most common meatborne bacterial pathogens in many developed countries *(22).* While Typhi is the more common human *Salmonella* serotype reported in Kenya, non-typhoid salmonellae (NTS) are also common in adults and young children *(1, 3, 9, 18).* Among the NTS, serotype Typhimurium is an important cause of morbidity and mortality, causing not only gastroenteric but also invasive infections, and some strains are resistant to antibiotics commonly used in human medicine *(2, 16, 18).* Poor sanitation, hygiene and inadequate water supplies contribute to salmonellosis transmission, particularly in slum areas, and foodborne transmission could occur. NTS have been detected in animals slaughtered locally and meat is a potential food vehicle *(14, 21). Campylobacter* spp. have similarly been isolated from Kenyan children hospitalized with diarrhoea also causing mortalities *(17).* While transmission routes are not clear for these infections, *Campylobacter* spp. have been detected in a variety of meat animals at slaughter *(19).*

In this paper, we report on a collaborative project undertaken to support preliminary microbiological risk management activities in the meat supply chains in Kenya based on the CAC approach *(4, 5).* At the same time, supportive data for the implementation of integrated national foodborne disease surveillance and monitoring program and a baseline for benchmarking future food safety risk mitigation measures were collected. Technical and financial support for the project were provided by the Food and Agriculture Organisation of the United Nations (FAO), and the World Health Organization (WHO) and the Kenya Medical Research Institute (KEMRI) in Nairobi, Kenya.

PROJECT APPROACH

Meat value chain, inputs and food safety regulation

Value chain analyses for beef and chicken were conducted to describe activities required to bring meat products from production to consumption including the magnitude of value added at each step, performance drivers, product flow, chain actors and their interrelationships and external partnerships *(10, 20).* A previous pig meat value chain analysis was used for pork *(7).* Details of regulations relevant to the chains were collected from national authorities, and key informant interviews on food safety regulation, surveillance, monitoring and enforcement were held with stakeholders, e.g., government veterinary and health officials, researchers in universities and the International Livestock Institute (ILI), and some NGOs and private sector representatives. A pilot study was conducted in Nairobi to identify supply chain characteristics that could impact safety and to plan the microbiological analyses. Four regions, Mombasa, Nairobi, Thika and Kisumu County, were chosen to represent the main socio-economic and infrastructure characteristics, namely farm size, whether abattoirs had export and/or domestic markets, level of abattoir infrastructure, and community location of retail outlets.

Bacterial hazards of concern that may be transmitted via meat

No human disease surveillance for enteric pathogens was available from which to define the health concerns from meatborne bacterial pathogens. KEMRI is a major Kenyan medical research organisation, diagnostic facility and reference centre for typing enteric pathogens; therefore, their experience and research and relevant literature were used. NTS *(12, 13, 17, 18), Campylobacter* spp. *(16)* and AMR *(13, 15, 21)* were identified as significant microbial human health concerns that could be transmitted by meat and that had been detected in meat animals *(14, 15, 21).* A survey of diarrhoeal pathogens and AMR among children under 5 years old presenting with diarrhoea at five hospital clinics in the area of the meat supply chains was conducted to provide supporting evidence.

Pathogen–product pathways and hygiene, and antimicrobial resistance and usage

The prevalence of NTS and *Campylobacter* spp., indicators of hygiene and process control (total *E. coli* counts) and AMR of pathogens and indicators (*E. coli* and *Enterococcus* spp.) were determined along the product pathways at key points (on farms, abattoirs, and retail outlets) selected to represent the socio-economic and infrastructure variables, where applicable, and in the 4 regions identified in the value chain analysis, over 12 months, including the dry and rainy seasons ***(Table 1).*** Unstructured observations and descriptions of the sites were recorded.

To gain insight into on-farm antimicrobial usage and farmers' perceptions, knowledge and practices that may drive the use and emergence of drug resistance, questionnaires were administered to 200 small-scale farmers keeping mixed livestock, predominantly poultry. Discussions were conducted with private sector institutions, including small farmer groups and/or NGOs involved in the poultry sector.

Stakeholder engagement

The proposed end users of the project outputs included policymakers and food chain actors so it was essential to engage with them, encourage input of their knowledge, experience, gain their support, and to foster ownership. Three workshops were conducted: first, the importance of food safety and AMR control and the principles of a risk based management approach; second, sharing and feedback on study findings, and defining priority actions and policy options; and finally, defining appropriate interventions at national and regional levels and mapping the way forward for national and regional policies. Representatives from other African countries, especially neighbouring countries, and East African community (EAC) representatives involved in food safety management and Codex activities were included as observers, to share in and refine the process and encourage uptake of the principles involved. The EAC participation highlights the importance of policies harmonization and regional integration of processes addressing foodborne pathogen contamination and AMR.

MAIN PROJECT FINDINGS AND OBSERVATIONS

Meat value chain, inputs and food safety regulation

The value chain analysis provided a summary of the importance of the meat industries to Kenya, the chain dynamics and actors, and allowed planning of the microbiological investigation. Kenya is both an importer and exporter of livestock and livestock products. Poultry meat is imported from the European Union (EU) and African countries and is exported mainly to African countries and the Middle East. Kenya imports live beef cattle for breeding, meat and edible offals, most commonly from Austria and China, and trade has recently recovered following a period of political instability. Kenya exports its own live animals, edible offals and beef mainly to African countries and the Middle East. The export value from the overall beef value chain has increased five-fold between 2005 and 2010. Pork is both exported and imported, with one major industrial/integrated commercial producer, and the domestic market has dependencies on the tourism industry. Poultry production ranges from small-scale village or backyard production to integrated industrial production. The small producers are subject to high incidences of poultry diseases, diseconomies of size and scale, lack of market competitiveness, weak technical capacity, lack of market information and value adding, in contrast to industrial establishments driven by international market access requirements that include food safety. There are three beef production systems: extensive pasture, dairy and commercial ranching. The supply chain is complex, with many "middlemen" and markets. Pigs are produced in commercial and traditional/backyard systems. Slaughtering of cattle and pigs is carried out at large commercial abattoirs (200 animals/day), at small-scale establishments with minimal facilities (~50–70 animals/day) operated by municipal councils or cooperative groups, or at simple concrete slaughter slabs (~2–5 animals/day), unprotected or shaded or in the open, with hand- carried water only. Animals are slaughtered according to the prevailing customs/traditions and religious beliefs of the people. Meat is retailed through outlets with increasing levels of facilities and infrastructure and were broadly classified, using local terminology as: low (slum areas), middle (small urban shopping centres) and high income (up-market residential).

More than 22 Acts of Parliament governing food safety were identified. These were legislated within different government organizations, with individual mandates presenting difficulties in coordination, priority setting and implementation. Although food safety laws exist, the implementation was generally observed to be weak, mainly due to lack of clear assignment of roles and responsibilities in enforcing the legislation. Multiple overlapping regulatory and certification agencies (e.g., Departments of Fisheries, Veterinary Services, Public Health and Sanitation) resulted in increased compliance costs, fragmented surveillance, enforcement failure and lack of a through chain approach. For example, comprehensive standards were applied to feed for poultry though not pigs, many of which scavenge, or for beef cattle, mainly produced under traditional (pastoral) and ranching production systems on natural pastures. At retail, the presence of informal food outlets and markets provided challenges for effectiveness of surveillance and enforcement of existing food safety standards.

Bacterial hazards of concern that may be transmitted in meat

Feacal samples from 632 children with diarrhoea at city, rural and slum area hospitals in the supply chain areas were collected. NTS, *Shigella* and *Campylobacter* spp. were detected in 5%, 8% and 12% of the samples, respectively, and AMR, as described later in this paper, was common (detailed results to be published elsewhere).

Hygiene and pathogen contamination along the meat chains

Food safety and hygiene observations and almost 5,000 samples were collected in a prospective survey of the meat chains ***(Table 1).*** The detailed survey results, pathogen and AMR studies will be published elsewhere; significant findings are summarised here. Microbial contamination varied between meat species and was dynamic along their supply chains. *Campylobacter* spp. (mainly *C. jejuni*) were predominant in poultry and in chicken meat, detected in almost half of the samples overall. The prevalence of *Campylobacter* spp. in chickens increased from small to large farm holdings in contrast with NTS ***(Fig. 1).*** NTS were detected on chicken and pork, more frequently than on beef, and from effluent at the abattoirs.

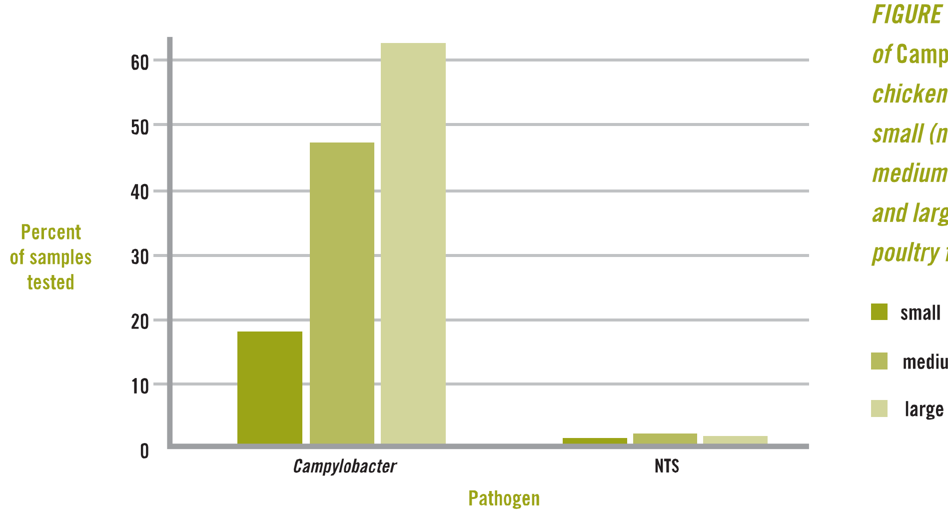

FIGURE 1. Detection rates of* Campylobacter spp. *among chicken feces from small (n = 1,850 samples), medium (n = 871 samples) and large (n = 607 samples) poultry farms in Kenya.

TABLE 1. Pathogen and AMR survey plan of the meat food chains and human diarrhoeal cases in children (< 5 yr) conducted over a 12-month period in Kenya

POINT IN CHAIN	FEATURES	SAMPLING PLAN	NUMBER SAMPLES	MICROBIOLOGICAL ANALYSES
On farm	Small, medium, large	Faeces (rectal swabs) stratified sampling of every 10th farm	320	*S. enterica, Campylobacter* spp.: isolation, AMR* *E. coli*, *Enterococcus* spp.: isolation, AMR
Abattoirs	Slaughter slab, small – medium, commercial	Rectal swabs pre-slaughter; carcasse swabs post-slaughter before chilling where chilling occurred; 10 animals/day/visit, every 2nd or 3rd animal depending on number slaughtered	4,816	*S. enterica*, *Campylobacter* spp.: isolation *Campylobacter* spp.: enumeration on chicken *E. coli* enumeration for hygiene assessment *E. coli*, *Enterococcus* spp.: isolation, AMR
Retail	Low, middle, high class	100 g retail meat purchased; stratified cross-sectional survey including every 5th outlet	800	*S. enterica*, *Campylobacter* spp.: isolation, AMR *Campylobacter* spp.: enumeration on chicken *E. coli* enumeration for hygiene assessment *E. coli*, *Enterococcus* spp.: isolation, AMR
Abattoir effluent	Beginning, mid-way, end of slaughtering day	Effluent sampled in wet and dry season, respectively	82	*S. enterica*, *Campylobacter* spp.: isolation AMR
Patients at clinics or hospital	Outpatient < 5 yr with diarrhoea: 2 Nairobi, 1 provincial, 2 coastal areas	Faeces	632	*S. enterica*, *Campylobacter* spp., *E. coli*: isolation, AMR

***AMR – resistance patterns for classes of antimicrobials commonly available for farmers and patients in Kenya were tested: tetracyclines, chloramphenicol, sulphonamides, beta-lactams and quinolones.**

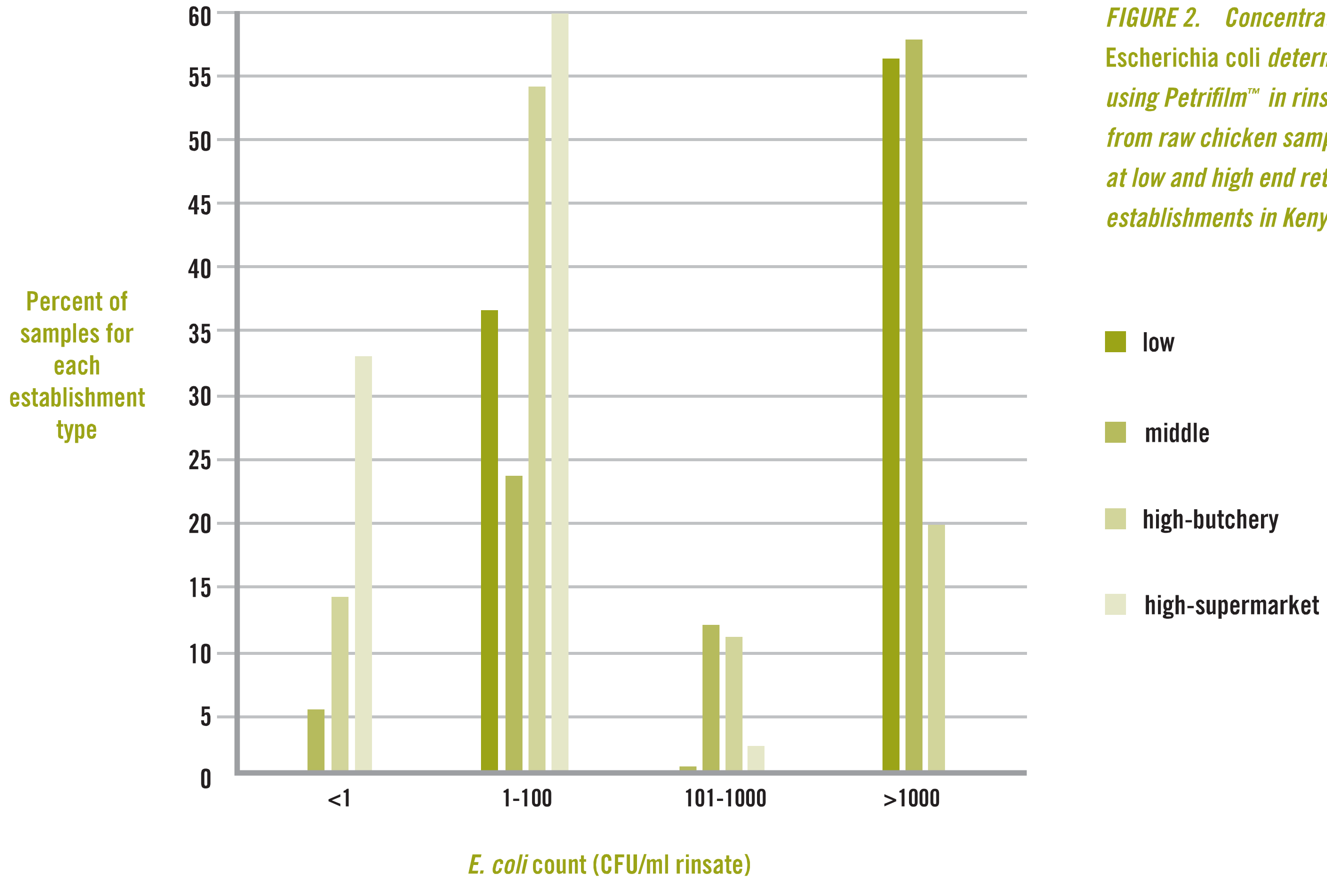

FIGURE 2. Concentrations of* Escherichia coli *determined using Petrifilm™ in rinsate from raw chicken sampled at low and high end retail establishments in Kenya.

Based on presence and counts of *E. coli* on carcasses post-slaughter, the processing hygiene performance was significantly compromised and variable at the small abattoirs and slaughter slabs and chicken markets. Poor hygiene practices, extensive manual handling and limited worker skills, poor infrastructure, and lack of quality and quantity of water were observed as common features of these sites. Pre-and post-mortem inspection of animal health was undertaken at smaller works, although a public health risk-based approach to food safety control was lacking. In contrast, the commercial establishments had few carcasses contaminated and then at low levels. Typically they had higher and faster throughputs and had greatly improved infrastructure, they were operating under HACCP based food safety programs and hygiene prerequisites, and their performance was incentivized by their need to gain market access.

In retailed raw meats, chicken at high end butcheries and supermarkets, delivered from commercial suppliers and serving higher income customers, overall had the lowest levels of *E. coli* contamination compared with chicken at markets slaughtered on site ***(Fig. 2).*** Mean counts on beef were higher at retail (0.2 $\log_{10}$ CFU /cm^2) than post-slaughter (0.03 $\log_{10}$ CFU/cm^2). Carcasses from small establishments were observed being transported in crowded, unrefrigerated trucks, or portioned meat and offals transported at ambient temperatures in non-insulated metal bins on the back of motorbikes. This meat is exposed to human handling during various trade transactions post-slaughter.

Antimicrobial use and resistance in isolates from diarrheal patients and the meat chains

Antimicrobial agents were regularly used on farms with oxytetracycline most commonly used among small scale poultry farmers and others included fluoroquinolones (norfloxacin and enrofloxacin), erythromycin, sulphonamides and co-trimoxazole. Antimicrobials were readily available and mostly purchased over the counter or from animal health assistants, and fewer than 20% of farmers understood the public health risks of AMR associated with inappropriate antibiotic use. There was poor appreciation of preventative animal health and farm hygiene practices as safer and more economical alternatives. Veterinary drug quality was identified by farmers as an issue, as a third were dissatisfied with available products, and approximately a third of the drugs failed quality tests carried out by the National Quality Control Laboratory. About half of farmers kept records of livestock treatments, and two-thirds said they understood the importance of complying with pre-slaughter withdrawal periods for antibiotics.

Overall AMR among the pathogens and indicators tested was highest in poultry isolates followed by those from pigs and cattle, probably reflecting the more intensive poultry farming and higher levels of antimicrobial usage observed. The animal and meat isolates were commonly resistant to ampicillin, tetracycline, co-trimoxazole and streptomycin, and multi-resistance to up to six antimicrobials was detected. The AMR range was broader among poultry and chicken meat isolates, with notable additional resistance to quinolones and third-generation cephalosporins critically important in human medicine. There was a trend for increased AMR prevalence and multi-resistance among isolates from commercial abattoirs sourcing chickens from medium and large scale commercial farms. Tetracycline resistance was most common along chains beginning with small scale farms, correlating with farmers commonly reporting its use. *Campylobacter* spp. isolates from chicken carcasses were resistant, albeit at low levels, to ciprofloxacin, and *Enterococcus* spp. were resistant to vancomycin, that requires follow up to determine the health risk. AMR in *E. coli* and NTS from pigs also included quinolones and third-generation cephalosporins, and nearly a third were multi-drug resistant to the most common antibiotics used. Differences in AMR patterns were observed between isolates from beef carcasses at the abattoir and those from retail beef in some supply chains, suggesting the possibility of the introduction of contamination from food handlers and the environment in that setting.

The AMR patterns of *E. coli* isolated from children < 5 yr. at outpatient clinics in the meat chain study areas reflected the commonly used antimicrobials in human medicine, including ampicillin, co-trimoxazole, streptomycin and amoxicillin-clavulanic acid with lower levels of resistance to third- generation cephalosporins and ciprofloxacin. Generally, AMR and multi-resistance were higher in isolates from children than from the meat chain, except for cotrimoxazole and tetracycline resistance prevalences in poultry and pigs that were comparable. The prevalence of AMR among *E. coli* was significantly higher in urban health facilities than a rural health facility. Highest-resistance levels were recorded at a main public primary care facility, where almost a third of isolates from this hospital had multi-resistance to six or more antimicrobials and 6% to nine antimicrobials. The community around the rural health center had less access to antimicrobials, and other factors such as exposure to animals, consumption patterns of meat and meat products, and hygiene. These variables need to be considered in further investigation of the role of meatborne AMR transmission.

DISCUSSION AND CONCLUSIONS

The primary objective of food safety risk management is the protection of the health of consumers *(5)*. A structured approach to risk management recommended to national governments by Codex includes several steps including: preliminary risk management activities, evaluation of options, implementation, monitoring and review of the decisions. The preliminary activities in this context include: identification of a food safety problem; establishment of a risk profile; ranking of hazards for risk assessment and risk management priority; establishment of a risk assessment policy; commissioning of the risk assessment, and consideration of the results *(4, 5)*. In this project, preliminary food safety risk management activities were undertaken for the poultry, pig and beef meat value chains in Kenya. From prior research and stakeholder discussions it was decided to focus on zoonotic bacterial foodborne hazards and AMR and the activities undertaken included microbiological studies to help define the health issue linked with these hazards and provide elements of a risk profile.

A first step in this study was to conduct value chain analyses that provided valuable information in a systematic format. The increasing importance of the meat industry for the Kenyan economy and society, and thus a need for food safety risk management, was identified. It provided a detailed description of the farm to table continuum for each meat species, the supply pathways, the value added at each stage and the actors involved. Using this information it was possible to design the hazard study and to choose the key chain points and variables at each point that may impact on food safety risk factors and risk management. For example, the different types of production systems, different slaughter capabilities and infrastructure, and different retail outlet locations were defined, and representative regional areas were chosen. Although not included here, further information, such as food consumption patterns and typical meat dishes consumed and their features that would impact on food safety (e.g., cooking methods) were described that would be needed by risk managers in ongoing activity such as a more detailed risk profile and assessments, leading to practical implementation of recommendations to improve safety along the meat value chain.

The surveys of the prevalence of pathogens and AMR along the meat chains and in diarrheal stools of children in the retail distribution areas confirmed the public health concern for the presence of these hazards and of AMR to antimicrobials, including those critically important in human medicine (fluoroquinolones and third-generation cephalosporins) in both human and animal sector. Commonality was observed in the AMR in the same bacterial species from both sources although the level of multi-resistance and incidence was higher for the human isolates. Meat may be just one transmission vehicle for these hazards and this does not provide evidence of a direct causal relationship; however, it provides the direction for further work to define the epidemiological relationships and flags the need for urgent proactive risk management measures. From the survey results also, the major points in the chain where hazards are introduced and practices with the potential to influence risk were identified and indicated the need for a through chain risk management action plan including all stakeholders.

Slaughter at small-scale and slab abattoirs and at retail chicken markets had much poorer hygiene performance and greater potential to transfer feacal pathogens to carcasses than the larger establishments. While this may have been expected from observations, the survey provided scientific evidence of the differences and revealed the inconsistent performance at small low throughput establishments in different locations. A number of other factors characteristic of different establishments were identified for evaluation by risk managers in determining effective management options, e.g., infrastructure, water supplies and effluent disposal, skill level, food safety programs, and customer drivers such as export or domestic retail. Mapping the contamination levels to retail sites provided more evidence of greater concern for poultry and pork than beef and that those low-end outlets were a priority concern. For beef, increased contamination levels and some differences in AMR patterns was detected between post-slaughter and retail. This suggested the introduction of further contamination; cross-contamination and/or bacterial growth during meat transport, poor retail handling, and the need for further investigation of the cold chain and hygiene of premises, tools and food handlers. The qualitative and quantitative analyses were useful tools for illustration of the dynamics of bacterial contamination at stakeholder workshops, a concept that is difficult to grasp among those with no relevant training.

The on-farm antimicrobial usage and AMR surveys highlighted significant differences among the meat chains. The on-farm studies provided evidence for the critical need to educate the small scale farmers (especially poultry farmers) on prudent antimicrobial use, de-emphasizing the use of antibiotics for treatment of otherwise preventable hygiene-related diseases and emphasising the economic and market access advantage of prudent use. Policy development is required for all production systems, regardless of size, on the use of antimicrobials critical for human health. A comparable study of antimicrobial usage and the outpatients surveyed was not performed; however, the AMR among the human isolates provided evidence supporting the need for urgent action for AMR control in the health sector also.

The review of existing national policies and legislations pertaining to meat food safety management, current implementation and compliance revealed a fragmented system. In workshops and policy setting discussions, the need for harmonization of national food safety policies and legislations based on Codex principles and a One Health approach was agreed. The inclusion of other members of the EAC proved beneficial, as it was further agreed this was a priority in the broader EAC. Similarly, additional supporting activities were identified that should also ideally be harmonized within the EAC. These included: national and regional steering committees to harmonise and maximise food and foodborne disease monitoring and surveillance; inspection programs and training to address emerging issues such as use of antimicrobials in animal food production; capacity-building through participation in both the WHO Foodborne Disease Burden Epidemiology Reference Group (FERG) program and the Global Foodborne Infection Networks (GFN) that promote integrated, laboratory based surveillance, and inter-sectoral collaboration among human health, veterinary and food-related disciplines; improved laboratory infrastructure and training; and harmonization of laboratory standards and methods.

A significant amount of information to support risk managers was generated in this project, relating to important zoonotic bacterial hazards in the beef, pork and chicken value chains in Kenya, using a systematic approach as guided by Codex *(4, 5, 6).* The project provided a mechanism for dialogue among value chain actors and an illustration of the need for food safety management as well as AMR control in human medicine. The project outputs can be applied directly and also be used to direct further investigation. For the food sector, these included a baseline of pathogen contamination and hygiene performance, AMR and antimicrobial usage, along the continuum from animal production to retail from which risk managers can build their risk management, monitoring and surveillance programs and also the trade, economic and social environment in which risk management options have to be decided and implemented.

ACKNOWLEDGMENTS

The authors thank the FAO and WHO for financial and personnel contributions to the project, the support of KEMRI as the host institution, and to the Government Agencies of Kenya and other African nations and meat value chain stakeholders who contributed. In particular, thanks go to Dr. Vittorio Fattori and Dr. Patrick Otto of the Food and Agriculture Organization, Rome, Italy, Dr. Awa Aiidara-Kane, World Health Organization, Geneva, Switzerland and Dr. Patricia Desmarchelier, FAO Food Safety Consultant, Brisbane, Australia.

REFERENCES

1. Berkley, J. A., B. S. Lowe, I. Mwangi, T. Williams, E. Bauni, S. Mwarumba, C. Ngetsa, M. P. E. Slack, S. Njenga, C. A. Hart, K. Maitland, M. Englis, K. Mars, and J. A. G. Scott. 2005. Bacteremia among children admitted to a rural hospital in Kenya. *New Engl. J. Med.* 352:39–47.

2. Breiman, R. F., L. Cosmas, H. Njuguna, A. Audi, B. Olack, J. B. Ochieng, N. Wamola, G. M. Bigogo, G. Awiti, C. W. Tabu, H. Burke, J. Williamson, J. O. Oundo, E. D. Mintz, and D. R. Feikin. 2012. Population-based incidence of typhoid fever in an urban informal settlement and a rural area in Kenya: implications for typhoid vaccine use in Africa. *PLoS One.* 7:e29119.

3. Brent, A. J., I. Ahmed, M. Ndiritu, P. Lewa, C. Ngetsa, B. Lowe, E. Bauni, M. English, I. A. Berley, and J. A. G. Scott. 2006. Incidence of clinically significant bacteraemia in children who present to hospital in Kenya: community-based observational study. *Lancet.* 367:482–488.

4. Codex Alimentarius Commission (CAC). 2011. Guidelines for risk analysis of foodborne antimicrobial resistance. CAC/GL 77–2011.

5. Codex Alimentarius Commission (CAC). 2007. Working principles for risk analysis for food safety for application by governments. CA/GL 62–2007.

6. Codex Alimentarius Commission (CAC). 2005. Code of hygienic practice for meat, CAC/RCP 58–2005.

7. FAO. 2012. Pig Sector Kenya. FAO Animal Production and Health Livestock Country Reviews. No. 3. Rome.

8. FAO. 2011. World Livestock 2011. Livestock in food security in FAO, Rome.

9. Gordon, M. A., S. M. Graham, A. L. Walsh, L. Wilson, A. Phiri, E. Molyneux, E. E. Zijlstra, R. S. Heyderman, C. A. Hart, and M. E. Molyneux. 2008. Epidemics of invasive *Salmonella enterica* serovar Enteritidis and *S. enterica* serovar Typhimurium infection associated with multidrug resistance among adults and children in Malawi. *Clin. Infect. Dis.* 46:963–969.

10. Hellin, J., and M. Meijer. 2006. Guidelines for value chain analysis FAO. Rome.

11. Irungu, P., and T. M. Kimani. 2008. Contribution of the livestock sector to Kenya's GDP Nairobi: Agricultural Sector Coordination Unit (ASCU), Kilimo House, Nairobi.

12. Kariuki, S., G. Revathi, J. Kiiru, D. M. Mengo, J. Mwituria, J. Muyodi, A. Munyalo, Y. Y. Teo, K. E. Holt, R. A. Kingsley, and G. Dougan. 2010. Typhoid in Kenya is associated with a dominant multidrug-resistant *Salmonella enterica* serovar Typhi haplotype that is also widespread in Southeast Asia. *J. Clin. Microbiol.* 48:2171–2176.

13. Kariuki, S., G. Revathi, N. Kariuki, J. Kiiru, J. Mwituria, and C. Hart. 2006. Characterisation of community acquired non-typhoidal *Salmonella* from bacteraemia and diarrhoeal infections in children admitted to hospital in Nairobi, Kenya. *BMC Microbiol.* 6:101.

14. Kikuvi, G. M., J. N. Ombui, and E. S. Mitema. 2010. Serotypes and antimicrobial resistance profiles of *Salmonella* isolates from pigs at slaughter in Kenya. *J. Infect. Dev. Count.* 4:243–248.

15. Mitema, E.S., G.M. Kikuvi, H.C. Wegener, and K. Stohr. 2001. An assessment of antimicrobial consumption in food producing animals in Kenya. *J. Vet. Pharmacol.Ther.* 24:385–390.

16. Onyango, D., F. Machoni, R. Kakai, and E. N. Waindi. 2008. Multidrug resistance of *Salmonella enterica* serovars Typhi and Typhimurium isolated from clinical samples at two rural hospitals in Western Kenya. *J. Infect. Dev. Count.* 2:106–111.

17. O'Reilly, C. E., P. Jaron, B, Ochieng, A. Nyaquara, J.E. Tate, M. B. Parsons, C. A. Bopp, K. A. Williams, J. Vinjé, E. Blanton, K. A. Wannemuehler, J. Vulule, K. F. Laserson, R. F. Breiman, D. R. Feikin, M. A. Widdowson, and E. Mintz. 2012. Risk factors for death among children less than 5 years old hospitalized with diarrhea in rural Western Kenya, 2005–2007: A Cohort Study. *PLoS Med.* 9: e1001256.

18. Tabu, C., R. F. Breiman, B. Ochieng, B. Aura, L. Cosmas , A. Audi, B. Olack, G. Bigogo, J. R. Ongus, P. Fields, E. Mintz, D. Burton, J. Oundo, and D. R. Feikin. 2012. Differing burden and epidemiology of non-typhi *Salmonella* bacteremia in rural and urban Kenya, 2006–2009. *PLoS One.*7:e31237.

19. Turkson, P.K., K. J. Lindqvist, and G. Kapperud. 1988. Isolation of *Campylobacter* spp. and *Yersinia enterocolitica* from domestic animals and human patients in Kenya. *Acta Path. Microbiol. Immunol. Scand.* 96: 141–146.

20. van Melle, C., O. Coulibaly, and K. Hell. 2007. Agricultural value chain development in West Africa – Methodological framework and case study of mango in Benin.

21. Wesonga, S. M., G. M., Muluvi, P. O. Okemo and S. Kariuki. 2010. Antibiotic resistant *Salmonella* and *Escherichia coli* isolated from indigenous *Gallus domesticus* in Nairobi, Kenya. *East Afr. Med. J.* 87:205–210.

22. WHO. 2007. Food safety and foodborne illness. Fact Sheet No. 237. World Health Organization.