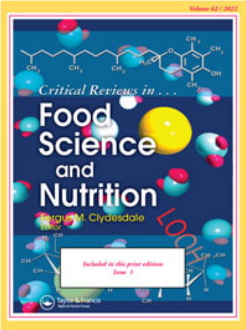

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REVIEW

Quantitative versus qualitative risk assessment of meat and its products: what is feasible for Sub-Saharan African countries?

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ABSTRACT

Prevalent risks in meat value-chains of sub-Saharan African (SSA) countries are increasingly attributed to microbial rather than chemical hazards. Resource constraints and lack of capacity has limited the utilization of risk assessment tools in the instituting of food controls to mitigate the risks. The review sought to bring to light the focus of risk assessment studies in SSA while generating evidence of feasible options to further the contribution of this component in risk mitigation. The informal street vending sector emerges as a priority in the meat value chain with a vendor population that are unwilling to abandon it. *Campylobacter* and *Staphylococcus aureus* are prevalent risks that have bedeviled this sector. However, limited risk assessment studies with capacity to inform proper food controls for the sector have been done. Evidence in place indicate that the incorporation of qualitative aspects in quantitative approaches serve as less-costly and effective ways of generating risk estimates. Limitations of capacity and gaps in epidemiological data are also circumvented. Considering that the street-vending sector is robust and its dynamics of operation are not fully in the picture of policy actors; incorporation of a participatory approach that combines qualitative and quantitative aspects of risk assessment is highly recommended.

KEYWORDS
Contamination; microbial; risk ranger; street-vending; food control; risk reduction

Introduction

Risk assessment (RA) is one of the three components of risk analysis and entails a process of estimation of probability and severity of an illness resulting from a hazard present in a specific commodity when consumed by a population. The evidence generated in risk assessment provides the scientific justification that guides risk management and risk communication (FAO and WHO 2006a). Risk assessment of human exposure to hazards adopts an integrative approach of establishing the probability and severity of human illness due to consumption of food with that specific hazard (Jeong et al. 2010). This whole process involves characterization of a product and its ingredients and raw materials at each stage of production process and value chain including handling and production equipment involved that may lead to occurrence of hazards (Chernukha, Kuznetsova, and Sysoy 2015). The sub-Saharan African (SSA) countries have limited use of this evidence-generating process as a basis to guide the food safety risk alleviation initiatives (FAO and WHO 2009a); this is despite global health indicators showing a great burden on the population due to risks resulting from food hazards (Fletcher, Stark, and Ellis 2011; Li et al. 2019).

Meat is considered one of the products that is of high risk of contamination thus lots of studies aimed at improving its safety have been done (Kim, Stein, and Pao 2015; Wahyuni, Vanany, and Ciptomulyono 2018; Zelalem et al. 2019). However, these surveillance studies have limited input in instituting proper food controls. Intake of meat entails consumption of both the unprocessed and processed products, subjected to various traditional or modern processing techniques (Larsson and Orsini 2014); with a variation in the intensity of risks posed due to processing and final product. The susceptibility of this delicacy to contaminants and the denouement of intake of these hazards necessitate the instituting of evidence-based controls to decipher and lower the risks posed. Less of evidence gathering approaches have been utilized to highlight the gaps in conducting these evidence generating studies in Africa. In deploying either the quantitative risk assessment (QRA), that generates a numeric risk estimate, or qualitative risk assessment, that ranks the likelihood of occurrence of the risk in various levels ranging from negligible to very high or on a relative scale (Snary et al. 2012); the purpose of the study and feasible risk management options informs the selection. Owing to major challenges in risk analysis and management, these studies have often been less utilized. Even with the challenges being experienced in the developing countries in terms of capacity and systems in place to conduct risk assessment in the meat industry, opportunities still exist that can be exploited to improve food safety situation of the region. This review of literature therefore focuses on the risk assessment of meat and its products, merits that would render incorporation of the combination of qualitative and quantitative aspects in risk assessment tenable in resource-

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limited settings and to propose future prospects for these settings in terms of using risk assessment tools to improve the food safety situation.

Meat consumption in Sub-Saharan Africa

Meat and its products are consumed in cuisines ranging from traditional to modern processing. Consumption of meat in all its kinds (beef, mutton, offal, lamb, goat meat, pork and poultry) is on the rise in the region (Chauvin, Mulangu, and Porto 2012; Desiere et al. 2018; Hrynick et al. 2019; Thomas et al. 2020). On the higher end, some countries within the region posted annual per capita consumption of $40.37, $34.91, $78.25, $105.53 and $29.34 for beef and veal; lamb, mutton and goat meat; pork; poultry; and other meats like the bushmeat, respectively (World Bank Group 2020). SSA countries had comparatively equal levels of consumption to countries in East Asia and Pacific, South Asia, Latin America and the Caribbean; closer equidistance in the dendogram (Figure 1), despite being the poorest region in the globe (Chauvin, Mulangu, and Porto 2012). This proves increasing affordability of meat among households in SSA. Additionally, the annual per capita consumption trends (in US dollar equivalence of 2010) of the various meats across the SSA countries were linked with that of various cereals and their products across the SSA countries (Figure 2): the higher the level of consumption of a cereal the higher that of meat and its products. Considering the increasing annual per capita consumption of cereals in SSA (Chauvin, Mulangu, and Porto 2012), that of meat and its products is expected to increase too.

With a comparison of the consumption at individual level; bovine, mutton and goat, poultry and pig meats are the four most consumed meats in SSA (Table 1). Save for southern Africa, bovine meat is the most consumed type across SSA for the period 2000–2013; poultry was the most consumed meat in southern Africa over the same period. With regional comparison, southern Africa consumed more than twice the levels in other regions: this is explained by the high meat production quantities in the region (FAOSTAT, 2020). Over the same period, an analysis documenting consumption across the region reported lower consumption levels in the rural areas (1–2 g per capita per day) as compared to the urban areas; the urban areas posted the highest intakes over the period with intake levels of up to >380 g per capita per day reported (Mensah et al. 2020). Bushmeat is famous in southern and western Africa (Friant et al. 2020); the consumption levels in Gabon were reported as high as 80 g per capita per day in the rural areas (Wilkie et al. 2005). However, little documentation of the intake levels of this meat in the specific regions do exist owing to the unstructured utilization and lack of formal marketing trends for it. Additionally, latest trends show decline in the intake of bushmeat as conversion to agriculture increases (Wilkie et al. 2016, 2005).

The consumption of meat in SSA is in various cuisines owing to adoption of modern and traditional processing. Intake of processed products such as beacon, ham and sausages is not as high as the unprocessed meat. Afshin et al. (2019) reported a lower intake of the processed products of <2.5 g per person per day than unprocessed meat (7–22 g per person per day) across SSA countries. Another study by Makita et al. (2017) reported an average daily intake of 611 g among consumers of roasted beef (*nyama choma*) in Tanzania whereas Ronald et al. (2016) reported an average intake of 133.25 ± 33.49 g of beef per person in a household survey in urban areas of Cameroon. Regional differences and consumer practices in the two areas explain the higher level of intake of the roasted meat than beef in the two areas. With a skewed analysis of the low income areas, a study in Kenya focusing on poultry consumption in informal settlements established that the mean weekly intake of poultry products was 140 g per person (Birgen et al. 2019). The increasing meat consumption has been attributed to various factors including increasing income (Desiere et al. 2018; Manyori et al. 2017), adoption or emergence of new recipes (Montcho et al. 2017), increased vending of affordable meats parts (Birgen et al. 2020; Toyomaki et al. 2011), changing lifestyles (Ogwok et al. 2014), and increased animal rearing (Roesel et al. 2019). Findings by Desiere et al. (2018) showed that doubling of income in SSA would result in 54–69% increase in meat consumption. An analysis of the meat market in Kenya, reported that chicken and beef (correlation coefficients of 0.728 and 0.712, respectively) were increasingly consumed with increasing income (Kenya Meat Trust 2019). Roesel et al. (2019) attributed the increasing consumption of pork in Uganda to increased rearing of pigs and value of pork as a food in festivities. With the perspectives of individual demographic characteristics brought into consideration, a study in Cameroon, established that with increasing age, the level of consumption of meat increased (Ronald et al. 2016). Those above 45 years consumed more than twice the daily intakes of children aged under 15 years. Therefore, the socio-demographic and economic characteristics of the consumers influence on the intensity of risks posed.

Attributable risks of consumption of meat and its products

The increasing consumption trend also come with additional public health concern mostly associated with food borne illnesses (Hiko, Asrat, and Zewde 2008; Zelalem et al. 2019). The meat supply chain has informal channels of vending that complements the formal ones in distribution and sales (Rani et al. 2017); however, there is little attention on food safety controls by the stakeholders in the former (Makinde et al. 2020). Moreover, consumers of these street-vended products at times consume undercooked meat exposing them further to danger (Mataragas, Skandamis, and Drosinos 2008). Further concerns arise from unhygienic preparation, handling and environmental conditions which aggravate the risks of food borne illnesses. The weak legislative framework to address the food safety frailties in the meat value chains in some SSA countries have resulted in increasing market share of meat from the informal slaughter

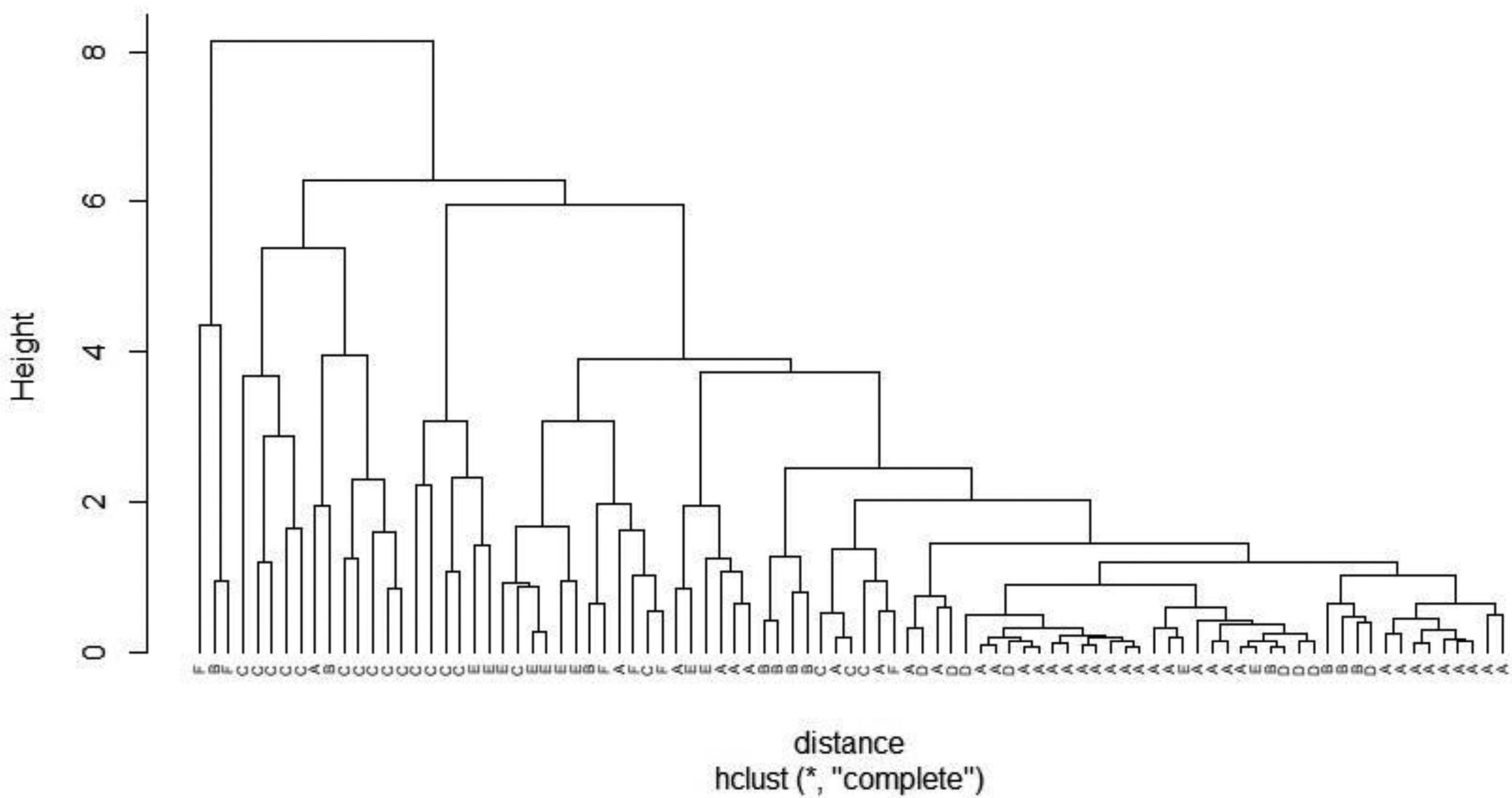

Figure 1. Cluster dendogram of annual global per capita consumption of meat and all its products.
The figure was generated using R statistical Package (R Core Team 2019) from the data obtained from World Bank Group (2020). Annual per capita intake was in US dollars equivalence of 2010. A, B, C, D, E and F represent sub-Saharan Africa, East Asia and Pacific, Eastern and Central Europe, South Asia, Latin America and the Caribbean and Middle East and North Africa regions, respectively.

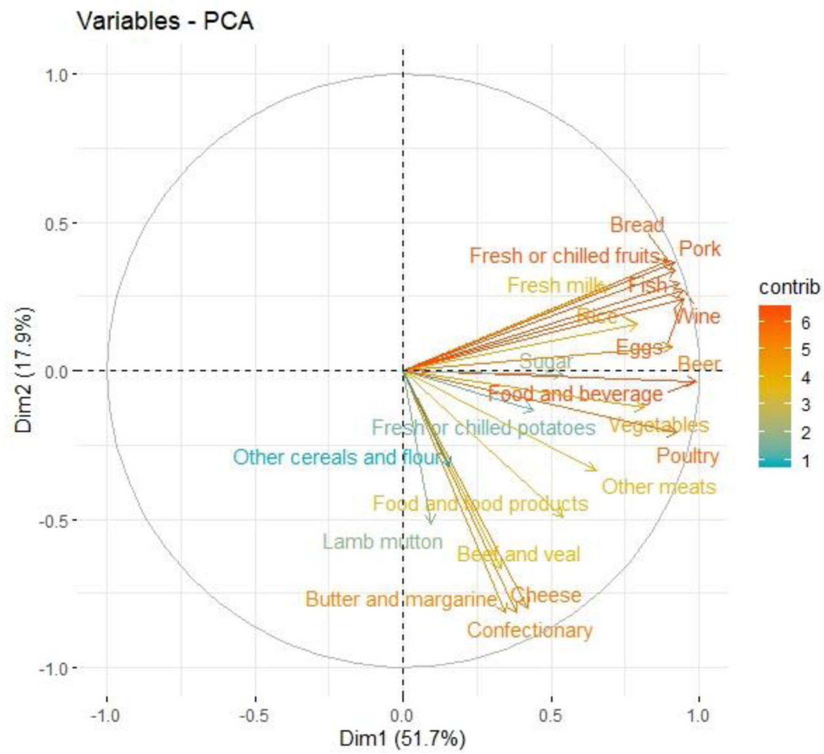

Figure 2. Comparison of annual per capita consumption trends of food items in sub-Saharan Africa.
Contrib- the contribution of a variables to the principle component 1 (Dim1) and 2 (Dim 2). The data used in the generation of this summary was obtained from World Bank Group (2020).

Table 1. Meat consumption trends in sub-Saharan Africa (g per capita per day).

		Year													
Region	Type of meat consumed	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Eastern Africa	Bovine Meat	2.12	2.03	2.14	2.13	2.1	2.22	2.28	2.23	2.28	2.24	2.29	2.24	2.07	2.05
	Mutton & Goat Meat	0.39	0.41	0.43	0.44	0.46	0.47	0.49	0.51	0.49	0.49	0.49	0.49	0.49	0.49
	Pigmeat	1.32	1.31	1.25	1.18	1.23	1.3	1.24	1.32	1.37	1.33	1.28	1.35	1.44	1.54
	Poultry Meat	0.37	0.41	0.41	0.4	0.39	0.4	0.38	0.39	0.39	0.41	0.43	0.43	0.42	0.39
Central Africa	Bovine Meat	2.79	2.74	2.66	2.58	2.51	2.58	2.49	2.52	2.59	2.5	2.25	2.29	2.31	2.12
	Mutton & Goat Meat	0.6	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.64	0.6	0.61	0.59	0.54	0.55
	Pigmeat	1.65	1.72	1.84	1.8	2.06	2.12	2.35	2.62	2.82	2.91	3	3.43	3.36	3.6
	Poultry Meat	0.58	0.52	0.76	0.97	0.99	0.91	1.06	1.11	1.22	1.18	1.47	1.77	1.69	1.78
Southern Africa	Bovine Meat	6.51	5.4	5.81	6.02	6.41	6.75	7.53	7.32	7.02	6.87	7.39	7.19	7.16	8.03
	Mutton & Goat Meat	2.11	1.68	1.47	1.57	1.6	1.59	1.71	1.46	1.77	1.74	1.62	1.51	1.54	1.92
	Pigmeat	2.41	2.49	2.38	3.01	3.35	3.36	3.26	4.56	5.62	6.01	4.06	4.12	4.2	3.87
	Poultry Meat	4.72	4.93	5.04	5.12	5.19	5.49	5.86	6.43	7.1	7.22	7.68	8.06	8.25	8.73
Western Africa	Bovine Meat	1.19	1.25	1.32	1.29	1.3	1.31	1.24	1.32	1.33	1.26	1.22	1.29	1.24	1.24
	Mutton & Goat Meat	0.67	0.7	0.7	0.7	0.71	0.71	0.72	0.73	0.72	0.73	0.73	0.73	0.73	0.71
	Pigmeat	0.84	0.85	0.94	0.9	0.9	0.92	0.95	0.94	0.94	0.95	0.95	0.98	0.98	0.99
	Poultry Meat	0.27	0.27	0.3	0.33	0.32	0.31	0.3	0.33	0.36	0.36	0.4	0.45	0.46	0.47
Africa*	Bovine Meat	2.29	2.14	2.25	2.26	2.3	2.39	2.46	2.45	2.43	2.39	2.4	2.39	2.36	2.39
	Mutton & Goat Meat	1.07	1.06	1.03	1.02	1.03	1.06	1.09	1.08	1.11	1.09	1.08	1.08	1.03	1.04
	Pigmeat	0.96	0.97	0.98	0.99	1.05	1.08	1.08	1.21	1.3	1.32	1.19	1.25	1.29	1.32
	Poultry Meat	0.98	1	1.03	1.07	1.07	1.08	1.12	1.19	1.25	1.28	1.38	1.42	1.46	1.51

*Represents the continental average consumption. Sourced from FAOSTAT (2020)

places (Rani et al. 2017). This poses additional risk concerns as the carcass is exposed to post-slaughter contamination through poor handling and temperature abuse. Coupled with proof of high incidences of meat-related foodborne illnesses (FAO and WHO 2009a), the risks in this sector need to be mitigated.

The concern in the intake of meat is not only acute, but also chronic especially among populations where meat compose a major component of the diet. Through exposure to red and processed meats and chemical constituents inherent in them, studies have established causative effect of various chronic diseases (Fiolet et al., 2018; Ruan et al. 2019). In as much as diet high in meat was established to have lower attributive risk as compared to other forms of diet, lower disability adjusted years (DALY's) and mortalities (Afshin et al. 2019);

consumption of red meat and its products have been shown to increase risks of cancer, cardiovascular and other degenerative diseases (Johnson 2017; Qian et al. 2020).

Risk assessment of meat and its products in Sub-Saharan Africa

Risk assessment is the scientific process that systematically evaluates food safety hazards that pose deleterious effects to health (Chizuru et al. 2004). The risk assessment models can adopt quantitative, semi-quantitative or qualitative approaches (Birgen et al. 2019; Manyori et al. 2017). The process entails four different steps namely hazard identification (the first step in risk assessment and entails qualitative elucidation of a hazard that is of public health importance (Makita et al. 2017)); hazard characterization (details the adverse effects resulting from exposure to a specific hazard, and entails establishing the dose-response relationship if the data is available (Chizuru et al. 2004; Toyomaki et al. 2011); exposure assessment (the qualitative and/or quantitative estimation of the probability of the consumption and amounts of hazard ingested from intake of a given quantity of food (FAO and WHO 2009b)); and risk characterization (the three steps are integrated to generate a risk estimate (Manyori et al. 2017)). Whereas to the consumers and majority of the non-scientific community, risk perception determines their judgments, the scientific community relies on the empirical evidence from risk assessment to inform the risk management and communication components of risk analysis. Risk perception on the other hand needs no justification. For instance, Prinsen et al. (2020) reported a high perception among butchers and eateries of greater risk posed by the practices of livestock owners and consumer preferences on the safety of meat. This may not be necessarily true when the risk estimate is established and the value-chain evaluated through a scientific criterion. For risk perception is also informed by socio-cultural factors among others.

Microbial risk assessment of meat and its products in Sub-Saharan Africa

Microbial risk assessment (MRA) seeks to provide understanding on the public health risks the population is exposed to through ingestion of a particular pathogen and/or their toxins in food (Fedoruk 2011). The tabular summary (Table 2) reveals that the microbial studies in SSA had greatly focused on beef, the most popular meat in the region. The studies show a high prevalence of microbes in meat and its products, with *Escherichia coli* and *Salmonella spp*. forming part of the most prevalent microorganisms; pointing to lapse in the food controls. Product handling and processing are known to be the major routes of entry of the aforementioned microorganisms into meat and its products (Gallagher et al. 2016). The prevalence of contamination of the processed meat products such as the meat pies with *E. coli* were as high as 54.3% (Claudious et al. 2020). In as much as high level contamination was reported among the processed products, the unprocessed products posted higher prevalence, 100%, of contamination with total aerobic counts and *E. coli* (Kagambèga et al. 2011; Niyonzima, Bora, and Ongol 2013). Meat and its products are also susceptible to microbial spoilage by biohazards such as *Clostridium perfringens, Campylobacter jejuni* and *Staphylococcus aureus* (Chernukha, Kuznetsova, and Sysoy 2015; Mataragas, Skandamis, and Drosinos 2008). A study on informally vended products like the African sausage (*mutura*) in Kenya reported a prevalent contamination with *S. aureus* of more than half (50.4%) of the products. Whereas in Nigeria informally vended products had no contamination of *S. aureus*, the handling was still questionable with *Salmonella* counts of 8.00 log CFU/g reported (Akusu and Wemedo 2016); this meets the threshold of established infective dose of 3–9 log cfu (Akbar and Anal 2015). In the case of ready-to-eat meat products such as cured meats, *Listeria monocytegenes* has been of concern too (Foerster, Figueroa, and Evers 2015). Any strategy in place to assure the microbial safety of these products would need a scientific justification, generated through risk assessment, for effective action.

The formal and informally vended, raw and cooked, fresh and preserved, and retailed and household-made meat products (Table 2) were contaminated with microbial pathogens, proving the need to institute evidence based controls in the sector: microbial risk assessment (MRA). Contamination with pathogens was established in raw, processed and cooked products of beef, goat and poultry meats. When performing MRA, both qualitative and quantitative aspects may be used (Birgen et al. 2019; Makita et al. 2017). The most prevalent microorganisms in meat have also been shown to be of the greatest interest in risk assessment, Table 3. *Salmonella spp.* was vastly studied across different countries and products followed by *Campylobacter spp.* due to the risk of illnesses posed and susceptibility of meat to their entry. MRA abides to the risk assessment methodology designed as per the Codex Alimentarius (FAO and WHO 2009c), with the epidemiologic data informing the exposure assessment which is an integral part of the process (FAO and WHO 2009a). Establishing the dose response of microbial hazards takes just a few hours or days (Oguttu 2015), and this may partly explain the greater interest in and ease in effecting studies on microbial hazards in this part of the globe. The major difference in the microbial risk assessment is the wide fluctuation of microbial counts due to processing and conditions in the value-chain (USDA/FSIS and EPA 2012). Modeling of the exposure to microbial hazards simulates various case scenarios with a variation in the risk estimate or rank based on the exposure pathway (Makita et al. 2017; Toyomaki et al. 2011). In her study, Niyonzima (2017) showed that instituting controls in the different exposure pathways has varied effectiveness too; the relative risk reduction of salmonellosis in meat chain in Rwanda ranged from 22.7% to 83.1%. Grace et al. (2008) and Chizuru et al. (2004) recommended the exploration of cost-effectiveness in risk management for effectiveness in risk mitigation, thereby the appropriate modeling of case scenarios becomes integral.

Table 2. Level of microbial contamination of meat and its products in sub-Saharan African countries.

Country	Type of meat product	Hazard	Level of microbial contamination	References
Burkina Faso	Meat (Beef, mutton, chicken)[1]	*E. coli*	100%[a]	(Kagambèga et al. 2011)
	Meat (Beef, mutton, chicken)[1]	*Salmonella*	09.3%[a],	
Ethiopia	Beef[1]	*E. coli*	8%[a]	(Hiko, Asrat, and Zewde 2008)
	Lamb and mutton[1]	*E. coli*	2.5%[a]	
	Goat meat[1]	*E. coli*	2.0%[a]	
Ethiopia	Goat carcass[1]	*Salmonella*	3.86%[a]	(Tadesse and Gebremedhin 2015)
	Beef carcass[1]	*Salmonella*	4.53%[a]	
	Minced beef[1]	*Salmonella*	8.43%[a]	
Ethiopia	Minced meat[1]	*E. coli*	43.7%[a]	(Zerabruk et al. 2019)
		Salmonella	6.25%[a]	
		S. aureus	37.50%[a]	
Ghana	Beef[1]	TVC	5.32 ± 0.71[b]	(Appiah 2016)
		TCC	4.21 ± 0.62[b]	
		S. aureus	3.02 ± 0.46[b]	
Ivory coast	Pork[1]	TVC	10.07-10.11[d]	(Alfred et al. 2019)
		S. aureus	5.30-6.49[d]	
		TFC	4.04-5.23[d]	
Kenya	Chicken[1]	*E.coli*	97%[a]	(Odwar et al. 2014)
		Coliform counts	78%[a]	
Kenya	African sausages (*mutura*)[2]	*Staphylococcus spp.*	50.4%[a]	(Karoki et al. 2018)
		Bacillus spp.	19.5%[a]	
		Streptococcus spp.	9.8%[a]	
		Proteus spp.	2.4%[a]	
		E. coli	1.6%[a]	
Nigeria	Fresh meat pie[1,2]	TVC	3.48-3.69[d]	(Clarence, Obinna, and Shalom 2009)
	Meat pie refrigerated for 2 days[1,2]	TVC	3.90-4.18[d]	
	Meat pie preserved in RT for 2 days[1,2]	TVC	4.48-4.58[d]	
Nigeria	Beef[2]	Total viable count	98%[a]	(Grace et al. 2015)
Nigeria	Street-vended meat pie[2]	TAC	NG-8.32[b]	(Akusu and Wemedo 2016)
		TCC	NG-8.22[b]	
		TFC	NG-8.45[b]	
		Salmonella	NG-8.00[b]	
		S. aureus	NG[b]	
		B. cereus	NG-7.92[a]	
		Moulds	NG-6.30[b]	
		Yeast	NG-7.60[b]	
Rwanda	Beef[1]	Total aerobic count	100%[a]	(Niyonzima, Bora, and Ongol 2013)
South Africa	Beef and chicken[2]	*B. cereus*	17%[a]	(Mosupye and Von Holy 2000)
		C. perfringens	1%[a]	
		S. aureus	3%[a]	
		V. metchnikovii	2%[a]	
South Africa	Beef stew[1]	TBC	3.9–6.15[b]	(Nyenje et al. 2012)
	Chicken stew[1]		5.9–6.2[b]	
Tanzania	Roasted meat (*Nyama choma*)[2]	*Campylobacter spp.*	7.7%[a]	(Toyomaki et al. 2012)
	Mishikaki[2]	*Campylobacter spp*	34.7%[a]	
Tanzania	Beef[1]	TVC	7.72[b]	(Ntanga 2013)
	Beef[1]	TCC	6.92[b]	
	Beef[1]	TFC	6.73[b]	
Tanzania	Roasted beef[1]	*C. coli*	0.37[c]	(Makita et al. 2017)
Zambia	Beef[1,3]	*Salmonella*	12.0%[a]	(Manyori et al. 2017)
Zimbabwe	Meat pies[1,3]	*E. coli*	54.3%[a]	(Claudious et al. 2020)
		S. aureus	25.7%[a]	

[1]Formally retailed meat;
[2]Informally retailed meat;
[3]Household-made meat products;
[a]Percent prevalence;
[b]Microbial counts (log cfu/g),
[c]Microbial counts (MPN/g) and
[d]Values were transformed from original cfu/g to log cfu/g. *B. cereus-Bacillus cereus*, *C. coli-Campylobacter coli*, *C. jejuni-Campylobacter jejuni*, *E. coli-Escherichia coli*, NG-no growth, RT-room temperature, *S. aureus-Staphylococcus aureus*, TAC-total aerobic count, TCC-total coliform count, TFC-total fecal coliform count, TVC-total viable count and *V. metchnikovii-Vibrio metchnikovii*.

Chemical risk assessment of meat and its products in Sub-Saharan Africa

Chemical risk assessment too follows the four integrative steps of risk assessment as outlined by Codex Alimentarius. Just like biohazards, the chemical contaminants can occur in meat and its products through multiple routes along the food chain. Chemical contaminants in meat that are of public health significance include mycotoxins, pesticide residues, residues of veterinary drug and heavy metals in primary production; food additives, processing migrants and processing contaminants in food processing; and packaging migrants in food packaging (Chizuru et al. 2004; Pavesi et al. 2017). Further contamination may also occur in product handling by the consumer or adulteration (FAO and WHO 2003; Pavesi et al. 2017). Tyokumbur (2016) established that the intestines were the most contaminated chicken offal retailed in Ibadan, Cote d'Ivore, with cadmium

Table 3. Risk assessment studies in sub-Saharan African countries.

Country	Type of hazard	Name of hazard	Type of meat	Type of risk assessment study	Risk assessment tool	Model	Risk estimate	Reference
Kenya	Microbial	*C. jejuni*	Street-vended poultry	Semi-quantitative	Risk Ranger	–	67[a]	(Birgen et al. 2019)
Nigeria	Chemical	Oxytetracycline and tetracycline residues	Beef	Quantitative	@risk	Riskpert	0.0232 (low)	(Adegboye 2011)
Nigeria	Chemical	Heavy metals	Beef	Quantitative	–	–	<1 (low)[b]	(Ya'u, Babagana, and Sani 2017)
Nigeria	Chemical	PAH	Beef	Quantitative	–	–	<1.0 (low)[b]	(Taiwo et al. 2019)
Rwanda	Microbial	*Salmonella*	Meat	Quantitative	sQMRA	sQMRA	1.7–3.4%	(Niyonzima 2017)
Senegal	Microbial	*Salmonella* *Campylobacter*	Chicken	Quantitative	mc2d package of R statistical package	Beta-poisson	16% (High) 3.3% (low)	(Pouillot et al. 2012)
South Africa	Microbial	*S. aureus*	Ready-to-eat chicken	Quantitative	@Risk	Beta-poisson	1.3% (low)	(Oguttu 2015)
Tanzania	Microbial	*Campylobacter*	Ready-to-eat beef	Quantitative	@Risk	Beta-poisson	1.4% (low)	(Toyomaki et al. 2012)
Tanzania	Microbial	*C. jejuni*	Roasted beef	Quantitative	@Risk	Beta-poisson	3.4% (low)	(Makita et al. 2017)
Zambia	Microbial	*Salmonella*	Beef	Quantitative	sQMRA	sQMRA	0.06–0.16 (low-high)	(Manyori et al. 2017)
ns	Microbial	*S. aureus* *Y. enterolitica* *Salmonella* *E. coli* *L. monocytogenes* *Campylobacter* HEV	Pork	Semi-quantitative	Risk Ranger	– 13–45[a] 16–65[a] 0–44[a] 13–72[a] 27–39[a] 57–66[a]	29–49[a]	(Mataragas, Skandamis, and Drosinos 2008)

[a]Relative risk ranked from 0-no risk to 100, where 0-no risk, >48 is high risk.
[b]Depicts the target hazard quotient, *B. cereus-Bacillus cereus*, *C. coli-Campylobacter coli*, *C. jejuni-Campylobacter jejuni*, *E. coli-Escherichia coli*, HEV-Hepatitis E virus, *L. monocytogenes- Listeria monocytogenes*, ns-non-specific to any country in SSA, PAH-Polycyclic aromatic hydrocarbons, *S. aureus- Staphylococcus aureus*, sQMRA-swift quantitative risk assessment (QMRA) and *Y. enterolitica-Yersinia enterolitica*.

at 0.713 ppm, way above a global set guideline limit of 0.05 ppm (FAO and WHO 2011a); owing to the production practices. Similar findings were reported by Ogwok et al. (2014) who established that lead in the organ meats retailed in Kampala City, Uganda, was beyond the 0.5 mg/kg wet weight; the regulatory limit in the Codex Alimentarius (FAO and WHO 2011a). This point to a variation in the risk posed due to consumption of different meat products. Such information is integral in generating controls and regulation with regard to chemical contaminants in food. Quantitative risk assessment of chemical hazards is usually complicated by the process of establishing dose-response relationship that tends to take years or lifetimes (Oguttu 2015). The review found few risk assessment studies documenting the chemical hazards in meat (Table 3), thus the discussion in the review was skewed toward MRA.

Quantitative risk assessment of meat and its products

SSA countries lack expertise and adequate infrastructure to carry out important scientific experiments including toxicological and epidemiological studies that would provide input into the risk assessment (FAO and WHO 2009a; Kussaga 2015). Novel tools may be developed in the quantification of risks of a particular pathogen in a specific food (Table 3). In their study Manyori et al. (2017) and Niyonzima (2017) used the swift quantitative microbial risk assessment (sQMRA) to evaluate risk of salmonellosis due to consumption meat in Zambia and Rwanda, respectively. Makita et al. (2017) too employed a QMRA that incorporated qualitative inputs in establishing the risk of campylobacteriosis due to consumption of roasted beef in Tanzania. Modeling of various risk scenarios help in the instituting of efficient controls in the value-chain. Manyori et al. (2017) established the risk of developing salmonellosis from low and medium consumption of beef as 0.06% and 0.08%, respectively; whereas that due to consumption of beef in restaurants was 0.16%. From this, it is easier to institute controls that are efficient and effective in mitigating the risk in a particular exposure pathway.

Conducting a full QMRA specified to a microbial hazard takes a long time to effect (FAO and WHO 2009a; Pouillot et al. 2012), no wonder the limited number of such studies in SSA countries. For this reason, quantitative risk assessment do incorporate qualitative inputs in generating the risk estimate (Makita et al. 2017). The exposure assessment component of quantitative risk assessment can be qualitative, deterministic or stochastic; with the complexity and amount of data needed increasing in that order (Chizuru et al. 2004). This is an additional cost-cutting and time-saving method. In developing the model for risk assessment of *Campylobacter spp.* in broiler chicken, FAO and WHO (2009a) incorporated qualitative inputs from various European countries for application of the model in various geographical settings including SSA. Niyonzima (2017) incorporated qualitative aspects in the QMRA for a faster generation of the risk estimate; the risk of developing salmonellosis from consumption of meat based meals was 1.7–3.4% depending on the specific pathway. Even with the incorporation of qualitative aspects, the technique was sufficient enough to identify the food preparation stage as the critical point for *Salmonella spp.* contamination of the meat in both households and food establishments. In their study, Toyomaki et al. (2011) successfully employed the QMRA to estimate risk, but this too was complemented with available epidemiological data from medical records and literature.

From the literature gathered, there was not a single full QMRA in SSA; however, the qualitative inputs and epidemiologic information availed from studies help complement the work of researchers in effecting QMRA studies.

Qualitative risk assessment of meat and its products

Qualitative risk assessment are also based on numerical data from the hazard characterization and exposure assessment, however, the risk characterization is usually categorical or descriptive in nature (FAO and WHO 2009d). The utilization of qualitative and quantitative inputs in the generation of risk estimates adopts the name a semi-quantitative risk assessment (Mataragas, Skandamis, and Drosinos 2008). The Risk Ranger, a tool developed for semi-quantitative studies, has a set of eleven questions whereby qualitative and quantitative inputs are provided to generate a categorical risk rank (Birgen et al. 2019). The risk assessment tool ranks risks from high risk (>48–100) to no risk (0). This aspect of risk assessment tends to be less costly and faster than the quantitative one; however, it may be limited in instituting process controls in some instances. This is resulting from lack of empirical values in the change of the parameter due to different processing. The qualitative risk assessment is recommended as a preliminary study to the QRA for it defines the nature and scope of work, feasibility and time that would be needed to address the needs of the risk managers (Chizuru et al. 2004). It also provides insight to the risk assessors of the extended need of a full QRA to fully establish the risk posed (FAO and WHO 2011b). On the other hand, a qualitative risk assessment would also employ some quantitative aspects too for one major reason: it is difficult to categorize some aspects of the study including prevalence and quantity of food taken (Chizuru et al. 2004).

Contribution of risk assessment of meat and meat products to public health status of Sub-Saharan African countries

Risk assessment provides the scientific justification for food safety controls by government bodies and authorities through food legislation. Appropriate level of protection (ALOP) and food safety objective (FSO) aim to make food safety control transparent and quantifiable (Gkogka et al. 2013). The ALOP points out the current food safety status achieved by the food controls in place, in essence ALOP can be regarded as an acceptable level of risk or tolerable risk because it connects FSO to public health goals (FAO and WHO 2006b). MRA is the mechanism that quantifies the impact of food controls in place on the risk resultant from a specific microbial hazard and provides the numerical description of protection due to the current food safety control system, thus contributing to the setting of the ALOP. On the other hand, food safety objectives (FSO) links the ALOP in place to the performance objective (PO) that are in place to control occurrence of microbial hazard in food (Walls 2006). Food controls such as hazard analysis critical control point (HACCP) and good manufacturing practices (GMPs) are then instituted to ensure FSO is met contributing to the realization of the ALOP and public health goals. FAO and WHO (2010) developed a web-based tool for risk assessment of chicken meat that provides input to Hazard Analysis Critical Control Point (HACCP); the tool enables risk managers to evaluate risk reduction options for cost-effectiveness.

The international markets in the developed countries are integral to the economies SSA countries (Wahidin and Purnhagen 2018). The strict food laws in these markets serve as a major call for upgrade of the food safety and public health status of the developing countries. Lack of resources among the developing countries has been a major setback in the efforts to ensure food safety in the meat industry in these countries (Rahmat, Cheong, and Hamid 2016). Poor traceability systems and presence of informal sectors in the meat industry that are largely unregulated has resulted into a poor food safety status in these developing countries (Jabbar and Grace 2012). Food safety regulations and legislations in these countries are at times outdated or non-existent, thus the great risk are posed due to consumption of poultry and other meat products (Kiilholma 2010). Low awareness has also been blamed for the poor food safety situations in these countries (Adesokan and Raji 2014). The overall contribution of scientifically generated evidence through risk assessment studies to public health status in these developing countries tend to be low due to the constraints limiting such studies.

Constraints of conducting quantitative risk assessment (QRA)

The prevalence of pathogens at each point of the agri-food chain must be established for QRA studies. This has been a challenge in most cases as noted in a study by Hathaway, Davies, and Ashby (2007). Establishing the prevalence of *Salmonella spp.* in meat at the point of slaughter was challenging and the data was largely missing. In resource-limited settings like in SSA countries where fewer studies are conducted, limited and missing data would greatly hinder quantitative risk assessment (FAO and WHO 2009a; Pouillot et al. 2012). Cases of limitation of data has at times had the qualitative and quantitative aspects of risk assessment yielding a semi-quantitative study (Birgen et al. 2019; Mataragas, Skandamis, and Drosinos 2008). This aspect of risk assessment uses assumptions established from empirical data in literature. In this case, this gives credence to, semi-quantitative and qualitative risk assessment for their simplicity as compared to QRA that requires quantification and comparisons for more accurate risk estimates to be developed thus a very difficult approach (FSANZ 2013).

QMRA also tends to be time consuming and sometimes impossible in case of limited data (EFSA 2008; Makita et al. 2017). EFSA reports limited use of especially QMRA in the international and national levels by risk managers as a result of this limitation. The qualitative aspects in risk assessment fills this gap by adopting empirical data from other studies (Mataragas, Skandamis, and Drosinos 2008). As in the case of FAO and WHO (2009a) study where they reported missing epidemiologic and surveillance data for *Campylobacter* infections in most of the SSA countries. This limitation was also established in the study by Birgen et al. (2019) whereby hazard severity input was adopted from other studies that were not based in the country. This limits the scope of the QMRA studies that can be conducted in these countries as the estimate would have a lot of uncertainties. In MRA studies, there are usually no set values thus a lot of modeling techniques including qualitative can be used (FSANZ 2013). In some cases, qualitative risk assessment serves as an initial study with the intention of carrying out a more expansive QRA (FAO and WHO 2009d; Makita et al. 2017). In emergencies, qualitative risk assessment serves as the best suited study to generate data within a short time.

In as much as QMRA is considered the best tool for development of food standards (Pouillot et al. 2012), it is also known to be resource-intensive thus very expensive (FAO and WHO 2009a). This may not make it tenable for most of the SSA countries who have limited resources employed in such studies. At times qualitative studies are carried out to demonstrate no need for an extensive and more expensive QMRA (FAO and WHO 2004, 2006a). This serves to make risk assessment more cost-effective and efficient. Even with QMRA, the deterministic model tends to be less expensive than the probabilistic model (FASFC Federal Agency for the Safety of the Food Chain (FASFC) 2011). However, the deterministic model has a similar shortfall as the qualitative risk assessment of at times being too simplistic.

Emerging risks in street-vended meats

Street-vended meats have become so popular in the urban areas of the SSA; for instance in Kenya the street foods vending complements bigger brands in product distribution (Promar Consulting 2016). The sector has vast involvement of the vulnerable groups, namely youth and women, who have limited access of economic resources. Involvement of women in street-vending of meat in Ethiopian city was reported to be 90% (Tesfaye et al. 2016). This sector has limited food safety risk assessment studies despite the deplorable hygiene conditions being reported (Bagumire and Rollanda 2017; Grace et al. 2008); posing the biggest risk of disproportionately high prevalence of foodborne illnesses (Thomas et al. 2020). This is partly attributed to the ever increasing population that heavily relies on the informal food supply chain. A semi-quantitative risk assessment on ready-to-eat-pork products found that *S. aureus* pose a high risk in these products (Mataragas, Skandamis, and Drosinos 2008). Similar findings were reported by Birgen et al. (2019) who utilized semi-quantitative aspects in the evaluation of street vended poultry in Kenya. These findings showed that the *Campylobacter spp.* poses a high risk in these particular products too. Food-related risk factors that aggravate microbial contamination in the street vended meats include raw material handling (FAO and WHO 2009a; Mosupye and Von Holy 2000); poor equipment, personnel and environmental hygiene (Birgen et al. 2020); contact surfaces (Mosupye and Von Holy 2000); unhygienic post-slaughter handling and storage (Rani et al. 2017); temperature abuse (Mataragas, Skandamis, and Drosinos 2008); and poor food safety and handling knowledge (Bagumire and Rollanda 2017; Zerabruk et al. 2019).

The sector has little regulation as compared to the formal food retail and distribution chains. The vast size of practice of street vending of meat (Githiri et al. 2016), and the myriad processing techniques and poor organizational structures (Makinde et al. 2020), render the sector quite difficult to regulate. Considering the weaknesses in the regulation of this sector (Rani et al. 2017), food regulatory and control system in Tanzania have adopted community emancipation and education aspects in addressing food-related illnesses through a multi-faceted approach (Hrynick et al. 2019). However, risk assessment studies needs to be done for proper controls. The question then is: are the qualitative aspects the answer to estimation of risks? Are these techniques of sufficiency to establish risk levels? Will this help in addressing these risks? For the first two questions the answer is "Yes". Birgen et al. (2019) established that in as much as the occurrences of pathogenic microbes in street-vended meat was high, *Campylobacter jejuni* was the one posing the highest risk. Mataragas, Skandamis, and Drosinos (2008) evaluated five microorganisms in different street-vended meats whereby only the *S. aureus* posed the greatest risk. This helps in prioritization and saving of resources. Quantitative techniques of risk assessment always seek to evaluate risks of significance to the population. The advantage of quantitative techniques is that it provides input toward instituting controls as it identifies the critical points in the value-chain (Toyomaki et al. 2011). Thereby, the answer to the third question would definitely be a "No". For sufficiency of food control, addressing the contribution of a critical point in the value chain to a risk is important. In such a case, the SSA countries have to take serious the recommendation by FAO and WHO (2009a) to address the shortfalls in their epidemiologic data and exposure routes to effect such robust studies.

Future prospects of risk assessment in Sub-Saharan Africa

Meat consumption in the region continues to increase and evolve into a myriad of recipes. Additionally, the countries in the region have to abide with the challenge of the street-vended meats for the foreseeable future; the reflective status in Burkina Faso showed that up to 90% of these vendors are unwilling to transition to the formal sectors (Montcho et al. 2017). Therefore, the food safety challenges posed by this sector are to persist in this region for quite some time. The greatest risk posed by the consumption of street-vended meats are food-borne illnesses due to the high microbial loads (Birgen et al. 2020). Feasible preventive mechanisms such as food safety and handling training can militate against consumer exposure to food hazards in this sector (Kussaga 2015). However, the need for estimation of risks for guided action cannot be overlooked. Effective controls in the meat value-chain addressing food safety in these countries must focus on the street-vended products. Thereby, the need for risk assessment studies to be done to elucidate the risks. However, gaps in epidemiologic data render the quantitative risk assessment quite costly and vast in its implementation (Odhiambo, Kebira, and Nyerere 2017). Such instances, a semi-quantitative risk assessment using the Risk Ranger has served to generate the risks estimates (Birgen et al. 2019; Mataragas, Skandamis, and Drosinos 2008). No matter the limitations in data and resources, addressing food safety risks in the overall meat value-chain must incorporate the risk assessment techniques. The Risk Ranger provides a processing chain for the food to be consumed that would thus help in ranking of the risk whereas also establishing controls for critical points. Grace et al. (2008) adds another perspective in risk assessment in resource poor setting; adopting a participatory approach. This technique adopts inclusion of the local community and stakeholders in risk assessment that furthers the development of workable solution; thus effectiveness of risk management (Grace et al. 2015). The participatory approach is thus recommended in value-chains and settings with scarce resources to help gain deeper understanding at minimal costs and workable recommendations from the risk assessment component (Oguttu et al. 2014).

Conclusion

The increasing consumption and diversification of meat processing, coupled with an expanding street vending, poses a challenge to the public health consumers of meat and its products in SSA. From the review, it is evident that less of the robust quantitative risk assessment techniques have been utilized to generate evidence to institute food controls to mitigate the food safety risks posed by contamination of meat and its products due to limitations of capacity and costs. Whereas, there have been risk assessment studies in the region, qualitative approaches have been wholly used or incorporated in the quantitative approaches. Of the greatest concern in the meat value chain in SSA were the microbial hazards rather than the chemical hazards. The risk assessment studies in the region has established that the risks posed by microbial pathogens range from low risk to high risk, with studies on informally vended products reporting high risks posed by products. It would be imperative that for proper controls to be instituted, risk assessment studies should establish the critical points of contamination. With the incorporation of the qualitative approaches into quantitative approaches, this is feasible while ensuring cost-effectiveness and limitations of capacity and robust data are circumvented. Additionally, it would be necessary to incorporate participatory approaches for more workable solutions and recommendations to be generated for the sector. Going forward, there is further need for more risk assessment studies that would be made feasible by participatory and qualitative approaches to generate data that would be of input in instituting food controls, especially, in the informal sector including street vending where the regulatory framework and food control are weakest.

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