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Review

Listeria monocytogenes at the food–human interface: A review of risk factors influencing transmission and consumer exposure in Africa

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Summary In African public health systems, *Listeria monocytogenes* is a pathogen of relatively low priority. Yet, the biggest listeriosis outbreak recorded to date occurred in Africa in 2018. This review highlights the factors that potentially impact *L. monocytogenes* transmission risks through African food value chains (FVCs). With the high rate of urbanisation, African FVCs have become spatially longer yet still informal. At the same time, dietary diversifications have resulted in increased consumption of processed ready-to-eat (RTE) meat, poultry, fishery and dairy products typically associated with a higher risk of *L. monocytogenes* consumer exposure. With frequent cold chain challenges, the potential of *L. monocytogenes* growth in contaminated RTE foods can further amplify consumer exposure risks. Moreover, the high prevalence of untreated HIV infections, endemic anaemia, high fertility rate and a gradually increasing proportion of elderly persons expands the fraction of listeriosis-susceptible groups among African populations. With already warmer tropical conditions, the projected climate change-induced increases in ambient temperatures are likely to exacerbate listeriosis risks in Africa. As precautionary approaches, African countries should implement systems for the detection and reporting of listeriosis cases and food safety regulations that provide *L. monocytogenes* standards and limits in high-risk RTE foods.

Keywords Food safety, food value chains (FVCs), *Listeria monocytogenes*, ready-to-eat (RTE) foods, risk factors.

Introduction

According to estimates of the World Health Organization (WHO) Foodborne Disease Burden Epidemiology Reference Group (FERG), foodborne diseases are responsible for 600 million illnesses and 420 000 deaths per year resulting in 33 million Disability Adjusted Life Years (DALYs) (Havelaar *et al.*, 2015). Of this global burden, low- and middle-income countries (LMICs) contribute a substantial share, accounting for 72% of global DALYs (Havelaar *et al.*, 2015; Unnevehr, 2022). The African continent contributes 43% of the global DALYs, making it the biggest contribution by a single region of the WHO (Havelaar *et al.*, 2015). Among bacterial foodborne diseases, listeriosis has a comparatively lower incidence, varying from 0.1 to 1.3 cases per 100 000 population per year around the world (de Noordhout *et al.*, 2014). However, despite its low incidence, invasive listeriosis has a high fatality

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rate (Desai *et al.*, 2019). It results in approximately 10 DALYs per 100 000 population, making it the deadliest of all bacterial foodborne infections (Havelaar *et al.*, 2015).

Notwithstanding the general trend of a higher burden of foodborne diseases in Africa, the incidence of invasive listeriosis is contrastingly lower in Africa compared to high-income regions of the world (de Noordhout *et al.*, 2014). From a total of 23 150 illnesses and 5463 deaths globally attributed to invasive listeriosis in 2010, the contribution of the African continent was only 16% (de Noordhout *et al.*, 2014). The reasons for the disparity in the incidence of listeriosis in contrast to other bacterial foodborne diseases on the continent have not been fully explored. Against a background of a historically 'low' incidence of the disease, the biggest outbreak so far in the world was recorded in South Africa in 2017–2018, where a total of 1060 laboratory-confirmed cases, and 216 deaths were reported (Thomas *et al.*, 2020). The mismatch between the historically low incidence and the occurrence of an outbreak of such magnitude in Africa is likely a reflection of deficiencies in food safety systems and knowledge of risk factors influencing *L. monocytogenes* transmission dynamics in African food value chains (FVCs). As countries undergo economic evolution and move from low- to higher-income states, their food safety systems also undergo a concomitant transformation accompanied by diversification in diets and consumer food choices (Jaffee *et al.*, 2020; de Bruin *et al.*, 2021). This food safety system transformation was referred to by Jaffee *et al.* (2020) as a food safety life cycle in which nations move from the 'traditional' to the 'transitional', 'modernising' and the 'post-modern' stages as they transition from the low-income to middle- and high-income stages of economic development respectively. In low-income countries, the spatially shorter value chains, and the predominantly traditional means of food production such as cooking close to the point of consumption can understandably reduce *L. monocytogenes* transmission risks (Barrett *et al.*, 2020). On the other hand, rising urbanisation in middle-income countries results in spatially elongated value chains and dietary diversifications towards the consumption of animal-source foods as well as processed ready-to-eat (RTE) foods (Barrett *et al.*, 2020). Despite the nutritional benefits of animal-source foods and the convenience of RTE foods, these dietary trends, unfortunately, result in a disproportionate amplification of *L. monocytogenes* consumer exposure risk (Jaffee *et al.*, 2020; de Bruin *et al.*, 2021). Thus, this review seeks to explore the distinctive characteristics of African FVCs and the potentially attendant risks of *L. monocytogenes* transmission. Furthermore, the review explores the possible risk factors that can exacerbate listeriosis incidence in contemporary African settings.

Listeriosis incidence in Africa

With much of the policy attention of African countries focused on food security (availability and affordability) and the major public health challenges like malaria, HIV/AIDS and tuberculosis, food safety-related challenges tend to get less attention (Jaffee *et al.*, 2020). Compared to other foodborne illnesses like salmonellosis, campylobacteriosis and *E. coli* gastroenteritis, listeriosis is generally an infrequent disease. Hence, it is not a priority disease in African public health systems and its incidence in Africa is not fully understood. In general, unless a foodborne disease causes a major public health or economic impact, many small outbreaks and sporadic cases often go unreported and unnoticed (Havelaar *et al.*, 2015). Like many other foodborne illnesses, there is no mandatory reporting of listeriosis in African countries (Grace, 2015). So far, only South Africa has classified listeriosis as a notifiable condition, a consequence of the outbreak in 2018 (Schutte *et al.*, 2019). Moreover, the main clinical features of invasive listeriosis, such as meningitis and meningoencephalitis that result from the invasion of the central nervous system, are also common features of other bacterial pathogens such as *Haemophilus influenzae*, *Streptococcus pneumoniae* and *Neisseria meningitidis* (Peltola *et al.*, 2021). Since *L. monocytogenes* is a less frequent cause, it is often excluded in the routine laboratory testing of cerebrospinal fluid (CSF) samples when bacterial meningitis is suspected. In an extensive review of the burden of meningitis in Africa, Peltola (2001) observed that about 10% of the aetiologies of bacterial meningitis were unconfirmed. Similarly, in a recent study on childhood bacterial meningitis in Angola, only 64% of the bacterial causes were confirmed (Peltola *et al.*, 2021). From these studies, it can be surmised that the unconfirmed causes could potentially be a result of the less commonly implicated pathogens like *L. monocytogenes*.

So far, South Africa is the only country that has randomly reported cases of listeriosis over the years. Through its National Institute for Communicable Diseases (NICD) and National Health Laboratory Services (NHLS), it is probably the only country with laboratory diagnostic and surveillance capacity for the disease. However, despite that, the country has not been able to provide any reliable listeriosis incidence data. In the absence of any reliable data, an inference of listeriosis incidence can only be made from the few studies so far reported in Africa. One retrospective review of neonatal and central nervous system (CNS) infection records at Tygerberg Hospital in Cape Town over the period 2006–2016, identified 51 sporadic cases with a prevalence of 0.04 cases per 1000 population (Oppel *et al.*, 2018). In the 2017–2018 outbreak, the estimated prevalence was as high as 4–5 cases per 100 000 population in the most affected districts (Thomas *et al.,* 2020). In that outbreak, 50% of the cases were pregnancy-associated, and the fatality rate was 27% (Thomas *et al.,* 2020). Besides the data from South Africa, a meta-analysis of pregnancy-associated listeriosis by Geteneh *et al.* (2022), identified a few studies from Nigeria, Senegal and Ethiopia. The pooled prevalence from these studies was 5.17% (Geteneh *et al.,* 2022).

African FVCs and *L. monocytogenes* food safety risks

Overview of *L. monocytogenes* transmission pathway

The main source of *L. monocytogenes* contamination of foods is the farm environment. Its chronic colonisation of the gastrointestinal tracts of livestock species creates a reservoir for the spread of the organism into soil, vegetation and surfaces and materials within the farm environment (Rodriguez *et al.,* 2021). Thus, raw foods such as milk and meat can directly be contaminated with the pathogen at the farm and during slaughter (Rodriguez *et al.,* 2021). Moreover, the use of animal manure and contaminated irrigation water is an additional route of pre-harvest contamination of field crops such as fruits and vegetables (Biswas *et al.,* 2018; Gholipour *et al.,* 2020). Notwithstanding the possibility of contamination of raw foods, many human outbreaks of listeriosis result from contaminated processed RTE foods (Fagerlund *et al.,* 2021). From its primary natural source on the farm, the pathogen is disseminated into food-processing environments through contaminated raw foods. Subsequently, its ability to colonise and persist in processing facilities often becomes a secondary source of post-process contamination of processed foods (Castro *et al.,* 2018; Sun *et al.,* 2021).

Characteristics of African FVCs and potential influence on *L. monocytogenes* transmission and consumer exposure

As African countries develop economically, their FVCs also undergo transformations that have an impact on food safety (Waage *et al.,* 2022). Propelled by rapid urbanisation and growing incomes, the value chains have changed from traditional through transitional to modernising as African countries move from low-income to middle- and upper middle-income levels (Barrett *et al.,* 2019). This evolution in food safety systems was referred to by Jaffee *et al.* (2020) as a food safety life cycle. Given that most African countries are in the LMIC (low- and middle-income) bracket, their FVCs are predominantly in the traditional and transitional stages. The characteristics of these value chains and the possible attendant risks of *L. monocytogenes* transmission and consumer exposure (summarised in Table 1) are discussed in this section.

Traditional FVCs are typically rural value chains of low-income countries. As foods are produced and consumed at home, these rural FVCs are spatially short and the diversity in foods is limited, being dominated by staple grains and fewer processed animal products (Barrett *et al.,* 2020). While poor hygiene and sanitary conditions and close interaction with farm animals in these rural agri-food systems could increase the risk of *L. monocytogenes* contamination of foods and lead to a potential direct human exposure (Rodriguez *et al.,* 2021), the homecooking of food and absence of extended refrigerated storage of food, attenuates the *L. monocytogenes* risk by preventing undue multiplication of the psychrotolerant organism to unsafe levels.

In middle-income countries facing rapid urbanisation, FVCs are in the transitional stage (Barrett *et al.,* 2019). These are spatially long value chains linking the urban population to the rural agricultural production areas (Barrett *et al.,* 2020). These FVCs are dominated by informal wet markets, street vendors and small-medium processors midstream between producers and consumers. Midstream processing increases the diversity of foods to include perishable fresh animal-derived (poultry, beef, fish and dairy) and horticultural commodities requiring preservation and refrigeration (Reardon, 2015). The concentrated purchasing power of the urban population creates a demand for high-value processed, ready-to-cook and RTE foods that save consumers food preparation time (Barrett *et al.,* 2019). Despite the benefits associated with diversified diets that bring about improved nutrition, these transitional FVCs are unfortunately associated with huge food safety challenges in African middle-income countries (Waage *et al.,* 2022).

Street-vended RTE foods are a common feature of the informal food market in African cities (Abrahale *et al.,* 2019). In South Africa, about 30% of the urban population depends on street foods for their daily dietary needs (Steyn *et al.,* 2011). Typically, street foods are prepared and sold by vendors on the street sides for immediate consumption. Their safety is compromised by inadvertent cross-contamination through poor handling practices and the unavailability of running water, washing and disinfection facilities (Kok & Balkaran, 2014). Moreover, the extended storage of foods post-preparation, the elevated ambient conditions of the African tropical climate, and inadequate or lack of refrigeration are all factors that collectively increase the risk of bacterial growth once the food is contaminated (Nkosi & Tabit, 2021; Oladipo-Adekeye & Tabit, 2021).

As economic development improves into upper middle-income levels, FVCs become more modernised with formal agri-businesses and food-processing enterprises and a dominant formal food retail sector (Jaffee *et al.,* 2020). The implementation of good hygiene and food safety management systems in modernised systems

Table 1 Food value chain transformation stages in Africa and their potential influence on *Listeria monocytogenes* transmission and consumer exposure risk

Food value chain stage	Economic development stage	Characteristic	Potential *L. monocytogenes* transmission and consumer exposure risks
Traditional	Low-income countries (46% of African countries)	• Spatially short rural agri-food systems • Foods are prepared and consumed at home • No processed or value-added foods	• Low risk due to homecooking • Risk of direct human exposure through proximity to farm animals
Transitional	Lower middle-income countries (42% of African countries)	• Spatially longer urban value chains dominated by informal wet markets, street vendors and artisanal processors serving growing urban population • Processed and value-added foods (including RTE foods) • Diversity in foods includes animal and perishable foods requiring preservation and refrigeration)	• High transmission risk in informal wet markets, street foods and artisanal processors • High risk of exposure through the consumption of animal-derived RTE foods. • High risk of exposure due to pathogen growth in contaminated RTE foods and inadequate cold chains
Modernising	Upper middle-income countries (12% of African countries)	• Spatially long urban value chains dominated by large formal food producers, processors and retailers • Investment in cold chains • Informal food markets and street foods are still a significant part of the value chains	• Reduced risk due to implementation of GAP, GHP and HACCP in formal value chains. However, the risk remains in informal markets and street foods

GAP, good agricultural practices; GHP, good hygiene practices; HACCP, hazard analysis critical control point. Food value chain stages and characteristics compilation was based on the review of literature (Reardon, 2015; Barrett *et al.*, 2020; Jaffee *et al.*, 2020).

significantly reduces food safety hazards (Jaffee *et al.*, 2020). However, even with dominant modernised systems in upper middle-income countries, small shops and informal markets continue to be major suppliers of food for a significant portion of low-income consumers (Hoffmann *et al.*, 2019). Thus, both formal and informal FVCs co-exist and intersect as the formal retail food sector is frequently a major supply source for the informal sector (Gbadegesin *et al.*, 2020). For instance, in South Africa and several other southern African countries, processed deli-meat products sourced from formal retailers are ingredients for preparing street-vended RTE foods (Ryan, 2019). Furthermore, the enforcement of quality and safety standards in formal retailers often results in rejected foods finding their way into the informal markets where they are sold at discounted prices to poorer urban households (Hoffmann *et al.*, 2019). In such situations, the public health risks of *L. monocytogenes* transmission can be aggravated by potential cross-contamination and improper storage conditions that encourage pathogen growth.

Risk factors exacerbating *L. monocytogenes* consumer exposure and infections in African settings

Consumption of high-risk RTE foods

As African countries urbanise and average incomes grow, the dietary share of processed foods among urban consumers has been increasing, while the share of staple grains has been declining (Reardon, 2015). Processed foods include low-value foods that are ready-to-cook and high-value foods that are ready to eat (Snyder *et al.*, 2015; de Brauw & Herskowitz, 2021). Along with an increase in the consumption of processed foods, is also an increase in the consumption of animal-derived foods, such as meat, fish and dairy products among the growing urban population (Reardon, 2015). While the consumption of animal-derived foods may be considered beneficial for human nutrition, such foods are incidentally the most frequently implicated in foodborne disease outbreaks (EFSA & ECDC, 2017; Ricci *et al.*, 2018). In addition to dietary changes, urbanisation and income growth are also accompanied by an increased tendency of consuming foods away from home. As has been observed by studies in South Africa and Nigeria, a great share of the food service providers in the rapidly growing African cities are formal restaurants, and informal street food vendors that serve RTE foods (Blick *et al.*, 2018; Hoffmann *et al.*, 2019; de Brauw & Herskowitz, 2021). A wide variety of RTE foods of animal origin is found in different regions of the continent (Adeyeye, 2017; Nemo *et al.*, 2017; Matle *et al.*, 2019; Gichure *et al.*, 2020; Makinde *et al.*, 2020; Adeyeye & Ashaolu, 2022). Owing to their high moisture content and neutral pH, meat, fish and dairy-based products are most at risk of *L. monocytogenes* growth during storage (Gérard *et al.*, 2018; Taylor *et al.*, 2019). Indeed, previous risk profiling has identified meat-based products as the highest-risk category of RTE foods, followed by dairy, fish and fruits and vegetables (FDA & FSIS, 2003; Batz *et al.,* 2014; WHO & FAO, 2022). Many of these RTE meat products, such as *nyirinyiri*, *suya*, *koche*, and smoked fish are traditional African products now produced for the urban informal food market by artisanal and small-scale processors (Table 2). However, others such as vienna sausages and frankfurters are exotic cooked or smoked meat products that are produced by large formal processors and consumed widely across the continent (Christison *et al.,* 2008).

In the last few decades, the *per capita* consumption of such high-risk foods has dramatically increased in Africa. A survey of food consumption changes in South Africa between 1999 and 2012 showed that the consumption of chilled ready meals and frozen processed foods increased by 50–100% (Ronquest-Ross *et al.,* 2015). In South Africa, most of the processed RTE meat products emanate from formal food production systems as factory-packaged or retail-sliced and re-packaged products (Matle *et al.,* 2019). They are also important ingredients in the preparation of street-vended foods. For example, polony, viennas and frankfurters are used in the production of *kota*, a street-vended sandwich that is widely consumed by South African urban populations (Steyn *et al.,* 2011). Although there are no systematic surveillance studies on the occurrence and contamination levels of *L. monocytogenes* among RTE foods sold in African cities, a few random reports have been recorded. Prevalence rates of 4% in processed meat products (*suya, balangu, kilishi, dambun nama*), 14% in street-vended *soy wara* (a soft cheese), and 25% in smoked fish have been reported in Nigeria (Salihu *et al.,* 2008; Ndahi *et al.,* 2014; Akanbi & Usoh, 2016; Usman *et al.,* 2016). In South Africa, prevalence rates of 4.3–14% were reported in RTE meat products, sandwiches and salads (Christison *et al.,* 2008; Matle *et al.,* 2019).

Cold chain challenges and *L. monocytogenes* growth potential

Inadequate cold chains are responsible for huge food losses in developing countries (IIR, 2020). Inadequate refrigeration equipment and chronic electricity supply challenges can make the sustenance of cold chains difficult in many African countries (IIR, 2020). Generally, the most common and easily discernible effect of an inadequate cold chain is the food quality deterioration that results from the growth of spoilage organisms. Normally, a high level of organisms in the range of 10^6–10^8 CFU g^{-1} is required before sensory quality deterioration becomes evident (Poghossian *et al.,* 2019). Yet, unlike the spoilage problem, the food safety risks arising from cold chain failures may not be easily detectable as the growth of pathogens may not produce any discernible sensory effects. Moreover, foodborne infections frequently result from the consumption of relatively lower levels of microbes than are required for spoilage. In more than 90% of listeriosis cases, the identified RTE foods frequently contain at least 2000 CFU g^{-1} of the pathogen (Ricci *et al.,* 2018). Worse still, the concept of food safety among African consumers is often misconstrued with negative sensorial perceptions of foods such as smell. Thus, temperature-abused leftover RTE foods can be consumed if the sensorial properties are deemed acceptable (Odeyemi *et al.,* 2019).

Table 2 Ready-to-eat (RTE) meat, fish and dairy foods with potential for *Listeria monocytogenes* transmission risk as they are produced and sold in African urban areas

RTE food category	Product examples	Product Description	Country	References
Meat	*Nyirinyiri*	Deep-fried fresh meat	Kenya	Gichure *et al.* (2020)
	Koche	Deep-fried beef or camel meat	Kenya	Werikhe *et al.* (2019)
	Mutura	Blood sausage made from goat or cow-cleaned intestines stuffed with cooked small pieces of meat and formed into long coils	Kenya	Karoki *et al.* (2018)
	Suya	Grilled meat	West Africa	Adeyeye & Ashaolu (2022)
	Kilishi	Smoked spiced meat	Nigeria	Ndife *et al.* (2022)
	Polony	Comminuted and cooked meat stuffed into large tubular nylon casings	South Africa	Cluff *et al.* (2017)
Fish	Smoked fish	Hot smoked fish	West and East Africa	Adeyeye & Oyewole (2016)
Dairy	*Omashikwa*	Buttermilk	Namibia	Bille *et al.* (2007)
	Wara and *Soy* wara	Curdled cow and soy milk products	Nigeria	Akanbi & Usoh (2016)
	Warankasi	Soft white cheese made from goat or cow milk	Nigeria	Adeyeye (2017)
	Amasi	Fermented cow milk	South Africa	Maleke *et al.* (2021)

In RTE foods (whose physicochemical properties permit growth), the cold growth ability of *L. monocytogenes* is an important food safety and public health risk. As a psychrotroph, *L. monocytogenes* is intrinsically adapted to growth under low-temperature conditions (Saldivar *et al.,* 2018). Besides the inherent growth ability, any fluctuations in temperature brought about by cold chain breaks can accelerate the multiplication in contaminated foods. Thus, foods with initially low levels of the pathogen can exceed the safety threshold in relatively short periods. Experimental models in RTE food matrices have shown that the growth rate of the organism doubles as temperature increases from 4°C to 8°C and from 8°C to 12°C (Kataoka *et al.,* 2017; Ziegler *et al.,* 2019). As the manufacturing processes for most RTE products involve some listericidal heating steps, *L. monocytogenes* contamination levels in the products at the point of release from the processor are usually low (frequently <10 CFU g^{-1}) (Angelidis & Koutsoumanis, 2006). Dose–response models and epidemiological data have shown that such low cell numbers (including a single cell) if ingested in food, have a low probability of listeriosis (Pouillot *et al.,* 2015; Ricci *et al.,* 2018; Sampedro *et al.,* 2022). However, the growth ability of the pathogen in refrigerated RTE foods amplifies the human exposure risk (Ricci *et al.,* 2018). Using risk assessment models, the overall impact of in-food growth was estimated to contribute up to 37% of the risk of human invasive listeriosis (Ricci *et al.,* 2018). Moreover, the handling of RTE foods along the value chain (e.g. retail-level slicing and re-packaging), further amplifies the consumer exposure risk. Risk assessment models estimate that retail-level contamination causes a two- to four-fold risk amplification compared to factory-prepackaged products (Ricci *et al.,* 2018). In many Southern African cities, RTE processed meats and cheeses are a common part of the local street food culture, especially as ingredients for street-prepared sandwiches (von Holy & Makhoane, 2006). Such high-risk RTE food products are often purchased from formal retail chains each day and can be kept for long hours unrefrigerated as the food preparation goes on during the day (von Holy & Makhoane, 2006). The growth potential of the pathogen in such foods can undoubtedly be a major public health challenge.

Food safety knowledge and practices of informal vendors and consumers

It is widely acknowledged that the food safety hazard awareness and handling practices among African informal food vendors are poor (Mwove *et al.,* 2020; Letuka *et al.,* 2021; Oladipo-Adekeye & Tabit, 2021; Azanaw *et al.,* 2022). As was observed in Kenya, Ethiopia and South Africa, inadequate food safety knowledge is a determining factor in the poor handling practices of informal food vendors (Letuka *et al.,* 2021; Nkosi & Tabit, 2021; Azanaw *et al.,* 2022). A survey of street food vendors in Johannesburg, South Africa found that at least 60% of them did not know the correct temperature for the hot and cold storage of RTE foods (Oladipo-Adekeye & Tabit, 2021). In Kenya, a similar survey found that foods requiring refrigeration are frequently kept at ambient temperatures by almost 80% of street vendors (Mwove *et al.,* 2020). Moreover, many vendors keep leftover foods for sale on the following day, sometimes without any form of preservation (Mwove *et al.,* 2020). With all these challenges, the possibility of *L. monocytogenes* contamination and growth presents a palpable consumer exposure risk.

In addition to the safety hazards emanating from informal food vendors, the consumer stage of the FVC presents additional challenges that could amplify *L. monocytogenes* exposure risk. In Europe, quantitative modelling has shown that one-third of listeriosis cases are due to pathogen growth in the consumer phase of the value chain (Ricci *et al.,* 2018). A survey of microbial hazards awareness among consumers of street-vended RTE foods in Johannesburg, South Africa showed that although the majority of consumers were aware of foodborne diseases and some pathogens, over 70% of the consumers had never heard about *L. monocytogenes* (Asiegbu *et al.,* 2016). In addition, a survey on consumer food safety perspectives in Ghana, Guinea, Kenya, Tanzania, Nigeria and Cameroon found that 67% of the consumers rely mainly on sensory properties such as smell, taste and appearance as criteria for safe food consumption (Odeyemi *et al.,* 2019; Isanovic *et al.,* 2023). With the habit of using sensory characteristics as indicators of food safety, African consumers could unwittingly be exposed to an increased risk of *L. monocytogenes* infections given the rampant practices of storing RTE foods under growth-permitting conditions for long periods.

Populations at risk

Susceptibility to invasive listeriosis varies among human populations. Many people are frequently exposed to *L. monocytogenes* through the ingestion of contaminated foods without showing any symptoms of invasive disease (WHO & FAO, 2022). Variability in susceptibility is influenced by an individual's CD4+ T-cell-mediated immunity (WHO & FAO, 2022). Pregnant women and their newborns (<28 days), elderly persons, individuals with untreated HIV infections, cancer patients, organ transplant patients and immunosuppressed patients are known to be among the susceptible subpopulations (WHO & FAO, 2022). Due to the decreased efficacy of cell-mediated immunity, HIV infection is an important risk factor for the incidence and severity of invasive listeriosis (Thomas *et al.*, 2020). With about 25.6 million people living with HIV, sub-Saharan Africa accounts for two-thirds of the global burden of HIV/AIDS (UNAIDS, 2022). Although a significant portion of this HIV-infected population is on antiretroviral therapy, an estimated 22% are not on treatment (UNAIDS, 2022). Moreover, about 8% of people on antiretroviral therapy do not have successful viral suppression (UNAIDS, 2022). With such a disproportionately high number of individuals with untreated HIV infections, the risk of invasive *L. monocytogenes* infections is a major concern for Africa. Using a dose–response model, Pouillot *et al.* (2015) estimated the probability of developing invasive listeriosis from ingesting a single cell of *L. monocytogenes* to be 100-fold higher for HIV-infected individuals than the general non-susceptible population. Epidemiological data from the 2017–2018 South African listeriosis outbreak demonstrated the impact of HIV infection as a risk factor in African settings, with a disproportionately higher number of cases observed among HIV-infected persons (Thomas *et al.*, 2020). Along with the high HIV infection rates, the fertility rate is likely to be another major risk factor in pregnancy-associated listeriosis. The estimated probability of developing invasive listeriosis in pregnancy is 1000-fold higher than the general non-susceptible population (Pouillot *et al.*, 2015). Compared to other regions, sub-Saharan Africa has the highest female fertility rates in the world (Atake & Ali, 2019). In the 2017–2018 South African outbreak, 50% of the total cases were pregnancy-related, the majority (87%) of which occurred in neonates (Thomas *et al.*, 2020). Moreover, a retrospective study of pregnancy-associated listeriosis cases in South Africa found that HIV seropositivity and anaemia were additional risk factors (Iiyambo *et al.*, 2022). Iron deficiency anaemia is an endemic problem in sub-Saharan Africa with prevalence rates of up to 60% in some worst affected countries (Kassebaum and GBD 2013 Anemia Collaborators, 2016). It is a known risk factor in human susceptibility to invasive bacterial infections (Abuga *et al.*, 2023).

Another major listeriosis risk factor that is likely to have a big influence on Africa is population ageing. In general, old age (>65 years) has been known to be associated with a high risk of mortality in cases of invasive listeriosis (Scobie *et al.*, 2019). At the current rate, the global proportion of older people is projected to increase (Rudnicka *et al.*, 2020). With the rise in ageing, a concomitant increase in the incidence of multi-morbidities has also been observed (Chang *et al.*, 2019). Many of these conditions such as cardiovascular disease, liver disease and haematological malignancy have been known to be co-morbidities associated with a high risk of mortality in cases of invasive listeriosis (Scobie *et al.*, 2019).

Regional food trade and globalisation

Global and regional trade in raw and processed food products is a significant part of African economies (Zamani *et al.*, 2021). Currently, most of the trade in the typical vehicle foods for *L. monocytogenes* transmission (meat, dairy and fishery) is in the form of imports into Africa, with limited intra-Africa trade (Zamani *et al.*, 2021). For instance, in 2018, West African countries imported about 484 million tonnes of poultry meat and milk products from the EU and North America, while South Africa imported 30% of its chicken meat requirements, mostly from Brazil (Makgopa, 2020; Zamani *et al.*, 2021). Although intra-Africa trade is not as prominent as food imports, the more industrialised countries like South Africa export both raw and processed meat products to neighbouring countries within the Southern African Development Community (SADC) region (Makgopa, 2020). South African companies and retail chains supply the bulk of the processed food products sold in countries such as Botswana, Namibia, Zambia and Zimbabwe (das Nair & Chisoro, 2016). The public health impacts of the regional trade were directly evident at the height of the listeriosis outbreak in 2018. Up to 15 countries (Angola, Botswana, Democratic Republic of Congo, Ghana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Nigeria, eSwatini, Uganda, Zambia and Zimbabwe) were affected by recalls of the contaminated polony (Olanya *et al.*, 2019). With such wide distribution networks of processed RTE foods, the African urban food systems pose a potential risk to epidemic listeriosis outbreaks.

Climate change effects

At the current rate of global warming, annual average surface temperatures are predicted to increase by up to 5°C by the end of the century (IPCC, 2021). The environmental effects of climate change have significant impacts on the epidemiology of foodborne diseases (Anas *et al.*, 2021). Several studies have provided evidence for a strong correlation between ambient temperature conditions and the incidence of infection by foodborne pathogens such as *Salmonella*, *Vibrio cholerae* and *Campylobacter* (Reyburn *et al.*, 2011; Jiang *et al.*, 2015; Kuhn *et al.*, 2020; Morgado *et al.*, 2021). As for *L. monocytogenes*, evidence from the listeriosis surveillance in the EU from 2008 to 2016 showed a seasonal pattern of cases with higher peaks during the warmer summer months (EFSA & ECDC, 2017). At the current rate, the African continent is predicted to record average temperature increases of 3.5–5.6°C by the end of the century (Almazroui *et al.,* 2020). On the other hand, precipitation predictions indicate spatial variations across the continent where the Northern and Southern regions are projected to get drier while the Central, East and West African regions are projected to have an increasing precipitation trend (Almazroui *et al.,* 2020).

An increasing trend in ambient temperatures will likely put a strain on cooling systems that could cause temperature fluctuations and enhance *L. monocytogenes* multiplication risks in contaminated foods (Hellberg & Chu, 2016). For instance, Christison *et al.* (2008) found that core temperatures of RTE foods in retail delicatessens in South Africa were ranging from 10 to 16°C instead of the recommended range of 4–8°C due to warm ambient conditions. Additionally, elevated ambient temperatures could affect the expression of virulence genes in the pathogen within the environment and the potential spread of hyper-virulent strains (Bruno Jr & Freitag, 2010; Levy *et al.,* 2016). As an environmental saprophyte, *L. monocytogenes* normally exists in an avirulent state in which virulence genes are repressed at temperatures of 30°C and below (Sibanda & Buys, 2022). Elevated temperatures at 37°C serve as a stimulus for the activation of virulence gene expression (Sibanda & Buys, 2022). In the normal infection cycle of *L. monocytogenes*, the activation of virulence gene expression occurs inside the host as the organism switches from the avirulent to the virulent state. Constitutive expression of virulence genes within the environment observed in some mutants has been associated with hyper-virulence (Bruno Jr & Freitag, 2010).

Based on overall predictions of precipitation trends for the African continent, the frequency and intensity of extreme weather (drought and floods) are likely to worsen (Almazroui *et al.,* 2020). Although there is currently limited data showing a correlation between drought and foodborne diseases, several factors suggest a possible increase in the risk of human exposure to foodborne pathogens (Levy *et al.,* 2016). These include the concentration of faecal contamination in water sources and greater dependence on non-potable sources of water for cleaning food-processing equipment and domestic use in times of drought (Levy *et al.,* 2016; Chersich *et al.,* 2018). A study by Wang *et al.* (2022) in African LMICs observed that mild and severe drought was associated with a 5% increase in the risk of diarrhoea. Likewise, Iwu *et al.* (2022) observed high levels of *L. monocytogenes* contamination in irrigation water from semi-arid regions of South Africa and an increased risk of human exposure through unintentional and intentional ingestion of such water.

In addition, drought-induced restrictions in potable water supplies, particularly in densely populated urban areas can lead to an increased risk of foodborne disease outbreaks. Burr *et al.* (1978) observed a strong association between water restriction times and rates of childhood diarrhoea. Similarly, evidence from around Africa has shown that higher precipitation and flooding events are associated with a high risk of foodborne diseases (Horn *et al.,* 2018; Cissé, 2019).

Listeria monocytogenes food safety standards in Africa

Microbiological safety standards can provide a regulatory guide that assures consumer protection against food safety hazards. A survey on microbiological standards conducted as part of this review showed that only a few African countries have any form of standards on *L. monocytogenes* in their food safety legislation (Table 3). Among these countries, the specified standards vary in terms of the allowable limits and the type of foods covered by the respective regulations (Table 3). Whereas some countries have requirements for the absence of *L. monocytogenes* in one or five samples of 25 g of raw and RTE products, others have limits of 100–1000 CFU g^{-1} (Table 3). Moreover, the food products listed in the respective regulations also vary with the focus seemingly on raw fishery, beef and poultry products. The focus on raw animal and fishery products is probably a reflection of efforts by African countries to meet the export safety requirements to overseas markets (World Bank, 2022). Indeed, many LMICs successfully export safe food but are unable to implement sustainable food safety systems that work for domestic settings dominated by informal markets and food vendors (Waage *et al.,* 2022). In view of the projected rise in the proportion of susceptible population groups and consumption of high-risk RTE foods, it will be prudent for African countries to develop domestic standards and regulations for the protection of consumers.

In countries with a higher level of formal food production like South Africa, the implementation of regulated standards would provide a significant level of consumer protection against potential outbreaks as the food business operator is an essential stage of ensuring the safety of RTE products before release to the market. Already, global guidelines for risk-based regulations for *L. monocytogenes* in RTE foods are available (CAC, 2009). However, data on the physicochemical profiles of African RTE foods, the growth potential of the pathogen in the respective foods, the amount and frequency of consumption of the foods, the virulence potential of strains found in the African food environment and susceptibility profiles of African populations are necessary to understand the relative risks to African consumers. In the aftermath of the 2017–2018 outbreak, the subject of mandatory *L. monocytogenes*

Table 3 Standards and limits for *Listeria monocytogenes* in foods as specified in the regulations of some African countries

Countries with standards for *L. monocytogenes*	Listed Foods	Limits	Regulation[†]
Djibouti	Meat and fishery products	<100 CFU g^{-1}	Official Journal of the Republic of Djibouti (Arrêté n°2000-0728/PR/MAEM)
Egypt	Pasteurised cream, whipped cream, fermented cream, butter, cheese, powdered milk, dietetic food intended for high-risk groups, frozen raw crustaceans and coleslaw	Absent in five samples of 1 g of product	Food and Agricultural Import Regulations and Standards of Egypt
Kenya	Meat products	Absent in a 25 g sample	Kenya Standard (DKS 2830: 2018)
Madagascar	Seafood and aquaculture products	Absent in five 25 g samples <100 CFU g^{-1} before the end of the product shelf-life	Ministry of Agriculture and Fisheries of Madagascar (ARRETE No 6235/2009)
Mauritania	RTE aquatic food products	Absent in five 25 g samples <100 CFU g^{-1} before the end of the product shelf-life	Arrête conjoint no. 2905
Mauritius	Infant formula, dairy products, cheese and other RTE food products	Absent in 1 g samples of infant formula and dairy products Absent in 25 g samples of cheese <1000 CFU g^{-1} in other RTE products	Mauritius Food Regulations (GN 173 of 1999)
Morocco	Meat, poultry and fishery products	Absent in five 25 g samples	Microbiological Standards for Food of Animal Origin, Morocco (MO1814)
Seychelles	Fishery products	Absent in five 25 g samples taken before the product left the establishment	Export of Fishery Products (Sanitary) Regulations (2010) of Seychelles
Saint Helena	RTE fishery products	Absent from five 25 g samples taken before the product left the establishment	Fish and Fish Products Regulations (2011) of St Helena
Tunisia	RTE processed bovine, poultry and lagomorph meat products	Absent in five 25 g samples before the products have left the establishment <100 CFU g^{-1} in products before the end of shelf-life	Journal Officiel de la République Tunisienne (2013)
Uganda	Fishery products	<1000 CFU g^{-1}	The Uganda Gazette, The Fish (Quality Assurance) Rules, 2008
United Republic of Tanzania	Raw or cooked red meat sausages	Absent from 25 g samples of the product	Tanzania Bureau of Standards (AFDC 22 (5279) P3)

[†]Regulations are available from the FAOLEX database (http://www.fao.org/faolex/en/).

standards for processed RTE meat products was debated among authorities and industry stakeholders. Based on submissions from representatives of food manufacturers and the food retail sector, the adoption of the Codex 100 CFU g^{-1} *L. monocytogenes* limit for RTE meat products appeared to be a common agreement (CGCSA, 2018). Ultimately, the role of governments and public health institutions in controlling and regulating the informal food sector and effective consumer risk education will be crucial in preventing big outbreaks in future.

Conclusions and future directions

On a global level, the incidence of invasive listeriosis is comparatively lower than other bacterial foodborne diseases, yet it has the highest fatality rate. In Africa, listeriosis is not given much attention in public health systems. In the absence of systems for identifying and reporting cases, the incidence of the disease is hard to establish. However, the occurrence of the greatest outbreak in history in South Africa in 2018 is an indication of the potential public health dangers of ignoring the disease in Africa. With the transformation of value chains and diet diversification brought about by the rapid urbanisation of many African countries, several risk factors create opportunities for *L. monocytogenes* transmission and consumer exposure. The increased consumption of high-risk RTE meat, fishery and dairy foods, cold chain challenges that increase the potential for pathogen multiplication, a high proportion of listeriosis-susceptible subpopulations, inadequate consumer food safety knowledge and climate change effects are all risk factors that could potentially exacerbate consumer exposure and listeriosis outbreaks in African settings. As a precautionary approach, it will be necessary for African countries to implement systems for the detection and reporting of listeriosis cases. This could be done systematically through the laboratory diagnosis of meningitis and maternal infections, especially where the common bacterial causes are excluded. Furthermore, such laboratory-based surveillance should be enhanced by genomic surveillance techniques like whole-genome sequencing that improve the efficiency of outbreak detection and epidemiological identification of implicated RTE foods. In addition, food safety regulations that include *L. monocytogenes* standards and limits in high-risk RTE foods will be necessary to provide a layer of consumer protection. In light of the wide diversity of potentially high-risk African RTE products, a risk profiling of these foods with regards to the ability to support *L. monocytogenes* growth under the commonly used temperature–time conditions of storage is necessary as a basis for customised food safety standards for African settings. Other mitigatory measures should include consumer risk education and dietary guidelines for listeriosis-susceptible subpopulations.

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Thulani Sibanda: Conceptualization (lead); formal analysis (lead); visualization (equal); writing – original draft (lead). **Victor Ntuli:** Conceptualization (equal); writing – original draft (equal). **Swaleha Hudaa Neetoo:** Conceptualization (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Ihab Habib:** Conceptualization (equal); writing – original draft (equal). **Patrick Murigu Kamau Njage:** Conceptualization (equal); writing – original draft (equal). **Angela Parry-Hanson Kunadu:** Conceptualization (equal); writing – original draft (equal). **Anthonia Helga Andoh:** Writing – original draft (equal). **Ranil Coorey:** Funding acquisition (equal); writing – original draft (equal). **Elna M. Buys:** Conceptualization (lead); funding acquisition (lead); project administration (lead); resources (lead); supervision (lead); visualization (equal); writing – review and editing (equal).

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The authors declare no conflict of interest.

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Ethics approval was not required for this research.

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