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Microbiological safety of ready-to-eat foods in low- and middle-income countries: A comprehensive 10-year (2009 to 2018) review

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Abstract

Ready-to-eat foods (RTEs) are foods consumed without any further processing. They are widely consumed as choice meals especially by school-aged children and the fast-paced working class in most low- and middle-income countries (LMICs), where they contribute substantially to the dietary intake. Depending on the type of processing and packaging material, RTEs could be industrially or traditionally processed. Typically, RTE vendors are of low literacy level, as such, they lack knowledge about good hygiene and food handling practices. In addition, RTEs are often vended in outdoor environments such that they are exposed to several contaminants of microbial origin. Depending on the quantity and type of food contaminant, consumption of contaminated RTEs may result in foodborne diseases and several other adverse health effects in humans. This could constitute major hurdles to growth and development in LMICs. Therefore, this review focuses on providing comprehensive and recent occurrence and impact data on the frequently encountered contaminants of microbial origin published in LMICs within the last decade (2009 to 2018). We have also suggested viable food safety solutions for preventing and controlling the food contamination and promoting consumer health.

KEYWORDS

consumer protection, food safety, foodborne bacteria, mycotoxins, public health

1 | INTRODUCTION

Ready-to-eat foods (RTEs) are foods consumed without any further processing or preparations. They could be traditionally or industrially processed, packaged, or unpackaged and are usually considered to comprise, mainly, the publicly vended foods consumed immediately or later (Cerna-Cortes et al., 2015; FAO & WHO 2004; Von Holy & Makhoane, 2006). Similar to other regions, RTEs are widely consumed in low- and middle-income countries (LMICs) due to ease of production, availability, affordability, and palatability (Al Mamun, Rahman, & Turin, 2013a; Al Mamun, Rahman, & Turin, 2013b; Mensah, Yeboah-Manu, Owusu-Darko, & Ablordey, 2002). RTEs can be processed from single or mixed raw ingredients, such as cereals, fish, meat, nuts, and spices, into foods that may be liquid, semi-solid, or solid in consistency (Adebayo-Oyetoro et al., 2017; Ceyhun Sezgin & Sanher, 2016; Feglo & Sakyi, 2012). Based on the type of processing technique and packaging material, RTEs could range from traditionally processed foods such as *chaat* in India (Agrawal, Gupta, & Varma, 2008), *matoke* in Uganda (Bardi et al., 2014), and *warankasi* in Nigeria (Adeyeye, 2017) to industrially processed foods such as bread, biscuits, canned sardine, ice cream, and pizza. Depending on the type, RTEs can be consumed by different groups of people ranging from children to adults. For instance, *kulikuli* is mostly consumed by children of school age as well as adults in Nigeria and Benin (Adjou, Yehouenou, Sossou, Soumanou, & De Souza, 2012; Ezekiel et al., 2013). In addition, RTEs are the preferred food by individuals who are often very busy and have less time to prepare meals while at work.

It is on record that many RTE vendors in LMICs often lack knowledge about good hygiene practices, which may predispose the foods to microbial contamination (Al Mamun et al., 2013a, 2013b; WHO, 2010). The situation is further complicated by the practice of vending RTEs in outdoor environments. Consequently, the foods are exposed to aerosols, insects, and rodents, which serve as sources of food contaminants (Fowoyo & Igbokwe, 2014; Mensah et al., 2002). The microbial contaminants of RTEs include bacteria (for example, species of *Bacillus*, coagulase negative Staphylococci, *Escherichia coli*, *Klebsiella pneumoniae*, *Listeria monocytogenes*, *Pseudomonas* spp., and *Staphylococcus aureus*; Annan-Prah et al., 2011; Fadahunsi & Makinde, 2018; Felgo & Sakyi, 2012; Gdoura-Ben Amor et al., 2018; Kharel, Palni, & Tamang, 2016; Tambekar, Jaiswal, Dhanorkar, Gulhane, & Dudhane, 2009), fungi (for example, diverse toxigenic species of *Aspergillus*, *Alternaria*, *Fusarium*, and *Penicillium*; Adjou et al., 2012; Oranusi & Nubi, 2016), parasites (for example, *Ascaris lumbricoides* and *Toxoplasma gondii*; Abd El-Razik, El Fadaly, Barakat, & Abu Elnaga, 2014; Manyi, Idu, & Ogbonna, 2014), and viruses (for example, hepatitis A virus; Yongsi, 2018). Additionally, the contaminating bacteria and fungi may further constitute increased public health risk by secreting toxic compounds such as cereulide (Ceuppens et al., 2011) and mycotoxins (IARC, 2015), respectively, at different stages during food production. Nonmicrobial-related RTE contaminants include heavy metals (for example, lead; Jalbani & Soylak, 2015) and pesticide residues (for example, tetradifon; Skretteberg et al., 2015) mostly found in plant-based RTEs, as well as polyaromatic hydrocarbons from car fumes and other industrial sources (Proietti, Frazzoli, & Mantovani, 2014). Depending on the type and concentration of contaminant, amount of food ingested by consumers, and health status of the consumer, acute or chronic foodborne diseases (FBD) may be result. On the other hand, continuous daily exposure to single or mixtures of these food contaminants via consumption of contaminated RTEs could produce a plethora of adverse health effects. Observable effects may range from mild to recurrent nausea, vomiting, and diarrhea (Ceuppens et al., 2011) to severe complications such as cancers, neural tube defects, and even human fatalities (Gibb et al., 2015; IARC, 2015; JECFA, 2017, 2018; Kamala et al., 2018; Wild & Gong, 2010). Thus, improperly prepared RTEs in LMICs, where regulations and monitoring for compliance are grossly inadequate, may constitute a huge risk to public health.

The World Health Organization (WHO) of the United Nations reported that LMICs, particularly those in the African and South-East Asian sub-regions, suffer significantly from the burden of FBD (Havelaar et al., 2015), sometimes resulting to huge economic losses. To put this into proper perspective, the World Bank estimates that the total productivity loss associated with FBD in LMICs is about US$44.4 billion per year, whereas the annual cost of treating these diseases costs several billion dollars (Jaffee, Henson, Unnevehr, Grace, & Cassou, 2019). Obviously, FBD constitute a major impediment to growth and development in the affected LMICs, because resources used in treating these preventable diseases could be redistributed into building other sectors of the economy (Alimi, 2016). In addition, FBD pose a threat to several of the Sustainable Development Goals of the United Nations in LMICs (FAO/WHO, 2018; Havelaar et al., 2015). Consequently, there is a need to intensify efforts to reduce microbial contamination of RTEs across LMICs. One way to achieve this is to harness recent data (2009 to 2018) on microbial contamination profiles of RTEs available in LMICs, with a view to providing information on the most likely encountered microbial contaminants and suggest viable solutions for preventing and controlling the menace. Food contaminants of microbial origin are prioritized in this review owing to their top-ranking on the list of foodborne hazards by the WHO (FAO/WHO, 2018).

Thus, this comprehensive decade (2009 to 2018) review focuses on (a) documenting the diversity of RTEs in LMICs; (b) identifying the potential contamination sources; (c) X-raying the adequacy of detection methods applied to food contaminants of microbial origin in the regions; (d) outlining the microbiologically related hazard groups and their health effects; and (e) proffering a cocktail of food safety solutions that could be applied in LMICs for the enhancement of the RTE chain and promotion of consumer/public health. For the purpose of this review, LMICs are considered to include low-income and lower middle-income countries based on the recent categorization by the World Bank for the 2020 fiscal year (World Bank, 2019).

2 | DIVERSITY OF RTEs IN LMICs

In different regions of LMICs, RTEs are adopted and accepted as part of the cuisine of the people, thus giving them an identity and heritage, which are often passed across generations (Kraig & Taylor, 2013). For example, *uttapam* processed from rice and *warankasi* obtained from raw milk are RTEs indigenous to the people of southern India and northern Nigeria, respectively (Iwuoha & Eke, 1996; Ray, Ghosh, Singh, & Mondal, 2016). Central to RTE processing are raw ingredients, which are mostly of plant (such as, grains, nuts, and spices) and animal origin (such as, fish, meat, and milk).

Typically, the choice of RTE ingredients is largely influenced by culture and belief, income, and socioeconomic status. For example, in some parts of the Middle East and North Africa, pork is considered as unacceptable; hence, it is replaced by other meat source (such as mutton or beef) in RTEs (Benkerroum, 2013). Despite the fact that RTEs are largely region specific, there is a high propensity to try out new types of foods introduced from other parts of the world, mostly due to human migration. RTEs such as *sharwama* (Middle East) and *samosa* (Middle East and Asia) have become globally acceptable and are widely consumed especially in several LMICs (Privitera & Nesci, 2015).

Interestingly, RTE recipes and processing techniques are often similar across regions despite their diversity, although the RTE local names largely differ. For example, the grilling or roasting technique commonly applied during meat processing into *nyama choma* in Kenya (Mwangi, den Hartog, Mwadime, van Staveren, & Foeken, 2002) is also applied to process meat into *suya* in Nigeria (Obadina, Oyewole, & Ajisegiri, 2013). Similarly, fava beans are fried with other ingredients to produce *falafel* in Egypt (El-Shenawy, El-Shenawy, Mañes, & Soriano, 2011) and *madlu'e* in Syria (Ceyhun Sezgin & Şanher, 2016). Table 1 shows the diversity of RTEs in some LMICs. Obviously, frying, roasting, and grilling are considered the prominent techniques employed in the RTE processing across LMICs.

3 | POTENTIAL SOURCES OF CONTAMINATION OF RTEs

In LMICs, RTEs are processed and sold under unhygienic conditions such that the risk of exposure to food contaminants is increased (Al Mamun et al., 2013a, 2013b; WHO, 2010). These conditions as well as other factors are discussed below.

3.1 | Quality of ingredients

The use of high-quality ingredients is critical to ensuring the safety of RTEs. However, in LMICs, it is common practice for vendors to purchase low-quality (often visibly bad) ingredients (such as cereals, legumes, spices, and vegetables) that are prone to heavy contamination by bacteria, fungi, and their toxins (Alimi, 2016) for RTE processing. Obvious reasons for the utilization of low-quality ingredients include poverty (less income to purchase high-quality ingredients); the need to generate more family income, which leads to purchase of large quantity of low-grade ingredients at low cost (often mixed with very small quantity of high quality ingredients) for RTE processing; and low awareness of the severity of FBD. To worsen the scenario, the low-quality ingredients are often not properly processed or are undercooked. Consequently, microbial spores or their toxins may be carried over into the finished products, thus constituting a health risk to the consumers (Alimi, 2016; Khairuzzaman, Chowdhury, Zaman, Al Mamun, & Bari, 2014).

3.2 | Contaminated food process chains

Central to RTE preparation is water, which is usually applied in large proportions during several processing steps such as dilution, fermentation, milling, steeping, and washing of RTE ingredients. Thus, it is crucial that water utilized for the processing of RTEs is free from microbiological contaminants. This is often not the case in many LMICs, especially in resource scarce rural settings, where potable water is not readily available (Ritchie & Roser, 2019; WHO, 2017). Consequently, water from questionable sources such as wells, streams, and rivers (sometimes stored for long periods in unsterilized open containers) is routinely applied during the processing of RTEs. Thus, the application of potentially contaminated water in RTE processing could predispose the foods to pathogenic bacteria such as *Campylobacter*, *E. coli*, *Salmonella*, *Pseudomonas*, and *Vibrio*. Consequently, consumers could be at risk of severe public health challenges (Rane, 2011).

Quality of food packaging materials is another critical factor to consider in evaluating the role of contaminated food process chains in RTE safety and consumer safety. In many LMICs, the choice of food packaging material depends on the type of RTE. Common packaging materials for locally processed RTEs include prewashed but unsterilized plastic bottles for packaging of liquid RTEs such as fermented beverages; polyethylene/nylon bags; or used paper (for example, newspapers). The utilization of these kinds of low-quality packaging materials may be direct source of pathogenic foodborne bacteria as well as fungal propagules; however, limited research data are available in this regard. Poor personal hygiene during food processing is an additional predisposing factor for RTE contamination during the process chain (Fellows & Hilmi, 2011). This is often facilitated by the low awareness level and poverty status of many of the local RTE processors in LMICs. Good personal hygiene is necessary during actual food preparation as well as during food packaging in order to limit RTE contamination.

3.3 | Unhygienic vending practices and conditions

Poor post-food production handling by vendors plays a key role in RTE contamination (Fellows & Hilmi, 2011). RTE vendors often lack good hygiene practices. A common scenario is vendors not washing their hands, the washing of hands with nonpotable (contaminated and unsterilized) water, or use of potable water but without detergents or disinfectants before RTEs are packaged. For instance, it is common vendor

TABLE 1 Diversity of traditionally processed ready-to-eat foods in low- and middle-income countries

Region	Country	Ready-to-eat food	Raw ingredients	Processing technique	References
Africa	Egypt	*Falafel*	Ground chickpeas and/or fava	Frying	El-Shenawy et al., 2011
	Ethiopia	*Injera* and *Wot*	Tef bread, beef, lamb, chicken, goat, lentils, or chickpeas, with spicy Berbere	Cooking	Reda, Ketema, & Tsige, 2017
	Ghana	*Banku kenkey*	Cassava/plantain and yams	Steaming/ boiling	Rheinländer et al., 2008
	Kenya	*Nyama choma* with *Ugali*	Beef, veal, sheep, lamb, goat, and maize/cassava dough	Grilling and steaming	Mwangi et al., 2002
	Morocco	*Merguez*	Lamb or beef, flour, and red pepper	Baking	Benkerroum, 2013
	Nigeria	*Chin chin*	Wheat flour and eggs	Frying	Adebayo-Oyetoro et al., 2017
		Suya	Spiced meat and onions	Grilling	Obadina et al., 2013
		Akara	Beans	Frying	Omemu & Aderoju, 2008
		Moi-moi	Beans, pepper, and onions	Steamed/ boiled	Nkere, Ibe, & Iroegbu, 2011
	Tanzania	*Ndizi Kaanga*	Bananas or plantains	Frying	Sanches-Pereira et al., 2017
	Uganda	*Matoke*	Mashed plantain and groundnut sauce	Steaming/ boiling	Bardi et al., 2014
Asia	India	*Chaat*	Flour, yoghurt, onions, sev, coriander, and spices	Frying	Agrawal et al., 2008
		Pakoda	Kodo millet, onions, green chillies, and spices	Frying	Deshpande, Mohapatra, Tripathi, & Sadvatha, 2015
		Pani puri	Unleavened Indian bread fried crisp, tamarind, chili, potato, onion, chickpeas, and various vegetables	Frying	Fellows & Hilmi, 2011
		Samosa	Flour, potato, onion, spices, oil, and salt	Frying	Kharel et al., 2016
	Indonesia	*Nasi putih*	long-grain rice, chicken, pork, dog meat, goat, or beef, coconut milk	Cooked	Neufingerl et al., 2016
	Pakistan	*Pahata roll*	Beef or chicken, bread, onions, tomato, and *raita*	Frying	Ceyhun Sezgin & Şanher, 2016
	Philippines	*Siomai*	Squid, fish balls, chicken, and dipping sauces	Frying	Kraig & Taylor, 2013
		Taho	Bean curd, syrup, and tapioca balls		Canini, Bala, Maraginot, & Mediana, 2013
Caribbean	Haiti	*Mayi moulen* with *pikliz*	Rice, beans, cornmeal mush, kidney beans, coconut, and peppers with spicy pickled carrots and cabbage	Boiling, frying	Ceyhun Sezgin & Şanher, 2016
Middle East	Palestine and Syria	*Madlu'e*	Sweet cheese curds, rich biscuit in Syrup, ground chickpeas, and/or fava beans	Frying	Ceyhun Sezgin & Şanher, 2016

practice to directly touch meat-based RTE (for example, *suya*) with unwashed hands during the postproduction slicing process. In addition, most vendors do not wear protective coverings (for example, nylon gloves) before the packaging of RTEs.

A major feature of RTE vending points in LMICs is their characteristic dirty surroundings. Vendors openly display the foods for sale in roadside make-shift sheds, which are sometimes situated close to dump sites or dirty stagnant roadside water. These serve as reservoirs to flies and other insects that are potential carriers of several bacterial pathogens (Lindh & Lehane, 2011). A study in Uganda revealed that 74.2% of vendors prepared food close to fly and insect infested trash receptacles (Muyanja, Nayiga, Brenda, &

Nasinyama, 2011). Furthermore, improperly washed vending utensils often contain leftover food particles suitable for proliferation of pathogenic microorganisms that could potentially cross-contaminate freshly prepared RTEs (Fellows & Hilmi, 2011; Muyanja et al., 2011). In many LMICs, the unhygienic vending condition is an easily controllable factor if regulations targeting RTEs and their vending become existent and are enforced.

4 | DETECTION OF CONTAMINANTS OF MICROBIOLOGICAL ORIGIN IN RTEs

Analytical techniques employed in the microbiological analysis of food typically include conventional (Mandal, Biswas, Choi, & Pal, 2011) and molecular methods (Law, Ab Mutalib, Chan, & Lee, 2015). A combination of these techniques, often referred to as "polyphasic approach," is usually applicable for high-throughput analysis of the food matrix (Randazzo, Scifo, Tomaselli, & Caggia, 2009). The application of conventional methods relies solely on the isolation of bacteria on general purpose or selective media (for example, nutrient agar, MacConkey agar, or eosin methylene blue) and of fungi on mycological media (such as, malt extract agar) (Samson, Houbraken, Thrane, Frisvad, & Anderson, 2019). Microbial isolation is typically followed by preliminary identification based on the assessment of morphological features including colony color, pigmentation, colony reverse color on selective media, microscopic characters, and reactions to a set of biochemical tests (for example, catalase, coagulase, and indole tests for bacteria) (Mandal et al., 2011). Majority of the studies on bacterial identification in RTEs in LMICs were solely based on conventional methods of microbe characterization (Table 2). The preferred application of conventional methods in microbial characterization in many LMICs is multifactorial including lack of molecular facilities, lack of expertise, inadequate research funding for human capacity, and infrastructural development. Although conventional methods are relatively cheaper compared to molecular methods, significant limitations such as laboriousness and low precision leading to species misidentification make the conventional method inappropriate for microbial typing (Law et al., 2015; Mandal et al., 2011; Zhao, Lin, Wang, & Oh, 2014).

In contrast, molecular methods offer a more sensitive and accurate mode of microbial identification (EFSA, 2013). These methods generally involve classifying pathogenic microorganisms based on genotypic traits as well as on genetic determinants known to increase their virulence and aid their adaptability to various food matrices (Hallin, Deplano, & Struelens, 2012; Mandal et al., 2011; Van Belkum et al., 2007). The ability of molecular techniques to accurately and rapidly detect pathogenic microorganisms known to cause FBD ensures source tracking and proper surveillance of RTEs (ECDC, 2013; Law et al., 2015). Consequently, high-throughput molecular methods such as next-generation sequencing and whole genome sequencing (WGS) add credence to inferences made from surveillance studies by highlighting phylogenetic similarities among microorganisms. WGS further provides information on the evolution of the microorganisms as well as their genetic determinants that could increase virulence and pathogenicity (Hazen et al., 2013; Leekitcharoenphon, Nielsen, Kaas, Lund, & Aarestrup, 2014). Aside the application of WGS in surveillance studies, it is an invaluable approach during cases of outbreaks because it gives a clearer picture of the possible source of outbreaks and provides sufficient data on ways to prevent the spread to other regions (Chin et al., 2011; Hendriksen et al., 2011). A typical example is the application of WGS in the 2010 cholera outbreak in Haiti, a LMIC. This technique revealed the *V. cholerae* strain(s) responsible for the outbreak may have been accidentally introduced from another geographical location (Chin et al., 2011; Hendriksen et al., 2011). Recently, molecular techniques including WGS have also been applied in other studies involving fermenters in traditional foods and pathogens in vegetable samples of LMIC origin (Adewumi, Oguntoyinbo, Keisam, Romi, & Jeyaram, 2013; Diaz et al., 2018; Ezekiel, Ayeni, et al., 2019; Igbinosa et al., 2018). These studies have mostly been conducted in collaboration with institutions in the North (Western world) where facilities and expertise are readily available; thus, technology and expertise transfer to LMICs are expected in the future.

In order to detect chemical contaminants of microbial origin in RTEs, several techniques including enzyme-linked immunosorbent assay (ELISA), high-performance liquid chromatography (HPLC), and liquid chromatography–tandem mass spectrometry (LC/MS–MS) can be applied. In most LMICs, the ELISA method represents the most viable technique for detection of frequently encountered chemical contaminants (for example, mycotoxins) in RTE foods. This is largely due to its low cost of analysis relative to high-end techniques such as the HPLC and LC–MS/MS. However, the ELISA technology has several limitations such as low sensitivity and inability to simultaneously detect multiple mycotoxins (Berthiller et al., 2013). In addition, ELISA kits are only readily available for the detection of single mycotoxins (for example, aflatoxin B_1, total aflatoxin, and ochratoxin A in foods). This constitutes a major hurdle to food safety especially in most LMICs, where there is frequent co-occurrence of multiple mycotoxins in dietary staples and RTE ingredients (Abia et al., 2017; Oyedele et al., 2017; Sombie et al., 2018; Warth et al., 2012). Thus, high-end chromatography–based techniques (for example, HPLC and the more

TABLE 2 Bacterial contamination of ready-to-eat (RTE) foods in low- and middle-income countries (2009 to 2018)

Region/ Country	RTE food	Potential source of contamination	Pathogen	Prevalence %(*n*/ *N*)	Analytical technique	References
Africa						
Burkina Faso	Grilled chicken	Poor hygiene practices	*E. coli*	27.45 (28/102)*	Conventional and Polymerase Chain Reaction (PCR)	Somda et al., 2018
Cameroon	Cooked pork	Poor hygiene and sanitary practices	*E. coli* *K. pneumoniae* *S. aureus*, *Salmonella* *Proteus vulgaris* *Shigella* spp.	54.4 (6/11)* 72.7 (8/11)* 81.8 (9/11)* 45.4 (5/11)* 27 (3/11)* 9 (1/11)*	Conventional	Yannick, Rawlings, & Emmanuela, 2013
Cote d'Ivoire	Cooked kebabs	Poor hygiene practices	*C. perfringens* *C. difficile* *C. sporogenes*	13 (81/222)** 20.5 (27/222)** 21.2 (91/222)**	Conventional	Kouassi, Dadie, Nanga, Dje, & Loukou, 2011
Democratic Republic of Congo	Bush meat Smoked fish	Poor hygiene and handling practices	*Salmonella* sp. *S. aureus* *Salmonella* sp. *S. aureus*	56.25 (9/16)* 93.75 (15/16)* 50 (9/18)* 33.3 (6/18)*	Conventional	Makelele et al., 2015
Egypt	*Shawarma*	Poor hygienic conditions	*Listeria* species *L. monocytogenes* *L. innocua*	24 (138/576)* 57 (328/576)* 39 (225/576)*	Conventional	El-Shenawy et al., 2011
Egypt	Sliced luncheon meat and chicken nuggets	Poor hygiene and food handling	MRSA	37.5 (30/80)*	Conventional PCR-Restriction Fragment Length Polymorphism (RFLP)	El Bayomi et al., 2016
Egypt	Burger sandwiches		*Listeria* species	60 (6/10)*	Conventional	Zaghloul et al., 2014
Egypt	*Shawarma* with salads		*C. jejuni* *S. enterica* *A. baumannii*	31.8 (22/69)** 13.04 (9/69)** 8.69 (6/69)**	Conventional and MALDI-TOF	Elbehiry et al., 2017
Ethiopia	*Ambasha*	Poor hygienic conditions	*E. coli* *Proteus* spp. *Klebsiella* spp. *Citrobacter* spp.	19 (4/21)*** 28.5 (2/7)*** 14.3 (1/7)*** 33.3 (3/9)***	Conventional	Eromo et al., 2016
Ethiopia	*Sambusa* *Bombolino* *Macaroni*	Poor hygienic conditions	*S. aureus* *E. coli* *S. aureus* *E. coli* *S. aureus* *E. coli*	56.2 (9/16)** 37.5 (6/16)** 66.7 (9/12)** 50 (6/12)** 58.3 (7/12)** 75 (9/12)**	Conventional Conventional Conventional	Derbew et al., 2013, Derbew et al., 2013, Derbew, Sahle, & Endris, 2013

(Continues)

TABLE 2 (Continued)

Region/ Country	RTE food	Potential source of contamination	Pathogen	Prevalence %(*n*/ *N*)	Analytical technique	References
Ghana	*Ice-kenkey* and *Macaroni*	Poor food handling Poor food handling	*Bacillus* sp. CoNS *Klebsiella* sp. *Enterobacter* sp. *E. coli* *S. aureus* *Aeromonas* sp. *Bacillus* sp. CoNS *Klebsiella* sp. *Enterobacter* sp. *S. aureus* *Aeromonas* sp.	5.9 (8/135)** 7.4 (10/135)** 0.7 (1/135)** 0.7 (1/135)** 0.7 (1/135)** 1.5 (2/135)** 3.0 (4/135)** 3.0 (4/135)** 4.4 (6/135)** 5.9 (8/135)** 0.7 (1/135)** 0.7 (1/135)** 4.4 (6/135)**	Conventional Conventional	Felgo & Sakyi, 2012 Felgo & Sakyi, 2012
Ghana	Fried rice	Poor hygiene practices	*E. cloacae*, *E. coli*, *K. pneumoniae*, and *S. aureus*	NA (NA)	Conventional	Yeboah-Manu, Kpeli, Akyeh, & Bimi, 2010
Madagascar	RTE pork	Poor hygiene practices	*Salmonella* spp.	5.0 (9/178)*	Conventional and serology	Cardinale et al., 2015
Nigeria	*Wara*, *Kununzaki*, Smoked fish, and Meat-pie	Poor hygienic conditions	*P. aeruginosa*, *P. putida*, and *P. mendocina*	NA (NA)	Conventional	Fadahunsi & Makinde, 2018
Nigeria	*Suya*	Poor hygienic conditions	*E. coli*, *Staphylococcus* spp., *Pseudomonas* spp., *C. septicum*, *Micrococcus* spp., and *B. alvei*	NA (NA)	Conventional	Adio, Ovuoraini, & Olubunmi, 2014
Nigeria	Locally processed fruit juice	Poor quality water	*Enterococcus* spp., *E. coli*, *Bacillus* sp., and *Staphylococcus* sp.	NA (NA)	Conventional	Agwa, Ossai-Chidi, & Ezeani, 2014
Nigeria	Boiled rice and beans Bread	Poor food handling	*E. coli* *E. coli*	100 (5/5)* 40 (2/5)*	Conventional	Bukar et al., 2009 Bukar et al., 2009
	Zobo drink		*E. coli* *S. typhi*	20 (1/5)* 20 (1/5)*		Bukar et al., 2009, Bukar et al., 2009
Nigeria	*Akara* and fried potato	Poor food handling practices	*S. aureus* and *E. coli*	NA (NA)	Conventional	Madueke, Awe, & Jonah, 2014
	Fried yam	Poor food handling practices	*K. pneumoniae*	NA (NA)	Conventional	Madueke et al., 2014
Nigeria	Cooked meat	Poor hygiene and sanitation practice	*Salmonella* spp.	18 (9/50)*	Conventional and PCR	Smith et al., 2012

(Continues)

TABLE 2 (Continued)

Region/ Country	RTE food	Potential source of contamination	Pathogen	Prevalence %(*n*/ *N*)	Analytical technique	References
Nigeria	Meat pie	Poor food handling practices	*Bacillus* spp. *S. aureus* *Klebsiella* spp. *Proteus* spp. *E. coli* *Shigella* spp. *Citrobacter*	85.0 (153/180)* 38.9 (70/180)* 18.9 (34/180)* 17.8 (32/180)* 10.0 (18/180)* 5.0 (9/180)* 5.0 (9/180)*	Conventional	Obande, Umeh, Azua, Chuku, & Adikwu, 2018
Nigeria	Egg roll		*B. atrophaeus* and *B. amyloliquefaciens*	NA (NA)	16S rDNA sequencing	Aruwa & Ogunlade, 2016
	Meat pie		*B. thuringiensis* and *B. subtilis*	NA (NA)	16S rDNA sequencing	Aruwa & Ogunlade, 2016
	Buns		*B. licheniformis*	NA (NA)	16S rDNA sequencing	Aruwa & Ogunlade, 2016
Kenya	Street vended meat	Poor hygiene practices	*S. aureus*	66.7 (6/9)*	Conventional and PCR	Gitahi, Wangoh, & Njage, 2012
Rwanda	Boiled beef, grilled chicken, grilled goat meat, grilled rabbit, and fried pork	Poor hygiene practices	*Salmonella*	11.7 (35/300)*	Conventional	Niyonzima et al., 2017
Sudan	*Um-Jinger*	Poor hygiene practices	*Bacillus* spp. *S. aureus* *E. coli* *Salmonella* spp. *Proteus* spp.	70.0 (42/60)* 68.3 (41/60)* 6.6 (4/60)* 5 (3/60)* 8.3 (5/60)*	Conventional	Abdallah & Mustafa, 2010
Sudan	*Shawarma*	Poor food handling	*E. coli* *S. aureus* *Salmonella*	NA (NA)	Conventional	Elfaki & Elhakim, 2011
Tanzania	Raw juice	Poor hygiene practices	*E. coli*	63.3 (19/30)*	Conventional	Nonga et al., 2015
Tunisia	Cooked poultry meat		*B. cereus*	32.7 (18/55)*	Conventional, PCR, and Pulsed-Field Gel Electrophoresis (PFGE)	Gdoura-Ben Amor et al., 2018
	pastries		*B. cereus*	46.2 (37/80)*	Conventional, PCR, and PFGE	Gdoura-Ben Amor et al., 2018
Asia						
Bangladesh	Sweets and dairy products	Poor hygiene and sanitation practice	*V. cholerae*	NA (NA)	Conventional	Mrityunjoy et al., 2013

(Continues)

TABLE 2 (Continued)

Region/ Country	RTE food	Potential source of contamination	Pathogen	Prevalence %(*n*/ *N*)	Analytical technique	References
Bangladesh	*Chotpoti*	Poor hygiene	*Acinetobacter* *E. coli* *Klebsiella* spp. *Proteus* spp.	66 (71/108)* 3 (3/108)* 54 (58/108)* 0.9 (1/108)*	Conventional	Hassan et al., 2016
Bangladesh	*Chatpati*	Poor hygiene practices	*Cronobacter sakazakii* *Listeria* spp. *Salmonella* spp. *Yersinia* spp.	100 (3/3)* 33.3 (1/3)* 66.7 (2/3)* 100 (3/3)*	Conventional	Tabashsum et al., 2013
Bangladesh	*Jhalmuri*	Poor food handling practices	Coliform bacteria	59.1 (13/22)*	Conventional	Al Mamun et al., 2013a
	Chotpoti	Poor food handling practices	Coliform bacteria	29.4 (5/17)*	Conventional	Al Mamun et al., 2013a
Indonesia	RTE noodle with chicken	Poor hygiene	Coliform bacteria and *S. aureus*	NA (NA)	Conventional	Adolf & Azis, 2012
India	Fruit juice	Poor water quality, unhygienic conditions	*E. coli* *Pseudomonas* spp. *Salmonella* spp. *Klebsiella* spp.	40 (31/77)** 25 (19/77)** 16 (12/77)** 3 (2/77)**	Conventional	Tambekar et al., 2009
India	RTE foods	Poor hygiene practices	*E. coli*	74 (37/50)*	Conventional, RFLP	Biswas et al., 2010
India	*Chowmein*	Poor hygiene practices	*B. cereus*, *E. coli*, *Salmonella*, and *Shigella*	NA (NA)	Conventional	Chauhan, Uniyal, & Rawat, 2015
India	Ice cream	Poor hygiene and sanitary practices	*Y. intermedia*	5 (1/20)*	Conventional and PCR	Divya & Varadaraj, 2011
	Pani puri		*Y. intermedia*	4 (2/20)*	Conventional and PCR	Divya & Varadaraj, 2011
	Bread sandwiches		*Y. enterolitica*	5 (1/20)*	Conventional and PCR	Divya & Varadaraj, 2011
India	*Chutney*		*B. cereus* (Biotype 6) *B. cereus* (Biotype 5)	38.46 (5/13)** 23.07 (3/13)**	Conventional	Hafeez, Iqbal, & Ahmad, 2012
	Mutton *tikka*		*B. cereus* (Biotype 3) *B. cereus* (Biotype 4)	29.63 (8/27)** 25.93 (7/27)**	Conventional	Hafeez et al., 2012
India	Bread *chop* and *Samosa*	Poor hygiene practices	*Bacillus* and *Staphylococcus*	NA (NA)	Conventional and Serology	Kharel et al., 2016

(Continues)

TABLE 2 (Continued)

Region/ Country	RTE food	Potential source of contamination	Pathogen	Prevalence %(*n*/ *N*)	Analytical technique	References
India	Dairy products	Poor food handling practices	MRSA	NA (NA)	Conventional, MALDI–TOF, and PCR	Manukumar & Umesha, 2017
Nepal	Fried rice	Poor hygiene practices	*B. cereus* *S. aureus* *S. typhi*	23.8 (5/21)** 19 (4/21)** 9.5 (2/21)**	Conventional	Ankita et al., 2012
Nepal	Chicken *momo*, *samosa*	Poor hygiene and poor food handling practices	*Staphylococcus* and *Salmonella*	NA (NA)	Conventional	Bohara, 2018
Nepal	*Puri*	Poor hygiene and poor food handling practices	*S. aureus* *E. coli* *B. cereus* *Citrobacter* spp.	55.5 (20/36)** 5.5 (2/36)** 27.7 (10/36)** 11 (4/36)**	Conventional	Khadka, Adhikari, Rai, Ghimire, & Parajuli, 2018
Pakistan	Pasteurized juice	Poor hygiene practices	*E. coli*, *Salmonella*, *Staphylococcus*, and *Pseudomonas*	NA (NA)	Conventional	Batool et al., 2013
India	*Panipuri*	Poor hygiene practices	*E. coli* *Klebsiella* spp.	6.25 (5/80)* 2.5 (2/80)*	Conventional	Kiranmai, Siva Kamesh, Divija, & Sara, 2016
Philippines	Hot grilled pork, hot grilled chicken	Poor hygiene practices	*E. coli*, *S. aureus*, *B. cereus*, and *Salmonella*	NA (NA)	PCR-based detection kits	Manguiat & Fang, 2013
Vietnam	Grilled pork meat	Poor hygiene practices	*S. aureus*	21.8 (7/32)*	Conventional and RFLP	Huong et al., 2009
	Ice cream		*S. aureus*	25 (3/12)*	Conventional and RFLP	Huong et al., 2009
	Fermented meat		*S. aureus*	13.8 (4/29)*	Conventional and RFLP	Huong et al., 2009

Note. Abbreviations: *n*, number of pathogen; *N*, number of samples/isolates/particular species; NA, not available; *A. baumannii*, *Acinetobacter baumannii*; *B. cereus*, *Bacillus cereus*; *B. alvei*, *Bacillus alvei*; *C. difficile*, *Clostridium difficile*; *C. perfringens*, *Clostridium perfringens*; *C. sporongenes*, *Clostridium sporongenes*; *C. septicum*, *Clostridium septicum:* CoNS, coagulase negative staphylococci; *E. coli*, *Escherichia coli*; *E. cloacae*, *Enterobacter cloacae*; *K. pneumonia*, *Klebsiella pneumonia*; *MRSA*, Methicillin-resistant *S. aureus*; *P. aeruginosa*, *Pseudomonas aeruginosa*; *P. putida*, *Pseudomonas putida*; *P. mendocina*, *Pseudomonas mendocina*; *S. aureus*, *Staphylococcus aureus*; *Y. intermedia*, *Yersinia intermedia*; *Y. enterolitica*, *Yersinia enterolitica*.

*Number of samples

**Number of isolates

***Number of a particular species

sensitive LC/MS–MS) are applied to give a more precise result and accurately quantify the concentration levels of multiple mycotoxins in several foods (Berthiller et al., 2018; Malachova, Sulyok, Beltran, Berthiller, & Krska, 2014). The application of these high-end techniques represents the gold standards for detection of multiple mycotoxins in food. However, these techniques are expensive and there is lack of skilled expertise in most LMICs, which makes routine application impracticable.

5 | PATHOGENIC BACTERIA IN RTEs FROM LMICs

The ability of pathogenic bacteria to proliferate in RTEs depends on several intrinsic (for example, nutrient composition) and extrinsic (for example, environmental temperature) factors (Smith & Fratamico, 2005). Upon consumption of contaminated foods, pathogenic bacteria can cause a wide range of adverse health effects including gastrointestinal-related diseases, thus constituting a huge health risk to consumers. The development of adverse health effects is, however, dependent on several factors including, but not limited to, number of pathogenic bacteria present in the food, age, and level of immunity of the consumer. In this section, we have clustered the diverse bacteria reported in RTEs across LMICs into two broad groups: Gram-negative and Gram-positive.

5.1 | Gram-negative bacteria

This group of bacterial species can be found in a wide range of habitats including the gastrointestinal tract of humans and animals. They contribute significantly to the FBD burden in LMICs (Kirk et al., 2015a, 2015b). Of major concern to food safety is the ability of some members, for example, *Vibrio cholerae* and *Salmonella* spp., to transfer and/or acquire virulent genes thereby leading to the proliferation of highly virulent strains (Alcaine et al., 2005; Seitz & Blokesch, 2013). Consequently, the presence of these strains in food could render it unsafe for human consumption and obviously threaten the health of the consumers. Diverse Gram-negative bacteria have been reported to contaminate RTEs across LMICs (Table 2). Among these, *E. coli*, *Klebsiella* species, *Salmonella*, and *Pseudomonas* were commonly reported. Abdallah and Mustafa (2010) and Bukar, Uba, and Oyeyi (2009) detected *Salmonella* in street-vended juice in Sudan (North Africa) and in *zobo* from Nigeria (West Africa), respectively. In addition, Biswas, Parvez, Shafiquzzaman, Nahar, and Rahman (2010) and Yannick, Rawlings, & Emmanuela (2013) reported the presence of *E. coli* in RTE meat from Bangladesh (Asia) and Cameroon (Central Africa), respectively, whereas diarrheagenic *E. coli* strains were recovered from grilled chicken in Burkina Faso (West Africa) (Somda et al., 2018). Similarly, *Pseudomonas* was detected in street-vended juice in Pakistan, (Batool, Tahir, Rauf, & Kalsoom, 2013), whereas in Bangladesh (Asia) and Ethiopia, *Klebsiella* was found to contaminate *chotpoti* and *ambasha*, respectively (Eromo, Tassew, Daka, & Kibru, 2016; Hassan et al., 2016).

5.2 | Gram-positive bacteria

Notable foodborne pathogens within this group (such as, *Bacillus*, *Listeria*, and *Staphylococcus*) are able to tolerate harsh food storage and processing conditions such as low temperature, low moisture content, and high acidity and salinity (De Noordhout et al., 2014; Kadariya, Smith, & Thapaliya, 2014; Stecchini, Del Torre, & Polese, 2013; Swarminathan & Smidt, 2007). These capabilities make them a major concern to food safety. Some species (such as, *Listeria monocytogenes*) are opportunistic in nature and can cause high mortality rates among infants, older adults, and immunocompromised individuals (Guillet et al., 2010; Nyenje, Green, & Ndip, 2012). There have been several reports on contamination of RTEs by Gram-positive bacteria especially *Bacillus* species, *Listeria* species, and *Staphylococcus aureus* across LMICs (Table 2). *Staphylococcus aureus* was detected in grilled pork meat, ice cream, and fermented meat in Vietnam (Asia) (Huong et al., 2009), whereas *Bacillus* species were recovered from *Um-Jinger* in Sudan (North Africa) (Abdallah & Mustafa, 2010). In Nepal (Asia) and India, *S. aureus* were also recovered from fried rice and *samosa*, respectively (Ankita, Prasad, & Umesh, 2012; Kharel et al., 2016). In addition, Tabashsum et al. (2013) and Zaghloul et al. (2014) reported *Listeria* in *pitha* and burger sandwiches from Bangladesh and Egypt (North Africa), respectively. In another study in the Democratic Republic of Congo, *S. aureus* was recovered from bush meat (Makelele et al., 2015). Diverse species of *Bacillus*, including *B. cereus*, were also detected in several RTEs including *meat pie*, *buns*, and jollof rice from Nigeria (Aruwa & Ogunlade, 2016). Similarly, in Tunisia, *B. cereus* contaminated cooked poultry meat and pastry products (Gdoura-Ben Amor et al., 2018).

6 | BACTERIAL TOXINS IN RTEs FROM LMICs

Beyond the mere presence of pathogenic bacteria in RTEs, bacteria sometimes secrete potent toxins that could pose additional health risks to the food consumers. Of particular importance are cereulide, botulinum toxin, and staphylococcal exotoxins discussed hereafter. Generally, there are sparse data on the detection of bacterial toxins in RTEs from LMICs in the decade under study. Obvious reasons include (a) lack of trained personnel and equipment for detection of bacterial toxins in RTEs and (b) possible biased interest of food microbiologists toward viable bacteria than on their toxins.

6.1 | Botulinum toxin

The botulinum toxin is a potent neurotoxin produced by toxigenic strains of *Clostridium botulinum* (Popoff, 2013). Ingestion of botulinum toxin through consumption of RTEs may result in botulism, a neuroparalytic disease that could be fatal in humans (Johnson & Montecucco, 2018). The presence of the botulinum toxin gene (BoNt/A) was reported in 4% of toxigenic strains of *Clostridium* species isolated from RTEs in Nigeria (Chukwu et al., 2016). However, no study has reported the presence of the toxin in RTEs in LMICs within the period under review.

6.2 | Cereulide

Cereulide is an emetic exotoxin from certain *Bacillus cereus* strains. It is highly stable at extreme temperature and pH, with report on stability at 121 °C for 2 hr and over the pH range of 2 to 11, which makes it very difficult to inactivate during food processing (Ceuppens et al., 2011; Rajkovic, Uyttendaele, & Debevere, 2005). Additionally, cereulide is particularly toxic to infants, sometimes causing acute toxicity (Shiota et al., 2010). Cereulide is able to contaminate a range of RTEs such as improperly cooked and stored rice, pasta, eggs, milk, and meat (Ceuppens, Boon, & Uyttendaele, 2013). To worsen the scenario, this toxin sometimes co-occurs with other potent fungal toxins in RTEs. Such co-occurrence may lead to additive and/or synergistic effects that could possibly compound the health risk to consumers upon ingestion (Beisl et al., 2019). Recently, one LC–MS/MS-based study reported the presence of cereulide (mean: 37 μg/kg) in all 50 RTE maize *fufu* from Cameroon, with 20% and 100% co-occurrence of aflatoxins and deoxynivalenol, respectively, in addition to other mycotoxins (Abia et al., 2017).

6.3 | Staphylococcal exotoxins

The staphylococcal exotoxin is a heat stable super-antigenic toxin (SAgs) produced predominantly by coagulase positive and a few coagulase negative Staphylococci (Even, Leroy, & Charlier, 2010; Zell et al., 2008). Staphylococcal exotoxins are responsible for food poisoning and toxic shock syndrome often characterized by vomiting, especially in immunocompromised individuals (Argudin, Mendoza, & Rodicio, 2010; Hennekinne, De Buyser, & Dragacci, 2012; Hu et al., 2007; Pinchuk, Beswick, & Reyes, 2010; Schelin et al., 2011). Staphylococcal food poisoning can be traced to poor handling of foods by handlers carrying enterotoxigenic *S. aureus* in their hands or noses, which may contaminate food products during packaging (Argudin et al., 2010). RTEs commonly implicated in *S. aureus* contamination include cakes, dairy products, flour-based products, meat pie fillings, salads, and sandwiches (Argudin et al., 2010). El Bayomi et al. (2016) reported the incidence of *S. aureus* in RTE chicken products in Egypt, but did not report the production of staphylococcal exotoxin by the bacterial isolates or its presence in the RTE. However, Huong et al. (2009) reported that 40% (n = 45) of *S. aureus* recovered from RTEs in Vietnam were enterotoxigenic.

7 | FUNGAL CONTAMINATION OF RTEs FROM LMICs

Fungal contamination of RTEs is commonplace in LMICs due to vendor practice of displaying the foods openly in markets, such that they are exposed to fungal spores. Diverse fungal genera contaminate food materials, but the frequently occurring ones in RTEs include *Aspergillus*, *Fusarium*, *Mucor*, *Penicillium*, and *Rhizopus*. *Aspergillus* and *Fusarium* were reported to contaminate retailed *kulikuli* (peanut cake) and salads from Benin Republic, Togo, and Nigeria (Adjou et al., 2012; Adjrah et al., 2013; Ezekiel et al., 2011). Similarly, *Aspergillus* and *Penicillium* were reported in street-vended doughnut, egg roll, and meat pie from Nigeria (Oranusi & Braide, 2012). In India, *Mucor* and *Rhizopus* contaminated street-vended rice-based *bhelpuri* (Das, Nagananda, Bhattacharya, & Bhardwaj, 2010). Although diverse fungal propagules can be recovered in RTEs, these viable fungi pose far less public health menace compared to the occurrence of their toxic secondary metabolites (mycotoxins) liberated into the foods.

7.1 | Mycotoxins in RTE ingredients

Several RTEs in LMICs are mostly cereal and nut based. These ingredients are known to be prone to toxigenic fungal contamination. Mycotoxigenic fungal species within the *Aspergillus*, *Fusarium*, *Penicillium*, and *Alternaria* genera can proliferate and produce toxic metabolites in the crops under favorable climatic conditions and poor pre- and postharvest practices, similar to those prevalent in tropical and subtropical regions where many LMICs are situated (Bankole, Schollenburger, & Drochner, 2006; Bhat & Vasanthi, 2003; IARC, 2015). The major mycotoxins of food safety importance include aflatoxins (AFs), fumonisins (FUM), ochratoxin A (OTA), citrinin, deoxynivalenol (DON), and zearalenone (ZEN).

Recent data on mycotoxin occurrence in raw grains from Africa and Asia allude to the severity of the mycotoxin menace in these regions (Ayalew, Hoffmann, Lindahl, & Ezekiel, 2016; Ezekiel et al., 2018; Misihairabgwi, Ezekiel, Sulyok, Shephard, & Krska, 2019; Pereira, Fernandes, &

Cunha, 2014). Of particular importance are AFs, FUM, and DON, which appear to occur more frequently at high levels in raw grains. Typical examples are the very high levels of AFs in groundnuts from Nigeria (max: 2,076 μg/kg) and Sierra Leone (max: 5,729 μg/kg) (Oyedele et al., 2017; Sombie et al., 2018), and in maize from Tanzania (max: 1,081 μg/kg) and Somalia (max: 1,407 μg/kg) (Kamala et al., 2015; Probst, Bandyopadhyay, & Cotty, 2014). To worsen the scenario, several mycotoxins often co-occur in RTE ingredients from LMICs. For example, AFs, FUM, and DON have been reported to simultaneously occur in maize from Burkina Faso, Cameroon, Mozambique, and Nigeria (Abia et al., 2013; Adetunji et al., 2014; Warth et al., 2012), whereas AFs and OTA co-occurred in rice from Pakistan (Majeed, Iqbal, Asi, & Iqbal, 2013).

7.2 | Mycotoxins in RTEs

Processing techniques (such as grain washing, fermentation, dilution, and heat treatment) routinely applied during RTE production may influence mycotoxin levels in the finished product (Ezekiel, Ayeni, et al., 2019; Ezekiel, Sulyok, et al., 2019; Karlovsky et al., 2016; Okeke et al., 2015, 2018). Nonetheless, mycotoxins in ingredients are commonly carried over to the final product albeit in varying concentrations depending on the toxin levels in the starting raw material (Ezekiel et al., 2015; Ezekiel, Ayeni, et al., 2019; Matumba et al., 2014; Okeke et al., 2015). Mycotoxin carry-over is typical, particularly in resource scarce rural settings, where local food processors commonly apply low-quality grains in the production of RTEs because high-quality grains are often sold for household income (Ayalew et al., 2016; Misihairabgwi et al., 2019). Consequently, human consumption of mycotoxin contaminated RTEs could constitute health hazards and some of which could include, but are not limited to, cancers, gastrointestinal barrier alterations, immunosuppression, growth faltering, and nephrotoxicity (IARC, 2015).

Details of mycotoxin contamination levels in RTEs across LMICs in the decade under review are highlighted in Table 3. Aflatoxins appear to be the most frequently studied mycotoxins in RTEs in LMICs, possibly due to their categorization as the most toxic and carcinogenic of all mycotoxins (IARC, 1993). Obviously, massive contamination levels in this group of foods widely consumed by all age groups have been reported in literature. Concentration ranges of the most potent carcinogenic mycotoxin, aflatoxins, have reached 2,820 and 3,328 μg/kg in peanut cake (*kulikuli*) and roasted peanuts from Nigeria and Sierra Leone, respectively (Ezekiel, Sulyok, Warth, Odebode, & Krska, 2012; Sombie et al., 2018). In addition, other mycotoxins have been reported to co-occur with aflatoxins in RTEs from several countries. These include OTA in peanut cake from Benin (Adjou et al., 2012; Ediage, Mavungu, Monbaliu, Van Peteghem, & De Saeger, 2011); beauvericin and OTA in peanut cake from Nigeria (Ezekiel, Sulyok, et al., 2012); DON, patulin, and ZEN in maize *fufu* from Cameroon (Abia et al., 2017); and OTA in *garba* from Cote d'Ivoire (West Africa) (Anoman, Koffi, Aboua, & Koussemon, 2018). In some other RTEs, several other mycotoxins, aflatoxins excluded, have also been reported (sometimes in co-occurrence). These include DON in fried maize and popcorn from Indonesia (Asia) (Setyabudi, Nuryono, Wedhastri, Mayer, & Razzazi-Fazeli, 2012), OTA in *garri* from Nigeria (Makun et al., 2013), OTA in biscuits and bread from Pakistan (Majeed, Khaneghah, Kadmic, Khanf, & Shariatig, 2017), and DON, FUM, T-2 toxin and ZEN in *garri* from Nigeria (Chilaka, De Boevre, Atanda, & De Saeger, 2018). A major concern is that many of the RTEs contained mycotoxin levels higher than maximum limits stipulated by the Codex Alimentarius and the European Union.

8 | PARASITES IN RTEs FROM LMICs

In addition to the contamination of RTEs by bacteria, fungi, and their toxic metabolites, parasites can also contaminate RTEs (Ayeni, Ofem, Duru, Oyedele, & Ezekiel, 2019; Manyi et al., 2014). Parasitic contamination is usually common in meat-based RTEs. The major contamination sources include the improperly cooked or roasted meat, contaminated water applied to wash the meats, and the slaughter environments. Although not much studies have been conducted in this regard, possibly due to perceived less severity of parasitic infections in humans, it is important to always determine the presence of all potential hazards in foods. This will ensure consumers are protected and they can have confidence in the safety of the foods.

Only two reports were found for the presence of parasites in RTEs in LMICs in the decade under review (Table 4). *Toxoplasma gondii* was reported in barbeque chicken, mutton kebab, and sausages from Egypt (Abd El-Razik et al., 2014), whereas *Ascaris lumbricoides*, *Entamoeba histolytica*, *Giardia lamblia*, and *Taenia* sp. were found in roasted meat (*suya*) in Nigeria (Manyi et al., 2014). Suffice to say that contrary to the perceived less severity of parasitic infections in humans, these infections can be deadly especially when parasites migrate to unwanted body organs or cause perforations of intestinal walls leading to severe complications (Tardieux & Menard, 2008). In addition, the combined risk of acute bacterial infection, chronic mycotoxin exposure, and parasitic infections in affected humans cannot be underestimated. Perhaps one major possible effect of such combined risk may be a contribution to malnutrition and growth faltering in children due to alterations of intestinal/gut integrity by mycotoxins, low assimilation of essential nutrients within the body system as a result of the parasites feeding on required

TABLE 3 Mycotoxins in ready-to-eat foods from low-and middle-income countries (2009 to 2018)

Region/Country	Ready-to-eat food	^{a}N	$^{b}N_p$ (%)	LOD(μg/kg)	LOQ(μg/kg)	Mycotoxins	Mean(μg/kg)	Range(μg/kg)	Analytical method	References
Africa										
Benin	*Kuli kuli*	45	ND	NA	NA	AFB_1	ND	25.5 to 455	ELISA & LC–MS/MS	Adjou et al., 2012
			ND	NA	NA	AFB_2	ND	33.9 to 491	ELISA & LC–MS/MS	Adjou et al., 2012
			ND	NA	NA	AFG_1	ND	0.41 to 100	ELISA & LC–MS/MS	Adjou et al., 2012
			ND	NA	NA	AFG_2	ND	22.0 to 87.7	ELISA & LC–MS/MS	Adjou et al., 2012
			ND	NA	NA	OTA	ND	0.3 to 2.0	ELISA & LC–MS/MS	Adjou et al., 2012
Benin	Peanut cake	15	14 (93)	2	6	AFB_1	ND	<LOQ to 282	LC/MS–MS	Ediage et al., 2011
			4 (27)	1	4	AFB_2	ND	<LOQ to 31.0	LC/MS–MS	Ediage et al., 2011
			10 (67)	1	3	AFG_1	ND	<LOQ to 79.0	LC/MS–MS	Ediage et al., 2011
			15 (100)	0	1	AFG_2	ND	6.0 to 96.0	LC/MS–MS	Ediage et al., 2011
			5 (33)	0.1	0.3	OTA	ND	<LOQ to 2.0	LC/MS–MS	Ediage et al., 2011
Cameroon	Maize *fufu*	50	12 (24)	0.15	0.5	AFB_1	0.9	ND to 1.8	LC–MS/MS	Abia et al., 2017
			50 (100)	3.2	10	FB_1	151	48.0 to 709	LC–MS/MS	Abia et al., 2017
			50 (100)	0.8	2.6	DON	23	14.0 to 55.0	LC–MS/MS	Abia et al., 2017
			15 (30)	5	17	PAT	105	12.0 to 890	LC–MS/MS	Abia et al., 2017
			50 (100)	0.1	0.3	ZEN	49	5.0 to 150	LC–MS/MS	Abia et al., 2017
Cote d' Ivore	*Garba*	300	170 (57)	0.00564	0.0188	AFB_1	3.44	0.02 to 35.8	HPLC	Anoman et al., 2018
			70 (23)	0.00151	0.0050	AFB_2	1.90	0.10 to 24.0	HPLC	Anoman et al., 2018
			140 (47)	0.00136	0.0045	AFG_1	8.07	0.56 to 69.3	HPLC	Anoman et al., 2018
			120 (40)	0.00143	0.0047	AFG_2	0.56	0.04 to 13.3	HPLC	Anoman et al., 2018
			190 (63)	0.0500	0.20	OTA	0.42	0.06 to 1.83	HPLC	Anoman et al., 2018
Egypt	Corn based snack	25	10 (40)	NA	0.5	AFB_1	3.85	0.59 to 15.8	HPLC	Amin, Abo-Ghalia, & Hamed, 2010
			1 (4)	NA	0.5	AFB_2	1.98	1.98	HPLC	Amin et al., 2010
Egypt	Hard cheese	50	19 (38)	50 ng/kg	NA	AFM_1	132	51.6 to 182	ELISA	Amer & Ibrahim, 2010
	Soft cheese	50	20 (40)	50 ng/kg	NA	AFM_1	70.6	52.0 to 87.6	ELISA	Amer & Ibrahim, 2010
	Processed cheese	50	11 (22)	50 ng/kg	NA	AFM_1	52.5	51.8 to 54.0	ELISA	Amer & Ibrahim, 2010
Egypt	Fresh *kariesh* cheese	25	8 (32)	NA	NA	AFM_1	3.6	1.95 to 6.11	Immuno affinity column with flurometric assay	Awad, Amer, Mansour, & Ismail, 2014

(Continues)

TABLE 3 (Continued)

Region/Country	Ready-to-eat food	[a]N	[b]N_p (%)	LOD(μg/kg)	LOQ(μg/kg)	Mycotoxins	Mean(μg/kg)	Range(μg/kg)	Analytical method	References
	Damietta cheese	25	12 (48)	NA	NA	AFM_1	6.7	1.54 to 14.7	Immuno affinity column with flurometric assay	Awad, Amer, Mansour, & Ismail, 2014
Ghana	*Ice-kenkey*	ND	ND	NA	NA	AFB_1	ND	7.01 to 20.5	HPLC	Atter, Ofori, Anyebuno, Amoo-Gyasi, & Amoa-Awua, 2015
		ND	ND	NA	NA	AFB_2	ND	0.51 to 1.63	HPLC	Atter et al., 2015
		ND	ND	NA	NA	AFG_1	ND	0.0 to 0.47	HPLC	Atter et al., 2015
Kenya	Roasted coated Peanut	101	ND	NA	NA	AFs	56.5	0.0 to 382	ELISA	Nyirahakizimana et al., 2013
	Roasted de-coated peanut	49	ND	NA	NA	AFs	19.9	0.0 to 201	ELISA	Nyirahakizimana et al., 2013
Kenya	Peanut butter	12	12 (100)	NA	NA	AFs	ND	ND	VICAM AflaTest immunoaffinity fluorometric method	Filbert & Brown, 2012
Malawi	Locally processed peanut butter	14	14 (100)	NA	0.5	AFB_1	ND	13.2 to 40.6	Immuno-affinity column and reversed phase liquid chromatography	Matumba et al., 2014
		14	14 (100)	NA	0.2	AFB_2	ND	1.7 to 7.2	Immuno-affinity column and reversed phase liquid chromatography	Matumba et al., 2014
	De-skinned roasted groundnut	15	11 (73)	NA	0.5	AFB_1	ND	0.1 to 12.3	Immuno-affinity column and reversed phase liquid chromatography	Matumba et al., 2014
		15	10 (67)	NA	0.2	AFB_2	ND	0.2 to 1.8	Immuno-affinity column and reversed phase liquid chromatography	Matumba et al., 2014
Nigeria	Corn based snack	3	3 (100)	NA	NA	AFB_1	14	6.0 to 30.0	Thin Layer Chromatography (TLC)	Ezekiel, Kayode, Fapohunda, Olorunfemi, & Kponi, 2012

(Continues)

TABLE 3 (Continued)

Region/Country	Ready-to-eat food	^{a}N	$^{b}N_p$ (%)	LOD(μg/kg)	LOQ(μg/kg)	Mycotoxins	Mean(μg/kg)	Range(μg/kg)	Analytical method	References
						AFB_2	8.0	ND	TLC	Ezekiel, Kayode, et al., 2012
						AFG_1	6.0	ND	TLC	Ezekiel, Kayode, et al., 2012
	Groundnut based snack	12	9 (75)	NA	NA	AFB_1	8.5	0.0 to 12.5	TLC	Ezekiel, Kayode, et al., 2012
						AFB_2	9.0	0.0 to 9.0	TLC	Ezekiel, Kayode, et al., 2012
						AFG_1	15.8	0.0 to 31.3	TLC	Ezekiel, Kayode, et al., 2012
	Nut-based snack	5	1 (20)	NA	NA	AFB_1	6.0	ND	TLC	Ezekiel, Kayode, et al., 2012
	Wheat-based snack	5	4 (80)	NA	NA	AFB_1	17.8	0.0 to 50.0	TLC	Ezekiel, Kayode, et al., 2012
						AFG_1	13	ND	TLC	Ezekiel, Kayode, et al., 2012
Nigeria	Peanut cake	29	29 (100)	2.0	NA	AFB_1	ND	ND to 2820	LC/ESI–MS/MS	Ezekiel, Sulyok, et al., 2012
			29 (100)	0.02	NA	BEAU	ND	ND	LC/ESI–MS/MS	
			4 (14)	4.0	NA	OTA	ND	ND	LC/ESI–MS/MS	
Nigeria	*Kokoro*	16	8 (50)	NA	NA	AFB_1	ND	0.75 to 7.25	ELISA	Onifade, Adesokan, & Adebayo-Tayo, 2014
Nigeria	Roasted groundnut	22	21 (96)	2	NA	AFB_1	14.1	1.3 to 59.1	High-Performance Thin Layer Chromatography (HPTLC)	Afolabi et al., 2015
			18 (82)	2	NA	tAF	23.9	1.3 to 134	HPTLC	Afolabi et al., 2015
Nigeria	Roasted cashew nut	27	ND	NA	NA	AF	ND	0.1 to 6.8	ELISA	Adetunji, Alika, Awa, Atanda, & Mwanza, 2018
Nigeria	Roasted groundnut	10	6 (60)	NA	NA	tAF	ND	1.20 to >20.0	ELISA	Ubwa et al., 2014
	Roasted cashew nut	10	2 (20)	NA	NA	tAF	ND	0.10 to 0.40	ELISA	Ubwa et al., 2014
Nigeria	*Garri*	18	18 (100)	0.001	NA	OTA	7.63	3.28 to 22.7	HPLC	Makun et al., 2013
Nigeria	*Garri*	24	9 (38)	14.5	29.0	DON	57	35.0 to 99.0	LC–MS/MS	Chilaka et al., 2018
			6 (25)	15.0	30.0	FB_1	60	45.0 to 80.0	LC–MS/MS	Chilaka et al., 2018
			5 (21)	10.5	21.1	FB_2	40	29.0 to 65.0	LC–MS/MS	Chilaka et al., 2018
			3 (13)	4.5	9.1	T-2	19	17.0 to 22.0	LC–MS/MS	Chilaka et al., 2018

(Continues)

TABLE 3 (Continued)

Region/Country	Ready-to-eat food	[a]N	[b]N_p (%)	LOD(μg/kg)	LOQ(μg/kg)	Mycotoxins	Mean(μg/kg)	Range(μg/kg)	Analytical method	References
			4 (17)	3.6	7.2	ZEN	14	11.0 to 17.0	LC–MS/MS	Chilaka et al., 2018
Nigeria	*Aadun*	5	5 (100)	NA	NA	AFB_1	ND	3.4 to 12.8	HPLC	Jonathan et al., 2015
				NA	NA	AFB_2	ND	2.8 to 3.2	HPLC	Jonathan et al., 2015
						AFG_1	ND	1.7 to 3	HPLC	Jonathan et al., 2015
				NA	NA	AFG_2	ND	1.6 to 3.2	HPLC	Jonathan et al., 2015
Nigeria	Sausage roll	4	4 (100)	NA	NA	AFB_1	ND	1.08 to 1.88	HPLC/MS	Jonathan, Okoawo, & Asemoloye, 2016
				NA	NA	AFB_2	ND	0.99 to 1.98	HPLC/MS	Jonathan et al., 2016
				NA	NA	AFG_1	ND	0.92 to 1.23	HPLC/MS	Jonathan et al., 2016
				NA	NA	AFG_2	ND	0.91 to 1.73	HPLC/MS	Jonathan et al., 2016
Sierra Leone	Roasted peanut	50	8 (16)	0.24	0.79	AFB_1	178	0.62 to 1,387	LC–MS/MS	Sombie et al., 2018
			3 (6)	0.4	1.3	AFB_2	96.4	6.49 to 271	LC–MS/MS	Sombie et al., 2018
			12 (24)	0.32	1.1	AFG_1	281	0.34 to 3,328	LC–MS/MS	Sombie et al., 2018
			2 (4)	0.8	2.6	AFG_2	378	14.7 to 742	LC–MS/MS	Sombie et al., 2018
			2 (4)	0.4	1.3	AFM_1	34	1.22 to 66.8	LC–MS/MS	Sombie et al., 2018
Sudan	Peanut butter	43	28 (65)	1.5	NA	AFB_1	223	73.9 to 534	HPLC	Elzupir, Salih, Suliman, Adam, & Elhussein, 2011
			42 (98)	0.09	NA	AFB_2	3.2	0.18 to 23.9	HPLC	Elzupir et al., 2011
			43 (100)	0.8	NA	AFG_1	137	26.5 to 401	HPLC	Elzupir et al., 2011
			4 (9)	0.4	NA	AFG_2	18.5	8.60 to 30.1	HPLC	Elzupir et al., 2011
			43 (100)	NA	NA	tAF	287	26.6 to 853	HPLC	Elzupir et al., 2011
Zambia	Peanut butter	109	100 (92)	NA	NA	AFs	18.9	1.75 to 147	CD–ELISA	Banda, Likwa, Bwembya, Banda, & Mbewe, 2018
Zimbabwe	Peanut butter	11	10 (91)	NA	NA	AFB_1	51	3.7 to 191	HPLC	Mupunga, Lebelo, Mngqawa, Rheeder, & Katerere, 2014

(Continues)

TABLE 3 (Continued)

Region/Country	Ready-to-eat food	[a]N	[b]N_p (%)	LOD($\mu g/kg$)	LOQ($\mu g/kg$)	Mycotoxins	Mean($\mu g/kg$)	Range($\mu g/kg$)	Analytical method	References
			4 (36)	NA	NA	AFB_2	ND	6.2 to 25.7	HPLC	Mupunga et al., 2014
			5 (45)	NA	NA	AFG_1	ND	9.3 to 47.1	HPLC	Mupunga et al., 2014
			1 (9)	NA	NA	AFG_2	ND	0 to 8.8	HPLC	Mupunga et al., 2014
			10 (91)	NA	NA	tAF	75.7	6.1 to 247	HPLC	Mupunga et al., 2014
Asia										
India	Chilgoza pine nuts	58	11 (19)	NA	NA	AFB_1	0.91	0.73 to 1.64	TLC & HPLC	Sharma, Gupta, & Sharma, 2013
			13 (22)	NA	NA	AFB_2	1.01	0.70 to 2.26	TLC & HPLC	Sharma et al., 2013
India	Jam	40	20 (50)	NA	NA	AFB_1	ND	1.52 to 183	HPLC	Nair, Ghadevaru, Manimehali, & Athmaselvi, 2015
Indonesia	Popcorn	7	7 (100)	20	NA	DON	127	59.9 to 202	HPLC–UV	Setyabudi, Nuryono, Wedhastri, Mayerm, & Fazeli, 2012
	Fried maize	9	9 (100)	20	NA	DON	155	67.1 to 348	HPLC–UV	Setyabudi et al., 2012
Pakistan	Biscuit	10	3 (20)	0.01	0.02 to 0.05	tAF	ND	0.04 to 2.28	RP–HPLC	Mushtaq, Sultana, Anwar, Khan, & Ashrafuzzaman, 2012
	Bread slice	3	1 (33)	0.01	0.02 to 0.05	tAF	ND	0.1 to 0.26	RP–HPLC	Mushtaq et al., 2012
Pakistan	Biscuit	5	2 (40)	NA	NA	OTA	23.9	ND to 360	LC	Majeed et al., 2017
	Bread	5	3 (60)	NA	NA	OTA	1.96	ND to 4.66	LC	Majeed et al., 2017
The Caribbean										
Haiti	Peanut butter	18	16 (89)	NA	NA	AFs	ND	ND	VICAM AflaTest immunoaffinity fluorometric method	Filbert & Brown, 2012

Abbreviations: NA, not applicable; ND, no data; LOD, limit of detection; LOQ, limit of quantification; AFB_1, aflatoxin B_1; AFB_2, aflatoxin B_2; AFG_1, aflatoxin G_1; AFG_2, aflatoxin G_2, AF, aflatoxins; tAF, total aflatoxin, AFM_1, aflatoxin M_1, OTA, ochratoxin; FUM, fumonisin; DON, deoxynivalenol; PAT, patulin; ZEN, zearalenone; TLC, thin layer chromatography; LC–MS/MS, liquid chromatography–tandem mass spectrometry; HPLC, high-performance liquid chromatography, ELISA, enzyme linked immunosorbent assay; LC/ESI–MS/MS, liquid chromatography/electrospray ionization–tandem mass spectrometric; RP-HPLC, reverse-phase high-performance liquid chromatography.

[a]Number of samples

[b]Number of positive samples

TABLE 4 Parasites reported in ready-to-eat (RTE) foods in low- and middle-income countries (2009 to 2018)

Region	Country	RTE food	Potential source of contamination	Parasite	Analytical method	References
Africa	Egypt	Barbeque chicken	Insufficient cooking	*Toxoplasma gondii*	PCR	Abd El-Razik et al., 2014
		Mutton kebab	Insufficient cooking	*T. gondii*	PCR	Abd El-Razik et al., 2014
		Sausage	Insufficient cooking	*T. gondii*	PCR	Abd El-Razik et al., 2014
	Nigeria	*Suya*	Lack of potable water for processing	*Ascaris lumbricoides*, *Entamoeba histolytica*, *Taenia* sp., and *Giardia lamblia*	Microscopy	Manyi et al., 2014

nutrients for child growth, and gastroenteropathy from severe foodborne bacterial infections in the gut; this postulation needs verification. Furthermore, it is pertinent to mention that compared to bacterial and fungal identification, parasites can be characterized with less sophisticated techniques (such as light microscopy; Cheesbrough, 1998). Thus, more reports on this foodborne hazard are expected in the future from LMICs where access to high-end molecular equipment (such as polymerase chain reaction and sequencers) may not be fully available.

9 | VIRUSES IN RTEs FROM LMICs

Notable foodborne viruses include hepatitis A and E, norovirus, and rotavirus (FAO/WHO, 2008; Maunula, & von Bonsdorff, 2016; Stals, Baert, Van Coillie, & Uyttendaele, 2012). These viruses are well equipped with machineries to withstand environmental stressors in food matrices. These stressors include extreme pH, harsh food processing and storage conditions (such as heat, freezing, and exposure to organic acids), and persistence in food contact surfaces (for example, stainless steel) (Hewitt & Greening, 2004; Koopmans, & Duizer, 2004; Lamhoujeb, Fliss, Ngazoa, & Jean, 2009). Unlike pathogenic bacteria, fungi, and parasites, foodborne viruses are obligate intracellular parasites, thus are incapable of replicating in an inert environment like food matrices (Koopmans, & Duizer, 2004). Thus, the viral load at the point of contamination is unlikely to increase (Koopmans, & Duizer, 2004; Newell et al., 2010). Nonetheless, low viral doses are required to cause an infection (Maunula, & von Bonsdorff, 2016), as such, viruses are a major concern to food safety.

Regarding the occurrence of viruses in RTEs from LMICs in the decade under review, we found only one report on the presence of hepatitis A virus in flour- and/or meat-based meal from Cameroon (Table 5; Yongsi, 2018). Obvious reasons for this paucity of data could be the lack of skilled expertise required for the detection of viruses in RTEs in LMICs, low amount of viruses present in foods, which makes detection very difficult, and variability of methods applied for different food matrices (Koopmans, & Duizer, 2004; Maunula, & von Bonsdorff, 2016). Nevertheless, several reports on human exposure to foodborne viruses in some LMICs via detection of these viruses in biological samples, for example, stool (Ayukekbong et al., 2011; Kumar, Basu, Vashishtha, & Choudhury, 2016; Mans, 2019; Mattison, Sebunya, Shukla, Noliwe, & Bidawid, 2010; Mukherjee et al., 2010; Omore et al., 2019) and blood (Chadha, Lole, Bora, & Arankalle, 2009; Teshale et al., 2010), suggest that humans are frequently exposed to foodborne viruses in LMICs.

Currently, norovirus and rotavirus rank among the leading cause of diarrheal-related deaths in humans particularly children in LMICs (Kirk et al., 2015a, 2015b; Lopman, Steele, Kirkwood, & Parashar, 2016; Mans, 2019; Parashar et al., 2009; Taneja & Malik, 2012). It is important to mention that rotavirus vaccines are now available and have been included in the national immunization programs in some LMICs (Patel, Glass, Desai, Tate, & Parashar, 2012; Shah, Tate, Mwenda, Steele, & Parashar, 2017). Furthermore, administration of these vaccines in humans has yielded some positive results as revealed in a few studies that reported reduction in human exposure to rotavirus in some LMICs (Armah et al., 2016; Bar-Zeev et al., 2015; Schwartz et al., 2019). Notwithstanding, rotavirus vaccines are not yet widely available in some LMICs (Motayo, Faneye, & Adeniji, 2018; Sindhu, Babji, & Ganesan, 2017). Contrary to the case of rotavirus, development of norovirus vaccines is still ongoing (Hallowell, Parashar, & Hall, 2018; Riddle, Chen, Kirkwood, & MacLennan, 2018), and thus a licensed norovirus vaccine is currently unavailable (Huys, Grau, & Karst, 2020). Taken together, indications are that these two viruses and other foodborne viruses could continually pose a threat to RTE consumers in LMICs. Consequently, in the interim, it is pertinent that in addition to screening for the presence of bacteria, fungi, and parasites in RTEs, food surveillance studies in LMICs should include the detection of viruses. This will provide data for relevant government agencies and policy makers to enact policies and drive regulations concerning foodborne viruses in RTEs.

TABLE 5 Virus reported in ready-to-eat (RTE) foods in low- and middle-income countries (2009 to 2018)

Region	Country	RTE food	Potential source of contamination	Virus	Analytical method	References
Africa	Cameroon	Flour and meat based	Poor hygiene practices	Hepatitis A virus	Direct flocculation and NASBA	Yongsi, 2018

NASBA, nucleic acid sequence-based amplification

10 | FOOD SAFETY SOLUTIONS AND FUTURE PERSPECTIVES

The search for interventions geared toward ensuring the safety of foods, RTEs inclusive, globally has been marked with successes as well as challenging efforts (FAO/WHO, 2018). Nevertheless, to make RTEs safe for consumers in LMICs, there is a need to adopt a holistic approach, which involves intervening in the areas highlighted below. Major factors to consider in proposing interventions for mitigating foodborne hazards in LMICs include the feasibility of the interventions considering the low-income status of greater population in the countries, sanitation and environmental conditions in the countries, and low awareness of the food safety issue as it affects human health among processors, vendors, and consumers of RTEs.

10.1 | Integration of control approaches

There is a need to focus interventions at the entire value chain, beginning from farm to fork. For example, a set of good pre- and postharvest practices has been suggested to reduce mycotoxin contamination of cereals and nuts that serve as RTE ingredients (Bandyopadhyay et al., 2016; Ezekiel et al., 2018). These practices include crop rotation, irrigation in areas of drought, timely harvesting, proper drying to safe moisture levels, sorting out the visibly discolored, infected and damaged grains, and storage in appropriate conditions to avoid moisture rise and insect infestation. In addition, good transport systems are essential to ensure the safety of grains moved within the different parts of the LMICs (Grace, 2015). To be specific, in many LMICs there are lack of good road networks connecting grain producing communities to municipal cities. The vehicles utilized for transport of the grains are also of low quality (often uncleaned). These factors need attention in order to reduce RTE contamination. In addition, it has been suggested that oxygenated tanks may be used to transport fresh fish alive to the point of sale (Grace, 2017). Access to portable water sources is also crucial to ensuring food safety especially in rural communities where the low-income households and food processors reside. Proper RTE storage facilities (for example, cold temperature) could also be useful to keep pathogenic microorganisms away (Kunadu, Ofosu, Aboagye, & Tano-Debrah, 2016). In addition, bacteriophages could be used as biocontrol agents against notorious psychrophilic foodborne pathogens such as *Listeria* spp. (Chibeu, 2013). Furthermore, there should be increased awareness on public health issues surrounding contaminated foods by educating food processors, vendors, and consumers on effective food handling, good personal hygiene, good handling, and processing practices. The advocacy and awareness efforts should also target policy makers and high-level government officials and should focus on their commitments and roles to providing those they govern and protect with basic amenities to enhance food safety and protect consumer health.

10.2 | Effective surveillance and monitoring of foodborne pathogens in RTEs

Surveillance and monitoring exercises aimed at identifying foodborne hazards are major steps toward the prevention and control FBD. Such program, if effectively executed, could bridge some enlightenment gaps among food vendors and processors depending on the food sampling points. Thus, it is imperative that regulatory officials effectively monitor RTEs for the presence of pathogenic microorganisms and their toxins before they are allowed in the market. However, monitoring at the local market in remote area may be a heinous task. One approach to tackle this problem is to increase food safety awareness and education; that is, mainstream food safety courses into the educational curriculum at the basic (primary) and high school (secondary) levels.

The quality of techniques applied during the surveillance studies is also crucial for proper risk assessment. Investments focused on building cutting-edge infrastructures in LMICs for proper monitoring of RTEs should be prioritized. Such advanced infrastructures will gradually erode the application of conventional techniques (such as, culture-based microbial isolations and thin-layer chromatography for toxin detection). Rapid techniques involving immunoassays and nucleic acid-based methods for foodborne pathogen detection (Lee et al., 2015) and liquid chromatography–mass spectrometric methods for microbial toxin analysis (Berthiller et al., 2017) should be adopted to enable accurate and high-throughput analysis.

10.3 | Building food safety expertise for monitoring and control of food contaminants in LMICs

It is crucial to invest in training researchers and food regulatory officers on modern technologies to detect microbial contaminants in RTEs in order to ensure proper surveillance and source tracking. This can be achieved through collaborations between relevant government agencies and research institutions in LMICs, as well as between food safety experts in LMICs and those in the economically developed world (Europe and North America). Forms of collaborations may include staff and student exchange for technology transfer, short training programs/fellowships, collaborative funding/grant acquisition for establishment of functional food safety centers equipped with state-of-the-art equipment in LMICs, as well as donation of equipment to LMICs. Country governments are also urged to prioritize food safety and thus invest in cutting-edge infrastructure and human capacity building for effective prevention and control of FBD as well as consumer protection.

Building expertise for food safety should also be viewed on the scope of the value chain. Consequently, farmers, food handlers, processors, and vendors should be educated on food safety regulations and standards. For example, they could be encouraged to form cooperative and industrial societies geared toward acquiring relevant skills and training to ensure good agricultural and processing practices, which may positively influence food safety (Kumar, Parappurathu, & Jee, 2013). In addition, there should be requisite infrastructures and good welfare packages to enable all relevant stakeholders carry out effective monitoring and control of food contaminants.

10.4 | Regulations: Setting and enforcement

Any need for regulations regarding RTEs (on-shelf and off-shelf) in LMICs? Would this impact negatively on food security? If it would, do we then prioritize food safety over food availability? The obvious answer should be YES! These are the obvious set of questions bugging the minds of food safety regulators in LMICs and militating against the establishment of regulations targeting RTEs, especially the locally produced ones. Taking a look at food production in some LMICs, it is observable that most LMICs conveniently produce in large quantities the raw ingredients (for example, cereals, nuts, and tubers) for RTEs. Obviously, the major problem with establishing regulations is not the availability of these foods, but how to ensure their safety. Thus, it is crucial to ensure the microbiological safety of these foods, which will help sustain food security. Consequently, there should be strict regulations guiding the production and sale of RTE ingredients and their finished products in countries where regulations are nonexistent. Where food regulations do exist, appropriate measures must be in place to enforce them. The regulations should cover all aspects of food safety and include the quality of ingredients, strict personal hygiene standards for RTE vendors (including routine health checks and certification from recommended health facilities), periodic inspection standards for all RTE retail points, and definition of acceptable standards for RTEs (for example, water quality standards, standard packaging materials, and vending sites/locations).

10.5 | Protection of consumer rights

Consumer demand for RTEs is high in LMICs; hence, consumers should be made aware of what to look out for in these foods and insist on details of processed RTEs to be provided. These will afford consumers the opportunity to make informed decisions on their choices of RTEs, thereby taking the first steps toward safeguarding their health. Consumer enlightenment can be achieved through various means such as soapboxes, the media, internet platforms (where available), and workshops. Education via the media and internet platforms could be useful tools for consumers in the urban and suburban areas owing to wider coverage and ability to transmit information to several people in a relatively short period (Jabbar, Baker, & Fadiga, 2010). However, in rural communities where media and internet facilities maybe unavailable, trainings involving major community stakeholders, for example, community heads and chiefs and local households, could be organized to disseminate such crucial information. Beyond being aware about the safety of RTEs, the government via relevant agencies in LMICs should enact and sustain policies to protect consumer rights. In addition, in cases of food fraud, consumers should be properly compensated, and strict penalties should be meted out to the defaulting food processor and/or vendor.

11 | CONCLUSION

This comprehensive review paper has presented robust data on the spectra of RTEs in LMICs, sources of microbial contamination of RTEs in the regions, techniques for detecting the microbial contaminants as well as the occurrences of various RTE contaminants of microbial origin. The paper has shown that RTEs are important food sources for a large set of the populations in LMICs due to the food diversity and ease of acquisition. However, these foods constitute a high-risk set of foods due to poor personal hygiene of processors, poverty, lack of insights and knowledge into the adverse health effects that could arise from consumption of contaminated foods, and nonexistent or inadequately enforced regulations. To tackle the challenge, we proposed a set of integrated and feasible food safety solutions and future perspectives tailored for LMICs in order to ensure safety of RTEs and protection of public health. These include, but not limited to, adoption of good agricultural, good processing and handling practices, effective surveillance and monitoring along the RTE chain, establishment and enforcement of regulations, capacity building of food safety experts, and enlightenment of the public (RTE processors, vendors, consumers, and government officials) on the following: dangers of consuming contaminated foods, strategies to avoid food contamination and enhance food safety, and their obligations to ensure the foods they consume are safe.

AUTHOR CONTRIBUTIONS

Conception of idea: C.N.E. Design of review outline: O.M.M. and C.N.E. Drafting and reviewing of study outline: O.M.M., K.I.A., R.A.A., and C.N.E. Sourcing literature: O.M.M. and K.I.A. Data compilation and preparation of tables: O.M.M., K.I.A., and C.N.E. Interpretation of data, preparation, and fine-tuning of draft manuscript: O.M.M., K.I.A., M.S., R.K., R.A.A., and C.N.E.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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