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Review

Listeria monocytogenes in food products, and its virulence in North Africa

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Abstract: *Listeria monocytogenes* poses a significant threat to food safety worldwide, including in African countries. This bacterium is capable of causing severe infections, particularly in vulnerable populations. In this review, we provide an overview of the prevalence, transmission, and control measures of *L. monocytogenes* in the food chain across North Africa. Various factors contribute to the persistence and spread of this pathogen in food production and distribution systems, including environmental contamination, improper handling, and inadequate hygiene practices. Understanding the dynamics of *L. monocytogenes* in the North African food chain is crucial for implementing effective control strategies to mitigate the risk of contamination and protect public health. This review highlights the rise of virulence genes in *L. monocytogenes* from food production, especially milk production, over the past five years and their subsequent identification in human *L. monocytogenes* isolates from listeriosis cases. This underscores the persistent challenges that *L. monocytogenes* may pose to food safety and public health in North African countries.

Keywords: *L. monocytogenes*; food chain; foodborne infection; North Africa; virulence genes; one health

1. Introduction

Foodborne diseases threaten food safety and global trade and challenge public health in Europe and many other countries [1]. *L. monocytogenes* is a widespread foodborne pathogen capable of causing severe disease. The estimated annual incidence of *L. monocytogenes* infections can vary based

on geographic region, data collection, and reporting [2]. For instance, in the United States alone, the Centers for Disease Control and Prevention (CDC) reports that every year close to 1600 individuals get sick, and 260 die from *Listeria* infections [3]. This might vary depending on time and location. Further, it is difficult to estimate the number of listeriosis cases as some diseases are not diagnosed or reported [4,5]. However, there has been a heightened awareness of *L. monocytogenes* in the food chain and in North Africa, where there are differences in food safety rules and regulations [2,6]. *L. monocytogenes* is present in various food and environmental samples in North Africa and constitutes a potential hazard to the public [7,8]. *L. monocytogenes* outbreaks cause hospitalization and fatalities that result in economic losses. Lack of adequate resources and regulatory constraints are barriers to overall control and highlight *L. monocytogenes* as a concern in the North African region.

North Africa, comprising Algeria, Egypt, Libya, Morocco, and Tunisia, is subject to challenging environmental conditions characterized by water scarcity. According to El Kenawy [9], in 2016, this region covers approximately 4,758,160 square kilometers, with 90% classified as dry or semi-dry areas, posing unique challenges for preventing and controlling foodborne diseases [10,11]. *L. monocytogenes* in the food chain is important for North Africa [12]. Additionally, the sociodemographic conditions, agricultural production, and food processing practices in North Africa may further sustain *L. monocytogenes* and present issues for food safety and human health [13]. The food products and environmental samples of *L. monocytogenes* within the region show that it is prevalent within the food chain of North Africa [14].

Several factors add to the difficulties of managing *L. monocytogenes* in food in this area. Deficient infrastructure for food production, processing, and delivery, poor hygiene practices, poor sanitation facilities, and insufficient access to clean water provide a suitable environment for contamination by *L. monocytogenes* [6]. In addition, weak regulatory oversight, limited monitoring systems, and lack of resources for food safety programs exacerbate the problem. Migration and urbanization also define dietary practices and contribute to the spread of *L. monocytogenes* [15]. Pregnant women, newborns, the elderly, and those with poor immunity are at a higher risk of developing listeriosis [16].

L. monocytogenes is a member of the Listeriaceae family of bacteria that is a Gram-positive, non-sporulating rod-shaped bacteria without capsules, 5 to 4.0 μm in width and 0.5 to 2.0 μm in length [17,18]. They are facultative anaerobes and are motile at temperatures between 10–25 °C. *Listeria* can grow across a wide temperature range (0–45 °C), various pH levels (4.5–9), and in high salt concentrations (10% NaCl). The genus Listeria includes 17 species, but only *L. monocytogenes* is known to cause foodborne illness in humans, while *L. ivanovii* primarily affects animals. These bacteria have been found in various food sources, including meat, seafood, dairy products, and vegetables, as well as in water, plants, soil, and the feces of asymptomatic human and animal carriers [19,20]. Consumption of contaminated food products accounts for an estimated 99% of all human listeriosis cases [21]. Clinical symptoms of listeriosis manifest as septicemia, meningitis, meningoencephalitis, prenatal infection, abortion, and gastroenteritis [22,23]. *L. monocytogenes* infections are accountable for the highest hospitalization rates among all foodborne pathogens and have also been linked to large outbreaks of human illness worldwide [24,25].

In North African countries, surveillance for *L. monocytogenes* is performed at different levels. The surveillance is conducted by the Ministries of Health at the national level that accumulate and share information on cases identified in healthcare facilities across the country [6]. Regional and local health departments also contribute to managing the cases in the respective areas. Centralized and regional laboratories employ microbiological methods to confirm *L. monocytogenes* and

epidemiologists investigate confirmed cases, source investigation, and case clustering [26]. Stakeholder engagement improves data sharing, coordination, and response. Information and communication campaigns focus on food hygiene issues and signs of illness. Education and training programs seek to enhance surveillance systems, health facilities, and professional competency to attenuate the likelihood of *L. monocytogenes* dissemination and enhance population wellness [27].

Our aims in this review are to outline the (i) knowledge and (ii) most recent trends regarding the frequency of virulence genes in *L. monocytogenes* found in North African countries in foods using literature that covers the last 20 years. As a secondary objective, we aim to shed light on the data regarding the present status of antimicrobial resistance.

2. Materials and methods

A comprehensive search was conducted in all electronic databases such as PubMed (https://pubmed.ncbi.nlm.nih.gov/), Scopus (https://www.scopus.com/home.uri), Web of Science (https://www.webofscience.com/wos/), and Google Scholar (https://scholar.google.com/) to identify studies conducted in the last twenty years [28]. The search was narrowed down using the following keywords for each country: *L. monocytogenes* in the food chain in Algeria; virulence gene profile of *L. monocytogenes* isolates in Algeria; and antimicrobial resistance among *L. monocytogenes*. Studies included in this review were those that reported the prevalence, antimicrobial susceptibility patterns, and virulence gene profiles of *L. monocytogenes* isolates obtained from samples from North African countries. Low-quality studies and inadequate data were also excluded from the review.

3. Status of human listeriosis in North Africa

The status of human listeriosis in North Africa shows a multifaceted relationship between the incidence of *L. monocytogenes* pathogenic bacteria and food combinations [6]. Research has revealed that different foodborne sources play a vital role in the contamination of *L. monocytogenes* in the human population within the region. Milk products have been a significant source of listeriosis, and they remain a constant threat to humans [29]. Several factors that cross-influence demography, healthcare, and environmental conditions define epidemiology within North Africa. However, there are variations in the specifics of epidemiological data from one country to another due to variances in reporting systems and concerns [30]. Infectious diseases like listeriosis impact the region, with prevalence influenced by local practices and resources [6]. It is important to understand that some countries have sound surveillance systems while others face various challenges. Measures to improve surveillance practices through partnership and capacity development have been pursued to this purpose. Nevertheless, the importance of data and data-driven approaches to tracking and containing infectious diseases is getting more attention. Thus, cooperation with health authorities and other institutions remains the key to stabilizing the epidemiological situation and meeting the population's health needs in North African countries [31].

The epidemiological landscape implies that the incidences of *L. monocytogenes* infections are not homogenous throughout North Africa, and as a result, it is significant to understand the dynamics in question [32]. Therefore, cultural practices in food handling and methods of food processing largely determine the probability of these infections. In addition, the global trade in food products and their supply chain has emerged as another factor that complicates the fight against these pathogens [33,34].

In North Africa, pregnant women might struggle to diagnose and treat listeriosis due to the possibility of limited access to healthcare services and prenatal care, especially in some areas [35]. In Algeria, Eleftherios Mylonakis et al., [36] documented the first two cases of neonatal listeriosis within 29 days in the same maternity hospital. One of them, the mother, resided on a farm 50 km from Algiers, and her family used to take fresh milk from their cow daily. In Egypt, a cross-sectional study was conducted among 50 pregnant women by EL-Naenaeey et al., [37] in which 4% tested positive for *L. monocytogenes*. The same survey identified *L. monocytogenes* in 8% of 200 milk samples and 4% of 50 feces samples from dairy cattle and established how *L. monocytogenes* pose a great danger to the public health of dairy products. The prevalence of *L. monocytogenes* in raw milk poses a public health risk for milk handlers, dairy farm workers, and milk consumers.

The detection and surveillance of *L. monocytogenes* among humans in the North African region help us understand the prevalence of listeriosis in the region. This knowledge is important as it reveals the genetic variation of *L. monocytogenes* and their ability to thrive on different foods. The prevalence of human listeriosis in North Africa indicates that the incidence of infection may be influenced by multiple food matrices [2]. Public health authorities, regulatory agencies, and the food industry need to work together to reduce the risk of contamination and to implement strict measures and controls that will guarantee the safety of the population in the region through prevention. This requires comprehensive research and coordinated initiatives to mitigate the potential impact of listeriosis.

4. Sources of *L. monocytogenes* in North Africa

L. monocytogenes is a foodborne pathogen that causes listeriosis, and this disease is serious and has high fatality rates, especially among persons with a weakened immunity system, including pregnant women, the elderly, newborns, and the immuno-compromised [38]. In North Africa, *L. monocytogenes* and factors that may be attributed to its prevalence are multiple. *L. monocytogenes* is mostly found in raw milk and dairy products like soft cheese; most dairy farms still perform traditional practices and have high incidences of consuming raw milk, contributing to the contamination [32,39]. Cheese and yogurt made from pasteurized milk can be again contaminated if certain measures are not observed while handling and packing the foodstuffs [40]. The especially vulnerable products include those that can be eaten without cooking, such as cold meat, delicates, pate, sausage, etc., if they were stored at improper temperatures or eaten after their expiration [41,42]. *L. monocytogenes* is largely found linked with smoked fish and any other processed seafood, particularly when they are not stored at the proper temperatures or consumed after their shelf lives [43]. Moreover, fresh fruits, vegetables, and other fresh produce like spinach and similar products can easily be contaminated through water or soil or during processing [44].

L. monocytogenes is a natural flora in soil and water. The pathogen invades food crops and water through contaminated water used in processing and irrigation besides the direct application of untreated manure, which circulates the pathogen within the food chain [45,46]. *L. monocytogenes* is capable of surviving on food processing plants' surfaces, and deposits may develop on the equipment or on the surfaces that are prone to make biofilms. When there is inadequate cleaning and disinfecting, such biofilms can attach and proliferate to the production stage, where they get transferred to the food products [47,48]. Cattle, sheep, and goats, for instance, can be asymptomatic carriers of *L. monocytogenes* and, therefore, shed the bacteria in their feces, contaminating feed and water [49]. Meat and poultry also easily become contaminated with *L. monocytogenes* during processing, slaughtering,

and packaging of poultry and poultry products [50].

L. monocytogenes can spread to humans both directly and indirectly. Direct transmission is more common among individuals in professions that involve close interaction with animals or animal products, such as farmers, veterinarians, slaughterhouse workers, poultry processors, and butchers [51]. Additionally, direct contact with pets infected with *L. monocytogenes*, especially puppies or kittens with *L. monocytogenes*-induced diarrhea, can be a source of infection [52]. While several indirect transmission routes from animals to humans exist, the most prevalent ones involve the consumption of contaminated milk, meat, or eggs [1].

In North Africa, various social factors contribute to malnutrition, including poverty, lack of access to clean water, insufficient food supplies, and inadequate healthcare services. Malnutrition weakens the immune system, making the body more susceptible to diseases such as listeriosis. Additionally, illnesses like AIDS increase the risk of *L. monocytogenes* infections. The immune system's reduced ability to fight pathogens in HIV/AIDS patients makes these individuals potential carriers and sources of *L. monocytogenes* transmission [53]. Street dogs and cats, especially those that move between neighborhoods and frequently enter people's homes, can also spread *L. monocytogenes*. Moreover, traditional food practices and limited refrigeration in rural areas can heighten the risk of foodborne illnesses. These unique conditions in North African countries highlight the need to understand the link between consumer health and immunity to listeriosis. Preventive and control measures for *L. monocytogenes* should address these risk factors to be effective. As shown in Figure 1, there are possible pathways of *L. monocytogenes* transmission to humans in North Africa.

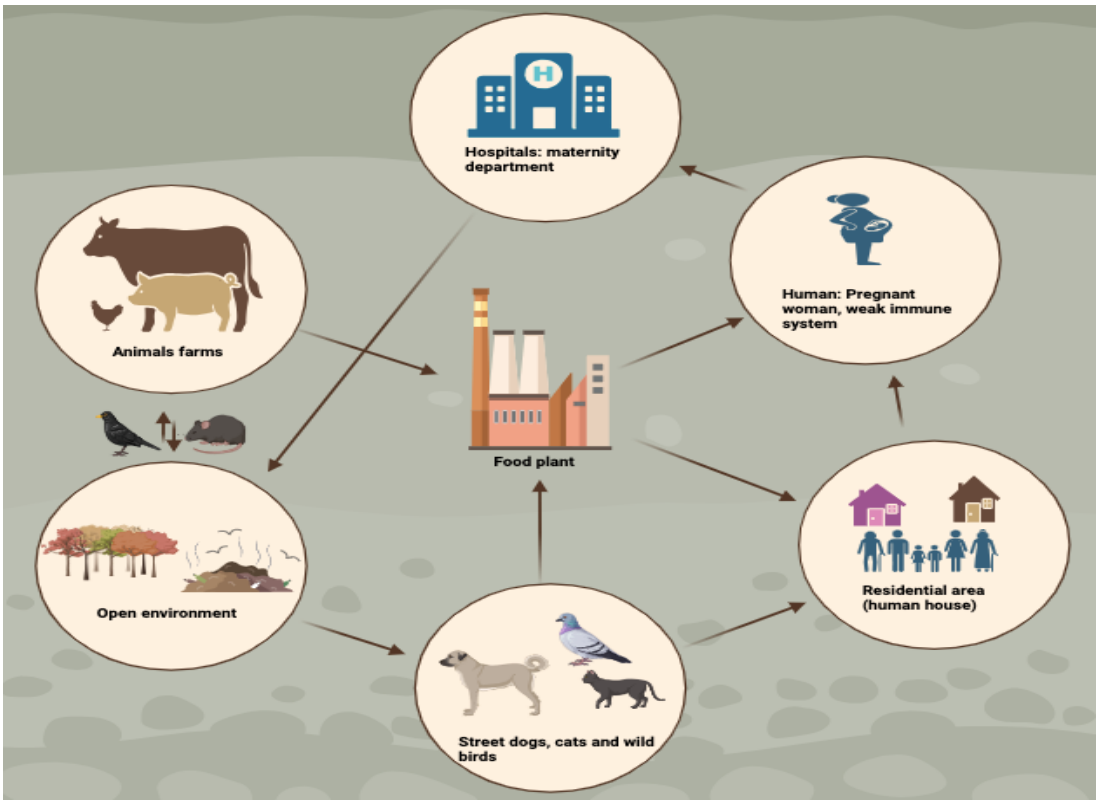

Figure 1. illustrates the potential pathways of *L. monocytogenes* transmission to humans in North African (accessed on August 5, 2024).

Table 1 summarizes research studies on *L. monocytogenes* frequency in North African food. Several researchers have documented the prevalence of *L. monocytogenes* in Algerian food products, highlighting public health risks. Abdellaoui et al., [54] found *L. monocytogenes* in 5.2% of 385 cheese samples. Benhalima et al., [32] reported *Listeria* spp. in 14.3% of 42 raw milk samples and 6.7% of 45 sausage samples, with *L. monocytogenes* present in only Sausage at 2.2%. Hamdi et al., [55] found *L. monocytogenes* in 2.6% of 153 raw milk samples. Bouayad and Hamdi [56] detected *Listeria* spp. in 9.3% of 227 ready-to-eat food samples (Figure 2).

Table 1. The occurrence of *L. monocytogenes* in North African foods.

Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
Algeria	Cheese (*n* = 385)	ND	5.2	ND	PCR technique	[54]
	Raw milk (*n* = 42)	14.3	ND	*L. innocua* (4.4), *L. seeligeri* (2.2).	API *Listeria* strips	[32]
	Sausage (*n* = 45)	6.7	2.2	*L. innocua* (4.4), *L. seeligeri* (0).		
	Foods ready to eat (*n* = 227)	9.3	2.6	*L. innocua* (4.8), *L. ivanovii* (1.3), *L. welshimeri* (0.4).	API *Listeria* strips	[56]
	Raw milk (*n* = 153)	ND	2.6	ND	API *Listeria* strips	[55]
Egypt	Tilapia (*n* = 40)	ND	5	ND	PCR technique (*16S rRNA*)	[44]
	Catfish (*n* = 25)	ND	8	ND		
	Vegetables (*n* = 90)	ND	1.1	ND		
	Poultry carcasses (*n* = 250)	ND	9.6	ND	API *Listeria* strips	[57]
	Raw milk (*n* = 153)	ND	10	ND	PCR technique (*16S rRNA*)	[58]
	Beef burger (*n* = 153)	ND	3.3	ND		
	beef sausage (*n* = 153)	ND	6.6	ND		
	Minced meat (*n* = 153)	ND	13.3	ND		
	Chicken fillet meat (*n* = 153)	ND	3.3	ND		
	Pasteurized milk (*n* = 100)	10	20	*L. innocua* (50), *L. ivanovii* (10), *L. grayi* (10), *L. welshimeri* (10),	PCR technique (*16S rRNA*)	[59]
	Chicken fillets (*n* = 100)	52	30.6	*L. innocua* (57.1), *L. ivanovii* (12.2), *L. grayi* (0), *L. welshimeri* (0),		
	Minced meat (*n* = 65)	ND	23	ND	MALDI-TOF MS	[60]

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Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Milk (*n* = 300)	ND	5.9	ND		[61]
	Raw milk (*n* = 50)	ND	20	*L. innocua* (2), *L. welshimeri* (6), *L. grayii* (4)	PCR technique (*16S rRNA*)	[62]
	Pasteurized milk (*n* = 50)	ND	0	*L. innocua* (0), *L. welshimeri* (0), *L. grayii* (0)		
	Flavored milk (*n* = 50)	ND	0	*L. innocua* (0), *L. welshimeri* (0), *L. grayii* (0)		
	Raw milk (*n* = 60)	28.3	13.3	*L. innocua* (3.3)	PCR technique (*16S rRNA*)	[63]
	Soft cheese (*n* = 30)	36.7	18.2	ND	PCR technique (*16S rRNA*)	[64]
	Ice cream (*n* = 30)	46.7	8	ND		
	Raw milk (*n* = 150)	8.7	61.5	*L. innocua* (23), *L. welshimeri* (15.4)	PCR technique (*16S rRNA*)	[65]
	Dairy products (*n* = 150)	ND	27.3	ND	PCR technique (*16S rRNA*)	[66]
	Milk (*n* = 120)	ND	7.5	ND	API *Listeria* strips	[67]
	Farm milk bulk tank (*n* = 25)	ND	0	ND	Biochemical tests	[68]
	Plain yoghurt (*n* = 25)	ND	0	ND		
	Fresh soft cheese (*n* = 50)	ND	14	ND		
	Raw Milk (*n* = 50)	ND	6	ND	PCR technique (*16S rRNA*)	[41]
	Ice Cream (*n* = 50)	ND	0	ND		
	Minced Meat (*n* = 50)	ND	14	ND		
	Fish Fillet (*n* = 50)	ND	8	ND		
	Sausage (*n* = 50)	ND	6	ND		
	Raw milk (*n* = 75)	27 (36)	22.2	*L. innocua* (25.9), *L. ivanovii* (3.7), *L. seeligeri* (3.7), *L. welshimeri* (7.4)	Biochemical tests	[69]
	Pasteurized milk (*n* = 50)	14 (28)	21.4	*L. innocua* (14.3), *L. ivanovii* (0), *L. seeligeri* (14.3), *L. welshimeri* (7.1)		

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Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Ice cream (*n* = 50)	19(38)	26.3	*L. innocua* (21), *L. ivanovii* (5.7), *L. seeligeri* (0), *L. welshimeri* (10.5)		
	Ras cheese (*n* = 50)	13(26)	15.4	*L. innocua* (23), *L. ivanovii* (15.4), *L. seeligeri* (0), *L. welshimeri* (0)		
	Ice cream (*n* = 200)	ND	5.5	ND	PCR technique (*16S rRNA*)	[70]
	Goat meat (*n* = 20)	20	50	ND	Biochemical tests	[71]
	Goat liver (*n* = 20)	30	33.3	ND		
	Goat kidney (*n* = 20)	30	33.3	ND		
	Goat lungs (*n* = 20)	0	0	ND		
	Goat rumen (*n* = 20)	50	30	ND		
	Soft cheese (*n* = 155)	14.2	4.5	*L. innocua* (9.7).	PCR technique	[39]
	Fillet fish (*n* = 100)	ND	7	ND	PCR technique (*16S rRNA*)	[72]
	Poultry meat (*n* = 90)	ND	10	ND	PCR technique (*16S rRNA*)	[73]
	Kariesh cheese (*n* = 120)	ND	0.8	ND	PCR technique (*16S rRNA*)	[48]
	Meat, hamburger (*n* = 50)	ND	2	ND		
	Chicken, broilers internal organs (*n* = 120)	ND	2.5	ND		
	Layers internal organs (*n* = 120)	ND	2.5	ND		
	Table eggs (*n* = 100)	ND	1	ND		
	Ducks internal organs (*n* = 60)	ND	1.7	ND		
	Silage (*n* = 90)	ND	3.3	ND		
	Fish, frozen fish (*n* = 100)	ND	1	ND		
	fish filet (*n* = 58)	ND	1.7	ND		
	Herring (*n* = 66)	ND	1.5	ND		
	Brain tissue, rabbit (*n* = 30)	ND	3.3	ND		
	Goats, fetal livers (*n* = 15)	ND	6.7	ND		

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Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Milk of dairy cows (*n* = 200)	19	4	*L. Ivanovii* (6), *L. innocua* (2), *L. grayi* (3), *L. Welshimeri* (4)	PCR technique (*16S rRNA*)	[37]
	Minced meat (*n* = 20)	50	15	*L. ivanovii* (10), *L. welshimeri* (5), *L. innocua* (20), *L. seeligeri* (0), *L. grayi* (0).	PCR technique	[42]
	Kofta (*n* = 20)	70	20	*L. ivanovii* (5), *L. welshimeri* (10), *L. innocua* (14), *L. seeligeri* (10), *L. grayi* (5).		
	Sausage (*n* = 20)	35	10	*L. ivanovii* (10), *L. welshimeri* (5), *L. innocua* (10), *L. seeligeri* (0), *L. grayi* (0).		
	Burger (*n* = 20)	60	15	*L. ivanovii* (15), *L. welshimeri* (10), *L. innocua* (10), *L. seeligeri* (5), *L. grayi* (5).		
	Luncheon (*n* = 20)	40	10	*L. ivanovii* (10), *L. welshimeri* (10), *L. innocua* (5), *L. seeligeri* (5), *L. grayi* (0).		
	Pasterma (*n* = 20)	25	5	*L. ivanovii* (10), *L. welshimeri* (0), *L. innocua* (5), *L. seeligeri* (5), *L. grayi* (0).		
	Vegetable (*n* = 331)	ND	14.2	ND	PCR technique (*16S rRNA*)	[74]
	Chicken meats (*n* = 100)	ND	2.8	ND	PCR technique (*16S rRNA*)	[75]
	Liver (*n* = 100)	ND	5.3	ND		
	Spleen (*n* = 100)	ND	2	ND		
	Kidneys (*n* = 100)	ND	3.3	ND		

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Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Raw milk, milking equipment, and hand swabs (*n* = 300)	26.3	23	*L. innocua* (3.3)	PCR technique (*16S rRNA*)	[76]
	Dairy products (*n* = 240)	10	33.3	*L. welshimeri* (12.5), *L. grayii* (45.8), *L. innocua* (8.3), *L. ivanovii* (0), *L.seeligeri* (0)	Biochemical tests	[77]
	Luncheon (*n* = 25)	ND	4	ND	Biochemical tests	[24]
	Beef burger (*n* = 50)	ND	8	ND		
	Sausage (*n* = 50)	ND	0	ND		
	Cottage cheese (*n* = 50)	ND	0	ND		
	Raw milk (*n* = 50)	ND	8	ND		
	Minced meat (*n* = 25)	ND	4	ND		
	Beef burgers (*n* = 50)	ND	32	ND		[78]
	Minced meat (*n* = 25)	ND	4	ND	PCR technique (*16S rRNA*)	
	Luncheon (*n* = 25)	ND	4	ND		
	Raw milk (*n* = 100)	ND	13	ND	Biochemical tests	[79]
	Raw milk (*n* = 51)	27.5	3.9	*L. ivanovii* (3.9), *L. innocua* (9.8), *L. seeligeri* (5.9), *L. grayi* (2), *L. welshimeri* (2).	Biochemical tests	[80]
	Kareish cheese (*n* = 51)	13.73	2	*L. ivanovii* (2), *L. innocua* (2), *L. seeligeri* (6.5), *L. grayi* (0), *L. welshimeri* (2).		
	Burger (*n* = 50)	8	ND	*L. ivanovii* (2), *L. innocua* (0), *L. seeligeri* (0), *L. grayi* (4). *L. welshimeri* (2).		

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Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Butter (*n* = 31)	6.5	ND	*L. ivanovii* (3.2), *L. innocua* (0), *L. seeligeri* (0), *L. grayi* (0), *L. welshimeri* (3.2).		
	Egg shells (*n* = 30)	ND	13.3	ND	PCR technique (*inlA*)	[81]
	Beef luncheon (RTE) (*n* = 40)	ND	15	ND	Biochemical tests	[82]
	Chicken luncheon (RTE) (*n* = 40)	ND	10	ND		
	Frankfurter beef (RTE) (*n* = 40)	ND	2.5	ND		
	Dairy product (*n* = 200)	ND	14	ND	PCR technique	[83]
	Frozen lean beef (*n* = 30)	20	3.3	*L. ivanovii* (6.7), *L. grayi* (3.3), *L. innocua* (3.3), *L. Seeligeri* (3.3), *L. welshimeri* (0).	API *Listeria* strips	[84]
	Raw milk (*n* = 30)	13.3	ND	*L. ivanovii* (3.3), *L. grayi* (3.3), *L. innocua* (0), *L. Seeligeri* (3.3), *L. welshimeri* (3.3).		
	Frozen catfish (*n* = 51)	ND	56.9	ND	Biochemical tests	[85]
	Mackerel (*n* 104)	ND	0.96	ND		
	Tilapia (*n* = 100)	31	4	*L. ivanovii* (8), *L. innocua* (5), *L. seeligeri* (5), *L. grayi* (3), *L. welshimeri* (6)	PCR technique	[86]
	Nile tilapia (*n* = 13)	ND	0	ND	Biochemical tests	[43]
	Mullet (*n* = 10)	ND	20	ND		
	Tuna (*n* = 12)	ND	16.7	ND		
	Blue crab (*n* = 12)	ND	33.3	ND		
	Shrimp (*n* = 14)	ND	42.9	ND		
	Bivalve mollusks (*n* = 10)	ND	60	ND		
	Meat products (*n* = 144)	28	58	ND	API *Listeria* strips	[87]
	Poultry products (*n* = 120)	19	48	ND		

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Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Seafood products (*n* = 120)	16	53	ND		
	Dairy products (*n* = 120)	23	63	ND		
	Plant products (*n* = 72)	39	61	ND		
	Minced frozen beef (*n* = 25)	32	4	*L. ivanovii* (0), *L. innocua* (28), *L. welshimeri* (0), *L. seeligeri* (0), *L. grayi* (0), *L. murrayi* (0).	Biochemical tests	[88]
	Luncheon (*n* = 25)	32	8	*L. ivanovii* (4), *L. innocua* (0), *L. welshimeri* (8), *L. seeligeri* (8), *L. grayi* (4), *L. murrayi* (0).		
	Frozen chicken leg (*n* = 25)	52	ND	*L. ivanovii* (12), *L. innocua* (8), *L. welshimeri* (8), *L. seeligeri* (0), *L. grayi* (16), *L. murrayi* (0).		
	Frozen chicken fillet (*n* = 25)	56	8	*L. ivanovii* (12), *L. innocua* (12), *L. welshimeri* (12), *L. seeligeri* (0), *L. grayi* (8), *L. murrayi* (4).		
	Egg shells (*n* = 100)	ND	7	ND	Biochemical tests	[89]
	Egg contents (*n* = 100)	ND	0	ND		
Libya	Raw cow milk (*n* = 20)	45	20	ND	Biochemical tests	[90]
	Laben (*n* = 20)	35	5	ND		
	Ricotta cheese (*n* = 20)	40	5	ND		
	Maassora cheese (*n* = 20)	40	5	ND		
	Chicken meat (*n* = 20)	45	20	ND		
	Chicken burger (*n* = 20)	60	15	ND		
	Raw beef (*n* = 20)	65	20	ND		
	Beef burger (*n* = 20)	60	5	ND		
	Beef sausage (*n* = 20)	55	20	ND		
	Ice cream (*n* = 160)	ND	4	ND	API *Listeria* strips	[91]
Morocco	Raw milk (*n* = 150)	ND	3.8	ND	PCR technique (*inlA*)	[92]

Continued on the next page

Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Traditional whey (*n* = 150)	ND	5.7	ND		
	Rayeb (*n* = 150)	ND	0	ND		
	Smen (*n* = 150)	ND	1.9	ND		
	Raw bovine meat (*n* = 150)	ND	1.9	ND		
	Raw poultry meat (*n* = 150)	ND	1.9	ND		
	Raw minced meat (*n* = 150)	ND	5.7	ND		
	Raw sausage (*n* = 150)	ND	5.7	ND		
	Raw fish (*n* = 150)	ND	1.9	ND		
	Salads (*n* = 150)	ND	0	ND		
	Beef meat (*n* = 140)	ND	7.1	ND	Biochemical tests	[93]
	Dairy products (*n* = 404)	3.2	0.7	*L. innocua* (1.5), *L. welshimeri* (0.7), *L. seeligeri* (0.3).	API *Listeria* strips	[94]
	Bovine meat products (*n* = 258)	12.8	2.7	*L. innocua* (9.3), *L. welshimeri* (0), *L. seeligeri* (0).		
	Poultry meat products (*n* = 103)	14.6	ND	*L. innocua* (13.6), *L. welshimeri* (1), *L. seeligeri* (0).		
	Pastries (*n* = 162)	4.9	3.1	*L. innocua* (1.9), *L. welshimeri* (0), *L. seeligeri* (0).		
	Salads (*n* = 143)	2.8	ND	*L. innocua* (2.8), *L. welshimeri* (0), *L. seeligeri* (0).		
	Chickpea flour cooked with eggs sold in the street (*n* = 20)	25	ND	*L. innocua* (25), *L. welshimeri* (0), *L. seeligeri* (0).		
	Mayonnaises (*n* = 6)	33.3	16.7	*L. innocua* (16.7), *L. welshimeri* (0), *L. seeligeri* (0).		
	Raw milk, Lben and Jben (*n* = 288)	ND	5.9	ND	API *Listeria* strips	[95]
	Red meats (*n* = 112)	4.5	20	*L. innocua* (80), *L. welshimeri* (0).	PCR technique (*hly*)	[96]

Continued on the next page

Country	Tested Food Samples (Total Number)	*Listeria* spp. % *	*L. monocytogenes* %	Other *Listeria* Species %	Confirmation Methods (If PCR Targets Genes)	References
	Ground meat and sausages (n = 240)	9.6	35	*L. innocua* (65), *L. welshimeri* (0).		
	Raw poultry (n = 74)	20	7	*L. innocua* (80), *L. welshimeri* (13).		
Tunisia	Fish (n = 50)	-	2	Not reported	API *Listeria* strips	[97]
	Sausage (n = 30)	-	3	Not reported		

*The percentage (%) of *Listeria* species is calculated from the positive samples (isolated target bacteria).

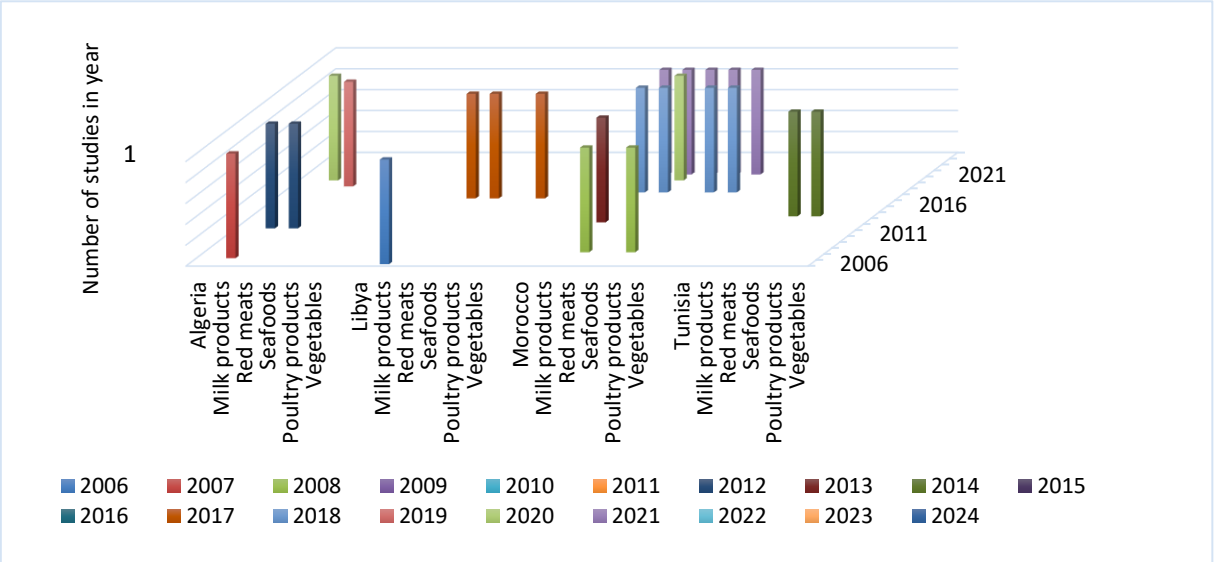

Figure 2. Studies that have detected the *L. monocytogenes* in foods in the last two decades in African, Libya, Morocco, and Tunisia.

In Egypt, many studies have been conducted to detect the occurrence of *L. monocytogenes* in foods (Figure 3). Milk products and red meats have shown the highest sources of *L. monocytogenes*. Recently, especially in 2021 and 2022, many studies have detected the occurrence of *L. monocytogenes* in milk products such as those by El-Baz and Elsayed [68], Abdeen et al. [41], and Elsayed et al. [61]. Additionally, red meats have been implicated as sources of *L. monocytogenes* by several studies. For example, Radwan et al. [60] detected *L. monocytogenes* in 23% of 65 minced meat samples, and Abou-Khadra et al. [58] detected it in 13.3% of 153 minced meat samples. Several researchers have also detected *L. monocytogenes* in seafood, poultry products, and vegetables, as shown in Table 1.

In Libya, according to Hesham et al, [90], *L. monocytogenes* was detected in various food sources. They sampled 20 samples from each source and found the bacteria in raw cow milk (20%), Laben (5%), Ricotta cheese (5%), Maassora cheese (5%), chicken meat (20%), chicken burger (15%), raw beef (20%), beef burger (5%), and beef sausage (20%). Additionally, El-Sharef et al. [91] detected *L. monocytogenes* in ice cream, with a prevalence of 4% out of 160 samples.

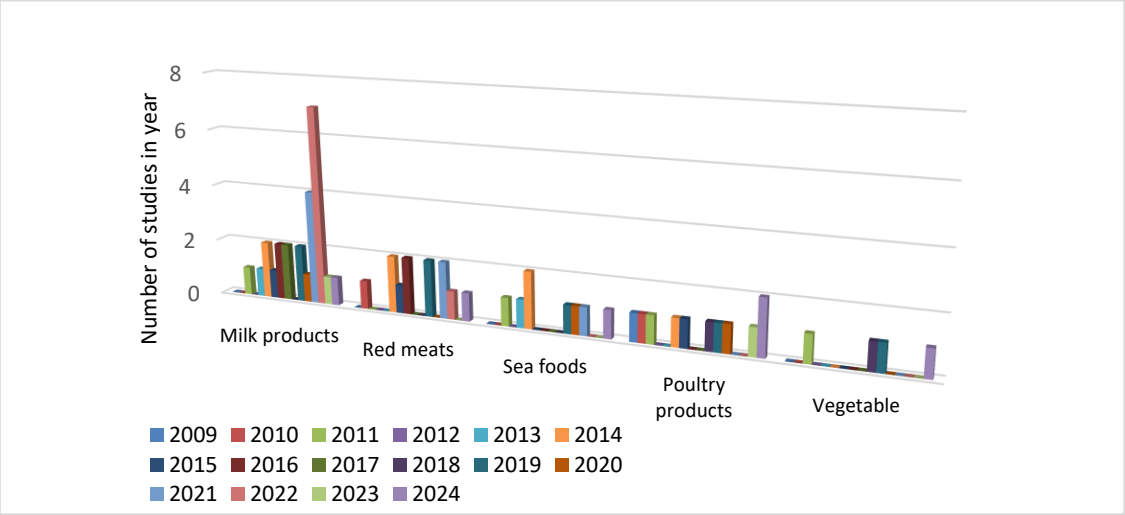

Figure 3. Studies that have detected the *L. monocytogenes* in foods in the last two decades in Egypt.

In Morocco, Boukili et al. [93] and Ennaji et al. [96] detected *L. monocytogenes* in red meats. Additionally, according to Bouymajane et al. [92], *L. monocytogenes* was isolated from raw milk at a rate of 3.8% out of 150 samples and from raw fish at 1.9% out of 150 samples. In Tunisia, Hmaïed et al. [97] found *L. monocytogenes* in fish, with a prevalence of 2% out of 50 samples, and in sausage, with a prevalence of 3% out of 30 samples (Figure 2).

Several studies describe the frequent isolation of *L. monocytogenes* in food products from North African countries. In Algeria, Abdellaoui et al. [54] detected *L. monocytogenes* in cheese samples, while Benhalima et al. [32] identified *L. monocytogenes* in raw milk and sausage. Several researchers who conducted studies in Egypt identified *L. monocytogenes* in milk products and red meats; however, Radwan et al. [60] and Abou-Khadra et al.. [58] documented a high prevalence of the bacteria. Hesham et al. [90] identified the bacteria in different foods in the Libyan context. In Morocco and Tunisia, researchers detected *L. monocytogenes* in raw milk, fish, and red meats. These researchers have pointed out that *L. monocytogenes* is prevalent in different types of foods in most of the North African countries. Thus, the simple identification of *L. monocytogenes* may not necessarily be a justifiable reason for initiating control measures. In the view of Habib et al. [6], it is vital to recognize all potential risks and investigate their interconnectedness if an upscale risk evaluation is to be produced. This way of handling control measures ensures that they are applied properly in combating *L. monocytogenes* contamination based on the risk factors inherent to the product. The key elements that may include the source of contamination, modes of transmission, and possible health risks should be evaluated to understand the best control measures. Surveillance efforts in Egypt emphasize the importance of vigilant monitoring, while in Morocco, the focus is on enhancing food security, particularly in meat products.

5. Virulence factors

L. monocytogenes is involved in foodborne diseases, and genes required for the virulence of bacteria are very important. These genes help the bacteria to adhere to and invade cells and tissues as

well as escape and neutralize the host's immune system [98]. They are crucial for *L. monocytogenes* to produce infections [99]. Knowledge of these genes is critical in formulating an effective means to contain and prevent foodborne diseases caused by *L. monocytogenes*. Thus, further elucidation of bacterial pathogenicity and stress factors at the molecular level must be established [19].

L. monocytogenes is a pathogen that leads to a foodborne illness known as listeriosis. The ability of *L. monocytogenes* to cause disease is largely attributed to its virulence genes, which play crucial roles in its interaction with the host [38]. Some of these genes involve the adhesion of the bacterium to host tissues, invasion of tissues, evasion of the host immune response, and general pathogenicity of the bacterium [100]. Internalin A (*inlA*) and Internalin B (*inlB*) are encoded surface proteins that promote adhesion and invasion of the bacteria to host cells. *inlA* binds to the E-cadherin receptor, which is present on the epithelial cell surface and *inlB*, binds to the Met receptor to facilitate the uptake of bacteria into the host cells [101]. The *hly* gene product is called Listeriolysin O, which facilitates the escape of the bacteria from the phagosome to the cytoplasm after being engulfed by host cells. This escape is essential for the bacterium not to be destroyed by the lysosomes of the host cell it has invaded [102]. Phospholipase enzymes (*plcA* and *plcB*) are involved in the action that breaks the phagosomal membrane and helps in the escape of the bacterium in the cytoplasm [103]. The *actA* encodes a protein that promotes actin polymerization, enabling the bacterium to move within the host cell's cytoplasm and spread to neighboring cells. The movement of these microorganisms is required for spreading the infection within tissues and this is achieved through the use of actin structures [104]. The *PrfA* gene encodes a transcriptional regulator that controls the expression of several virulence genes. *PrfA* is pivotal in orchestrating the bacterial response to environmental signals and ensuring the coordinated expression of virulence factors [105]. While these virulence factors provide a foundational understanding of *L. monocytogenes* pathogenicity, it is essential to analyze additional references and incorporate other key virulence gene clusters, such as *Listeria* pathogenicity islands (*LIPI*-1, *LIPI*-2, *LIPI*-3, and *LIPI*-4) [11,106]. These elements are essential for fully elucidating the complexity of *L. monocytogenes* virulence and its interaction with host systems. Expanding future studies to incorporate these components will provide a more comprehensive overview of the bacterium's mechanisms in causing listeriosis.

The study of virulence genes of *L. monocytogenes* is important to enhance the approach to listeriosis. Since the processes of bacterial pathogenicity can be described at the molecular level, researchers can develop specific strategies to prevent the effectiveness of bacterial actions [38]. For example, abstraction might temporarily inactivate enzymes or proteins that are important for bacterial attachment to and invasion of host cells and, thus, lower virulence. Information derived from virulence genes helps strategize on how to contain diseases within the populace. Improved techniques about the utmost view of virulence genes aid in watching and combating *L. monocytogenes* within the food chain system [107]. Moreover, it can assist in the development of vaccines that stimulate immune defenses against *L. monocytogenes*, this is because knowledge of the virulence factors enables the exclusion of related molecules and cells [108]. Knowledge of the roads and processes of invasiveness and cytopathogenicity also contribute to designing new anti-microbial compounds effective against particular bacterial processes [109].

The distribution of virulence genes of the *L. monocytogenes* isolates in food and human samples of the North African countries is depicted in Table 2. Several researches conducted in the last decade in Egypt aimed at detecting virulence genes in *L. monocytogenes* isolated from different foods. Since 2019, there has been an increase in the detection of virulence genes, including *hlyA* and *inlA*, *B*, *C*, and J in *L. monocytogenes* from milk products, red meat, seafood, and poultry products. This rise in

virulence gene detection coincides with an increase in human listeriosis cases, caused by *L. monocytogenes* carrying these genes, as illustrated in Figure 4. Other virulence genes such as *prfA*, *actA*, and *iap* have also increased during this period, with milk products being the main source of these genes (Figure 5). Researchers have detected the virulence genes in Morocco from red meat, milk products, seafood, and poultry products in 2020 and 2021, the studies found high levels of the *hlyA*, in *actA*, *inlA*, *inlJ*, *inlC*, *plcB*, and *prfA*. In Tunisia, Hmaïed et al. [97] detected *plcA*, *plcB*, *iap* from red meat, seafood and human listeriosis cases in the same geographical area and time.

Table 2. Distribution of virulence genes among *L. monocytogenes* in food and human samples across North African countries.

Country	Tested Food Samples or human	Total Number of *L. monocytogenes* isolates	Gene (%) *	References
Milk Products				
Egypt	Milk products	3	*hlyA* (66.7), *inlA* (66.7)	[58]
	Meat products	7	*hlyA* (57), *inlA* (100)	
	Poultry products	1	*hlyA* (100), *inlA* (0)	
	Milk products	25	*hlyA* (100), *inlB* (0), *perfA* (0)	[110]
	Milk products	1	*inlB* (100)	[111]
	Milk	20	*hylA* (100), *inlB* (100), *prfA* (100)	[112]
	Raw Milk	22	*hlyA* (100), *inlA* (50), *inlB* (100)	[65]
	Milk	9	*iap* (100), *hylA* (56), *actA* (22)	[67]
	Milk	33	*hylA* (85), *prfA* (85), *iap* (0)	[61]
	Milk products	36	*inlA* (100), *hlyA* (97), *plcA* (0), *inlB* (42), *prfA* (56)	[66]
	Milk products	7	*iap* (100), *hlyA* (86), *actA* (71)	[68]
	Milk products	16	*iap* (100), *hylA* (81), *actA* (69)	[69]
	Ice cream	11	*hylA* (91), *Iap* (27), *prfA* (46), *InlA* (82), *LuxS* (82), *flaA* (73)	[70]
	Milk of dairy cows	8	*inlA* (88), *inlB* (38)	[37]
	Mastitis milk	1	*inlA* (100), *inlB* (100)	
	Feces of dairy cows	4	*inlA* (75), *inlB* (25)	
	Raw milk	3	*inlA* (100), *hlyA* (100), *actA* (100), *prfA* (100)	[113]
	Milk products	8	*hlyA* (100), *flaA* (100), *inlA* (88), *inlB* (100), *inlC* (100), *inlj* (75)	[48]
	Milk, Milking equipment and Farm workers	69	*hlyA* (61), *prfA* (61), *inlA* (61), *inlB* (61)	[76]
	Milk products	3	*plcB* (100), *actA* (100), *hlyA* (100), *iap* (100)	[48]
Morocco	Milk products	6	*actA* (100), *hlyA* (83), *inlJ* (83), *inlA* (100), *inlC* (100), *plcB* (83), *prfA* (83)	[92]
Red Meats				
Egypt	Meat products	7	*hlyA* (57), *inlA* (100)	[58]
	Animal organs	31	*inlA* (100), *inlB* (100)	[114]

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Country	Tested Food Samples or human	Total Number of *L. monocytogenes* isolates	Gene (%) *	References
	Meat	9	*hlyA* (100), *pIcA* (0), *iap* (0), *prfA* (0), *inlA*	[73]
	Intestine	12	*hlyA* (100), *pIcA* (0), *iap* (0), *prfA* (0), *inlA* (25), *inlB* (0)	
	Sheep	16	*hlyA* (100), *iap* (0)	[115]
	Minced meat	9	*inlA* (100), *hlyA* (100), *actA* (100), *prfA* (100)	[113]
	Meat products	10	*inlA* (100), *hlyA* (100), *prfA* (90)	[50]
	Meat products	16	*iap* (100), *hlyA* (75)	[42]
	Goat fetal liver	1	*hlyA* (0), *flaA* (0), *inlA* (66.7), *inlB* (66.7), *inlC* (33), *inlj* (33)	[48]
	Rabbit (brain)	1	*hlyA* (100), *flaA* (100), *inlA* (0), *inlB* (0), *inlC* (33), *inlj* (0)	
	Ewe blood (Septicemia)	1	*hlyA* (100), *flaA* (100), *inlA* (100), *inlB* (100), *inlC* (100), *inlj* (100)	
	Processed meat	10	*hylA* (60)	[78]
	Beef luncheon	6	*inlA* (33), *inlC* (33), *inlJ* (33)	[82]
	Frankfurter beef	1	*inlA* (0), *inlC* (0), *inlJ* (0)	
	Meat products	23	*inlA* (100), *inlC* (100), *inlJ* (100)	[116]
Morocco	Red meats	7	*actA* (100), *hlyA* (100), *inlJ* (71), *inlA* (71), *inlC* (71), *plcB* (100), *prfA* (100)	[92]
	Beef meat	10	*actA* (100), *hlyA* (100), *inlJ* (100), *inlA* (100), *inlC* (100), *plcB* (100), *prfA* (100)	[93]
Tunisia	Meat products	1	*plcA* (100), *plcB* (100), *iap* (100)	[97]
Sea Foods				
Egypt	Fish	4	*inlA (100), hlyA (50)*	[44]
	Fish container	2	*inlA* (100), *hlyA* (50)	
	Fillet fish	5	*hlyA (100)*	[72]
	Tilapia fish	3	*inlA (100), hlyA (100), actA (100), prfA (100)*	[113]
	Seafoods	3	*hlyA (100), flaA (100), inlA (66.7), inlB (66.7), inlC (33), inlj (33)*	[48]
	Seafoods	7	*prfA* (100), *hlyA* (100), *actA* (100), *inlA* (100), *prs* (100)	[85]
	Blue crab	4	*inlA* (100), *inlC* (75), *inlJ* (75)	[43]
	Shrimp	6	*inlA* (100), *inlC* (83), *inlJ* (83)	
	Bivalve mollusks	6	*inlA* (100), *inlC* (83), *inlJ* (83)	
	Mullet	2	*inlA* (100), *inlC* (50), *inlJ* (50)	
	Tuna	2	*inlA* (100), *inlC* (50), *inlJ* (50)	
Morocco	Seafoods	1	*actA* (100), *hlyA* (100), *inlJ* (100), *inlA* (100), *inlC* (100), *plcB* (100), *prfA* (100)	[92]
Tunisia	Seafoods	1	*plcA* (100), *plcB* (100), *iap* (100)	[97]
Poultry Products				
Egypt	Poultry products	1	*hlyA* (100), *inlA* (0)	[58]

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Country	Tested Food Samples or human	Total Number of *L. monocytogenes* isolates	Gene (%) *	References
	Chicken carcass	24	*hylA (83), iap (100), actA (71)*	[57]
	Poultry meat	5	*inlA* (100), *hlyA* (100), *actA* (100), *prfA* (100)	[113]
	Poultry and poultry products	9	*hlyA* (89), *flaA* (89), *inlA* (56), *inlB* (67), *inlC* (33), *inlj* (56)	[48]
	Poultry	6	*inlA* (100), *hlyA* (100), *prfA* (100), *plcA* (0)	[75]
	Table eggs	4	*inlA* (100), *hlyA* (50)	[81]
	Chicken luncheon	4	*nlA* (25), *inlC* (25), *inlJ* (25)	[82]
Morocco	Poultry products	1	*actA* (100), *hlyA* (100), *inlJ* (100), *inlA* (100), *inlC* (100), *plcB* (100), *prfA* (100)	[92]
Vegetables				
Egypt	Vegetables	1	*inlA* (100), *hlyA* (100)	[44]
Human				
Egypt	Human stool	1	*inlB* (100)	[111]
	Human	5	*inlA* (100), *hlyA* (20)	[44]
	Human	5	*inlA (100), inlB (100)*	[114]
	Women	11	*hylA* (91), *Iap* (46), *prfA* (73), *InlA* (73), *LuxS* (82), *flaA* (64)	[70]
	Hand swab	3	*hlyA* (100), *pIcA* (0), *iap* (0), *prfA* (33), *inlA* (33), *inlB* (33)	[73]
	Stool	5	*hlyA* (100), *pIcA* (0), *iap* (0), *prfA* (0), *inlA* (20), *inlB* (0)	
	Stool of pregnant women	2	*inlA* (50), *inlB* (50)	[37]
	Woman blood (Septicemia)	1	*hlyA* (100), *flaA* (100), *inlA* (100), *inlB* (100), *inlC* (100), *inlj* (100)	[48]
	Human	5	*inlA* (40), *hlyA* (40)	[81]
	Human stool	1	*inlA* (0), *inlC* (0), *inlJ* (0)	[82]
Tunisia	Human	5	*plcA* (100), *plcB* (100), *iap* (100)	[97]

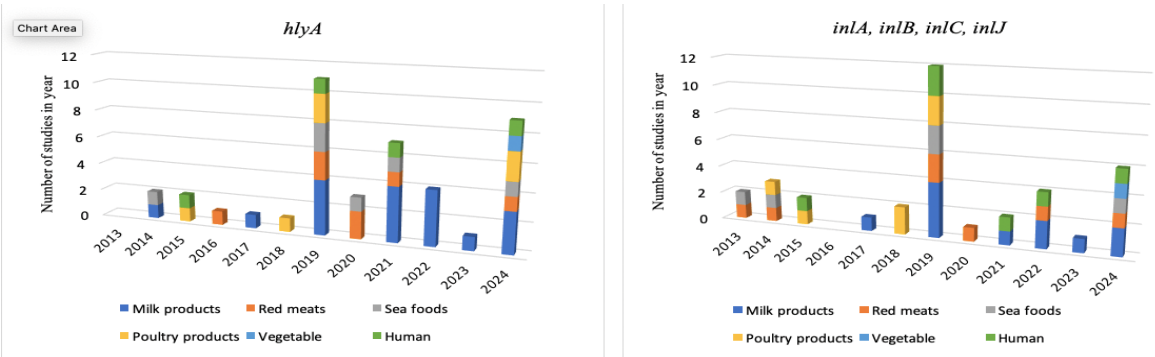

Figure 4. Studies where *hlyA* and *inlA*, *inlB*, *inlC*, and *inlJ* in *L. monocytogenes* were detected in foods and humans in Egypt.

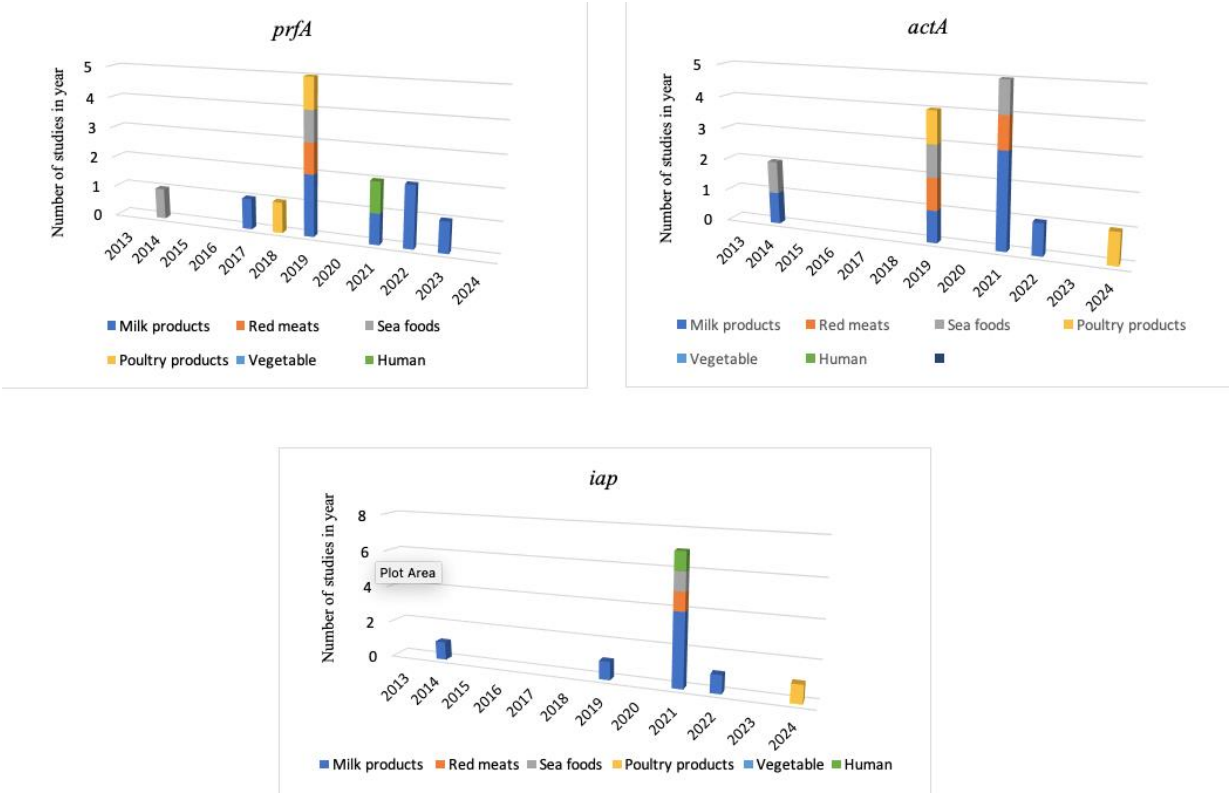

Figure 5. Studies where *prfA, actA*, and *iap* in *L. monocytogenes* were detected in foods and humans in Egypt.

The possible reasons and causes for the growing incidence of virulence genes, techniques of diagnosis, and surveillance activities have been enhanced to enable more frequent and efficient identification of virulence genes in foods. Such differences in food handling, processing, and storage may lead to the survival and multiplication of *L. monocytogenes* hence increasing its chances of getting into the food chain. The potential development of antibiotic resistance in *L. monocytogenes* could make it more resilient and harder to eliminate from food products, leading to higher rates of contamination. Globalization arising from the global trade and improved supply chain means that there is a wider dispersal of contaminated foods and this may lead to extensive circulation of virulence strains of *L. monocytogenes*. Temperature and relative humidity, which are some of the factors that determine the growth and spread of *L. monocytogenes* may change in the course of food production and their natural ecosystems. These factors together may explain the observed increase in virulence gene detection and the corresponding rise in human listeriosis cases.

This study shows that the increase of the virulence genes in *L. monocytogenes* obtained from food sources and its subsequent detection in isolates of human listeriosis suggests that there is a need for constant monitoring and improved food safety practices. Addressing the factors contributing to the spread of this pathogen is crucial to mitigate public health risks and reduce the incidence of listeriosis.

6. Antibiotic resistance

Antibiotic resistance in *L. monocytogenes* is a growing concern globally, including in North Africa [51,117]. Commonly used antibiotics for treating listeriosis include gentamicin, ampicillin, and

trimethoprim-sulfamethoxazole [118–120]. However, resistance to these antibiotics has been reported in various studies [121,122]. Ampicillin and penicillin are traditionally the first line of treatment for listeriosis, as resistance to these antibiotics in *L. monocytogenes* remains relatively rare [123]. However, isolated cases of resistance have been reported, necessitating close monitoring [121,124]. Gentamicin is often used in combination with ampicillin, and resistance to gentamicin has also been observed [123]. Resistance to tetracyclines (such as doxycycline), macrolides (such as erythromycin), and trimethoprim-sulfamethoxazole has been reported in studies across North Africa [41,125]. This resistance is concerning as these antibiotics are sometimes used as an alternative treatment for listeriosis. The presence of multidrug-resistant (MDR) *L. monocytogenes* strains has been identified, complicating treatment options. These strains often show resistance to multiple antibiotics, including those mentioned [57,126].

Some genetic relatedness has been observed in North African investigations between invasive resistant strains of *Salmonella*, *Campylobacter jejuni*, and pathogenic *Escherichia coli* isolated from humans and those from foods [10,11]. These facts mean that the analyzed food production systems are involved in the spread of multidrug-resistant bacteria [127,128]. Additionally, investigations have established the prevalence of resistance determinants such as β-lactamases in both *Salmonella* as well as the pathogenic *E. coli* within the same region, which are known to confer resistance to β-lactam antibiotics [129,130]. The same may apply to *L. monocytogenes* even though it has been less investigated, this pathogen has been known to be frequently recovered at different stages along the food processing and production. This stresses the ability of *L. monocytogenes* to acquire and transfer resistance determinants contributing to the need to establish more on the role of *L. monocytogenes* in AMR within the region [131,132].

According to Zakaria and Sabala [57], poultry meat can be a source of antibiotic-resistant *L. monocytogenes* strains, high resistance was detected in 24 isolates obtained from poultry meat, penicillin (17 isolates, 70%), tetracycline (22 isolates, 91.7%), and amoxicillin-clavulanic acid (14 isolates, 58%). There was less resistance to erythromycin (5 isolates, 20%), gentamicin and vancomycin (7 isolates, 29%), and chloramphenicol (4 isolates, 17%). In another study by Elsayed et al. [61], the strains obtained from Egyptian dairy cattle farms showed phenotypic resistance to most of the antibiotics tested, except for netilmicin and vancomycin. The strains from animal samples demonstrated high resistance to amoxicillin (95.2%, 80 of 84) and cloxacillin (92.9%, 78 of 84). In contrast, the strains from environmental samples exhibited significant resistance to cefotaxime (86.95%, 20 of 23). Additionally, 25 multi-antibiotic resistance patterns were identified in *L. monocytogenes* strains. All strains had a multi-antibiotic resistance index ranging from 0.22 to 0.78 and contained antibiotic resistance genes, including extended-spectrum β-lactamase genes (bla_{CTX}-M [92.7%] and bla_{DHA}-1[66.4%]), quinolone resistance genes (*qnrS* [91.2%], *qnrA* [58.4%], *parC* [58.4%], and *qnrB* [51%]), macrolide resistance genes (erm[B] [76.6%], *erm* (C) [1.5%], and *msr* (A) [27%]), trimethoprim resistance gene (*dfrD* [65.7%]), and tetracycline resistance genes (*tet* (M) [41.6%], *tet* (S) [8%], and int-Tn [26.3%]).

Saleh et al. [44] highlighted that many commonalities were observed among locally resistant *L. monocytogenes* isolates from tilapia, catfish, fish containers, cauliflower samples, and human samples. Among the listeriosis cases in humans, two isolates showed multi-antibiotic resistance, the first member to gentamicin, amoxicillin-clavulanic acid, tetracycline, ciprofloxacin and the second member to gentamicin, sulfamethoxazole-trimethoprim and ampicillin. Further, two other human isolates are resistant to gentamicin and ampicillin. In the same study, several isolates demonstrated resistance to

multiple antibiotics across sources: From hand swabs, one isolate was resistant to ampicillin, whereas one from a fish container swab was resistant to both ampicillin and tetracycline. One tilapia sample was resistant to gentamicin, sulfamethoxazole-trimethoprim, and ampicillin; another from tilapia was resistant to ampicillin alone; one from catfish showed resistance to both tetracycline and ampicillin; another from catfish was resistant to gentamicin and ampicillin; and one isolate from vegetables exhibited resistance to sulfamethoxazole-trimethoprim and ampicillin.

Antibiotic-resistant *L. monocytogenes* in North Africa have an impact on health and food safety. In this regard, enhanced monitoring and surveillance systems are necessary for establishing the levels of this pathogen and taking into account the resistance levels detected. Measures such as proper food hygiene and sanitation rules and policies formulated in admitting centers can go a long way in controlling contamination and potential infections. Furthermore, the role of educating the public and officials on the responsible usage of antibiotics in the treatment of human and animal diseases is essential to curb the spread of resistance. The threat of antibiotic resistance in *L. monocytogenes* in North Africa is gradually evolving, which necessitates the collaboration of health organizations, food safety departments, and the agricultural industry. Further investigations and monitoring of the literature are also required to determine the existing resistance trends and to design successful containment measures for this realized public health menace.

7. Conclusions

In summary, in this elaborate discussion, we establish the necessity of enduring research and monitoring of *L. monocytogenes* infection pathways in North Africa with a particular focus on milk products as a primary source. The rise of virulence genes in *L. monocytogenes* from dairy products and their subsequent identification in human *L. monocytogenes* isolates highlights that dairy products are the main sources of this pathogen in North Africa. Moreover, the discussion on antibiotic resistance underscores the urgency for enhanced surveillance, prudent antibiotic practices, and the development of comprehensive strategies to combat antimicrobial resistance in *L. monocytogenes* strains. It is crucial to take preventive steps to approach potential dangers that threaten the population's well-being and observe the efficacy of the treatment methods used in eradicating bacteria. Combating these challenges as a single entity supports the integrated initiatives towards enhancing improved health and safety conditions in the North African nations. Thus, it is crucial to establish a fixed system for pasteurizing milk on farms and ensure it is packaged cleanly and quickly immediately after pasteurization. Moreover, establishing robust surveillance networks is crucial for effectively controlling infections through a multi-sectoral approach that integrates laboratory diagnostics, epidemiological investigations, collaborative efforts, public awareness campaigns, and capacity building. Such an approach is essential for preventing diseases caused by *L. monocytogenes* within the region's populace. By leveraging these strategies, North African countries can mitigate the impact of *L. monocytogenes* infections, enhancing overall public health outcomes and ensuring the safety of food supplies and environments.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of Interest

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

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Authors contribution

Conceptualization, M.-Y.I.M.; Formal analysis, M.-Y.I.M.; Methodology, M.-Y.I.M.; Project administration, M.-Y.I.M.; Writing—original draft, M.-Y.I.M.; Writing—review & editing, M.-Y.I.M. and I.H.; Resources, I.H. Supervision, I.H. All authors have read and agreed to the published version of the manuscript.

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