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FOOD MICROBIOLOGY - RESEARCH PAPER

Risk factors for listeriosis due to sausage consumption in Mexico: consumer practices, bacterial survival, and quantitative microbial risk assessment

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Abstract
Listeriosis is a foodborne disease caused by *Listeria monocytogenes* (Lm), which represents a public health problem. Lm has been identified as an important contaminating bacterium of ready-to-eat meat products (RTEM) in Mexico. The objective was to explore the risk factors for acquiring listeriosis due to sausage consumption by defining the consumer profile, evaluating the survival of Lm in sausage (5, 10, and 25 °C for 32 days) and performing a quantitative microbiological risk assessment. The survey of 100 participants revealed that the factors compromising the safety of the RTEM by the consumer are the extension of the shelf life. Acquiring packaged RTEM was observed as a safe habit. All respondents stated that they were unaware of listeriosis, but 18% reported infections linked to RTEM, mainly sausage. The sausage supports the growth of Lm, whose population increases in congruence with temperature (25 °C > 10 °C >5 °C) and storage time ($P \leq 0.05$). The increase in temperature decreases the adaptation time ($Lag_{25\,°C} = 1.0$ h, $Lag_{10\,°C} = 92.5$ h, $Lag_{5\,°C} = 226.1$ h) and increases the growth rate ($\mu_{25\,°C} = 4.43$ CFU/h, $\mu_{10\,°C} = 0.075$ CFU/h, $\mu_{5\,°C} = 0.0026$ CFU/h) of Lm on the sausage. The risk of listeriosis due to sausage consumption increased according to the increase in temperature: 5.53×10^{-8}–1.42×10^{-5} (5 °C), 0.00616–0.111 (10 °C), and 0.109–1.00 (25 °C). Consumer education in the hygienic management of RTEM and information on associated pathogens will minimize the risk of disease.

Keywords Storage · Growth · *L. monocytogenes* · Ready-to-eat meat products

Introduction

The World Health Organization (WHO) recognizes foodborne illness (FBI) as a global public health problem. Listeriosis is primarily typified as FBI and is caused by *Listeria monocytogenes* [1], which belongs to *Listeria* spp. and corresponds to the most relevant species for causing severe diseases in man [2]. Listeriosis includes manifestations such as gastroenteritis, or serious invasive diseases such as septicemia, meningitis, or abortions [3]. The annual incidence of listeriosis has been estimated to be 0.1 to 11 cases per million inhabitants worldwide, reaching a mortality rate ranging from 20 to 30% [1]. Epidemiological investigations have indicated that listeriosis reports correspond to outbreaks associated with unpasteurized dairy products, meat products, and ready-to-eat vegetables [3, 4].

Listeriosis is not considered a mandatory disease by the General Directorate of Epidemiology (DGE) of Mexico. However, few scientific reports have justified the participation of *L. monocytogenes* as an etiological agent of diseases in the Mexican population with a high mortality rate (>50%) and without identification of the source of infection [5]. On the other hand, the presence of *L. monocytogenes* as a contaminating agent of raw meat foods [6], sausages [6–8], unpasteurized milk [9], and fresh cheeses [10–13] has been widely exhibited in the country.

In Mexico, the detection of *L. monocytogenes* in ham (1.4–8.3%) and sausage (10.4–11.7%) has taken special attention due to the prevalence of the pathogen reported [6–8], the risk of acquiring a sausage contaminated with

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the bacteria [7], and the pathogenic potential of isolates from this food [14]. However, the list of cases of listeriosis due to the consumption of contaminated sausages in Mexico is unknown. Given these arguments, it is possible to argue that the food can exert an influence on the survival of *L. monocytogenes* or that the consumer performs adequate hygienic practices for the management of sausages favoring the control of the bacteria.

The cooked sausage is defined as a cooked meat product ready for consumption that has been subjected to a time-temperature treatment that guarantees its safety and whose storage must be at 4 °C [15]. Therefore, the consumer can directly ingest the food without prior cooking within that validity and respecting good hygienic practices. However, the literature has identified poor hygiene and abuse of storage temperature as consumer practices that violate food safety [16, 17]. Although the food is ready for consumption, the presence of *L. monocytogenes* in packaged hams and sausages has been demonstrated [7].

In the literature, it has been described that cooked ham [18], vacuum-packed sausages [19], cured sausages [20], and fine cold meats [21] can allow the growth of *L. monocytogenes* during the shelf life of the food, and the growth rate of the pathogen is regulated by the storage temperature. Other scientific reports have indicated that the food matrix and its storage conditions can influence the ability of *L. monocytogenes* to sort the adverse conditions of the gastrointestinal barrier and modulate its virulence in the host [21].

Quantitative microbiological risk assessment (QMRA) is a tool based on a series of probabilistic mathematical models that allow describing the importance and warning of a danger to public health. The QMRA is composed of four elements: (i) hazard identification, (ii) exposure assessment, (iii) dose-reaction, and (iv) risk characterization. These models allow quantitatively inferring the proportion of people who would become ill or die from exposure to a pathogen, such as *L. monocytogenes* [22, 23]. Previously in Mexico, the risk of acquiring listeriosis (1.43×10^{-10} to 1.06) from the consumption of fresh cheeses contaminated with *L. monocytogenes* was exposed [12].

Given that the annual consumption (8 kg per capita) of sausages is increasing in Mexico [24], and the presence of *L. monocytogenes* is justified in these foods, the objective was to explore the risk factors for acquiring listeriosis due to sausage consumption by defining the consumer profile, evaluating the survival of *L. monocytogenes* in sausage (5, 10, and 25 °C for 32 days), and the performance of a quantitative analysis of microbiological risk.

Material and methods

Design and implementation of surveys

To define the consumer profile of ready-to-eat meat products, the survey was conducted electronically to 100 residents of the state of Culiacán, Sinaloa, Mexico, during the first half of 2020. A survey was constructed with questions to explore respondents' sociodemographic data, preference, and hygiene habits for food consumption (Table 1). The questions were developed with multiple choice reagents to simplify the answers. The survey was developed on the Survey Monkey platform, and the collected data was tabulated

Table 1 Characteristics of consumers of meat products in Mexico

Data	Characteristics	%
Gender	Female	50
	Male	50
Age range	15–25	57
	26–40	35
	41–60	8
Consumption of meat products cooked	Yes	100
	No	0
Preference of meat products cooked	Ham	46
	Sausage	41
	Chorizo	13
Purchase consideration	Taste	52
	Brand	31
	Price	11
	Hygiene	6
Intake per event (No. of pieces)	1	31
	2	50
	3	14
	4	5
Weekly consumption (times)	1	55
	2-3	42
	>4	3
Type of purchase	Package	72
	Bulk	28
Mode of consumption	No cooking	43
	With cooking	57
Home storage time (days)	1–2	40
	3–5	35
	> 7	25
Diseases due to consumption	No	82
	Gastroenteritis	18

n = 100 participants. The term gastroenteritis was used to indicate those respondents who presented some symptoms such as diarrhea, vomit, abdominal pain, or any associated symptom in Excel. The participation of the respondents was voluntary, and the data was handled under anonymity and confidentiality.

Preparation of sausage samples

Turkey sausage samples of a commercial brand and marketed in a local supermarket in Culiácan, Sinaloa, Mexico, were obtained. The product was packaged and stored at 5 °C, contained 10 pieces (500 g), and had valid shelf life. The food was exposed in a microwave for 75 s [25], and a microbiological analysis was performed to rule out the presence of *Listeria monocytogenes* [26]. Under aseptic conditions, the sausage pieces were removed from their packaging and cut into 2 cm^3 (2 cm × 2 cm × 0.5 cm) slices. Portions of 100 ± 5 g of sausages were weighed and placed in airtight sterile bags for later inoculation.

Inoculum preparation

This study included two strains of *L. monocytogenes* corresponding to a reference strain (*L. monocytogenes* ATCC 7644) and a food isolate (*L. monocytogenes* ID-95) [7]. The strains of *L. monocytogenes* were thawed (−80 °C), and the contents of the vials were transferred individually to 10 mL of trypticasein soy broth (TSB) to incubate at 37 °C for 24 h. Subsequently, an aliquot of each culture was grown in new TSB under the same conditions. The cultures were centrifuged (9800 × g for 10 min at 10 °C), and the pellets were resuspended in sterile phosphate buffer (PBS) and adjusted to a concentration of 1.0×10^8 CFU/mL (OD = 0.1, λ = 600 nm) at PBS. Serial dilutions were prepared to standardize a bacterial suspension of 1.0×10^5 CFU/mL. The bags with the sausage pieces (100 g) were inoculated by immersion (1:2 w/v) with 200 mL of a standardized bacterial (1.0×10^5 CFU/mL) suspension to reach a concentration of 10^3–10^4 CFU/mL of *L. monocytogenes* [18]. The samples were homogenized for 2 min, the liquid was drained, and the samples were stored in a biosafety cabinet prior to storage.

Bacterial growth model

Sausage samples (100 ± 5 g) were stored at 25 ± 1, 10 ± 1, and 5 ± 1 °C, and the concentration of *L. monocytogenes* was examined on the day of inoculation (zero time) and on storage days 2, 4, 8, 16, and 32. An aliquot of each culture was taken to enumerate the number of bacteria in modified Oxford agar, and the plates were incubated at 37 °C for 48 h. The trials were conducted in duplicate. The survival results of *L. monocytogenes* strains were averaged and expressed in Log CFU/g. In addition, kinetic parameters were calculated, including adaptation time (Lag), growth rate (μ), generation time (g), and maximum population density (N) using the Gompertz model:

$$N = A + C * e\,(-e(-B(t - M))) \tag{1}$$

Where N is the concentration in time (Log CFU/g), A is the initial concentration (Log CFU/g), C is the value of the lower asymptote (Log CFU/g), B is the maximum relative growth rate (CFU/h), and M is the time of the maximum absolute growth rate (CFU/h). The values of R^2 and MSE (mean square error) were calculated for the validity of the model.

QMRA

Exposure analysis

This study assumes the scenario of acquiring listeriosis from the consumption of sausages contaminated with *L. monocytogenes* in the population of Mexico. To define the size of the portion of sausage consumption by the population in Mexico, it was modeled by analyzing the data obtained from the sausage consumption survey carried out (Table 1), and the stratum population records in Mexico of the National Institute of Statistics and Geography [27]. To determine the portion of sausage consumed by the pregnant women population, it was assumed that 6.17% of women of reproductive age (15–49 years) were pregnant in the survey. This rate was calculated with the number of births (2,092,214) in women of reproductive age reported by INEGI in 2019. The analysis indicated that the average portion of daily consumption for the population was 14.8 g of sausage. The dose of exposure to *L. monocytogenes* was estimated considering the maximum concentration of the pathogen per gram of sausage according to its storage temperature and the size of the portion consumed (Table 2).

Number of annual servings of sausage ingested

To estimate the number of annual servings for each subpopulation at risk in Mexico, the number of individuals from each population stratum in Mexico was multiplied [27] by the frequency of sausage consumption by stratum

Table 2 Parameters of exposure analysis of *L. monocytogenes* in sausage

Parameter	Unit	Assumptions
Concentration of *L. monocytogenes* at 5 °C	CFU/g	1.04×10^{-3}
Concentration of *L. monocytogenes* at 10 °C	CFU/g	1.16×10^{-8}
Concentration of *L. monocytogenes* at 25 °C	CFU/g	2.16×10^{-9}
Amount of sausage consumed per serving	g/day	14.8
Annual portion for healthy population	g	150.8
Annual portion for the elderly population	g	136.9
Annual portion for pregnant women	g	25.5

population (survey data) by 365 days (Table 2). According to the population census, Mexico has a population of 126,014,024 inhabitants [27]: 79.8% (100, 550, 297) are individuals aged 5–59 years, 12% (15, 142, 976) are individuals >60 years old, and 1.8% (2,092,214) are women who gave birth in 2019.

Dose-response model

The estimation of the probability of infection because of a certain level of exposure to *L. monocytogenes* was performed by an exponential dose-response model as expressed in the following formula:

$$P = 1 - \exp(-D * r) \quad (2)$$

Where P is the probability of infection of a person exposed to a dose of N of ingested *L. monocytogenes* cells, D is the exposure dose of *L. monocytogenes*, and r is the average probability of developing listeriosis by ingestion of an *L. monocytogenes* cell in a specific portion. The r values used were 3.59×10^{-12}, 6.83×10^{-11}, and 9.22×10^{-10} for healthy, elderly (>60), and pregnant population, respectively [28].

The annual risk of infection was estimated using the following formula:

$$P(\text{year}) = 1 - \left(1 - P * P_{\text{id}}\right)^{E} \quad (3)$$

Where P (year) equals the annual risk of infection, P is the prevalence of *L. monocytogenes* in sausage (4.2%) [7], P_{id} is the probability of infection of an individual exposed to a dose of N cells of *L. monocytogenes*, and E is the annual number of servings of sausage consumed per person (Table 2) [29]. Risk variability and uncertainty spread with a Monte Carlo simulation (10,000 iterations). Analyses were performed using Oracle Crystal Ball software (vs.11.1.2.4) and Excel (vs.16.39). In addition, to estimate the annual cases of listeriosis in the population of Mexico, the 2020 Mexican Population Census [27] was considered.

Statistical analysis

The results of the surveys were analyzed using descriptive statistics and probability in Microsoft Office Excel 2013. For the survival of *L. monocytogenes*, a bifactorial analysis of the bacterial concentration according to the time and temperature of storage was performed. Statistical significance was judged at a level of $P \leq 0.05$ (Minitab19). The calculations of the kinetic parameters and the Gompertz model were performed using the programs Statistic 13 and Microsoft Office Excel 2013.

Results and discussion

Consumer profile

Table 2 shows the results of the interviewed population. The respondents belonged to both genders (50%), and the main age range (57%) was 15–25 years. Regarding consumer preference, it was observed that 100% of respondents consume some type of cooked meat products, being ham (46%) and sausages (41%) the most preferred products. The frequency and amount of consumption in the majority (81%) of respondents are 1 (31%) to 2 pieces (50%) once a week (55%). All respondents confirmed that they were unaware of listeriosis, but 18% of people reported having a gastrointestinal infection due to consuming some type of cooked meat products, mainly when they ate sausage (56%, n =10/18).

The profile of the sausage consumer is heterogeneous (Fig. 1a), and 24% (10/41) of the population reported suffering from some symptom associated with gastrointestinal infections (Fig. 1b), mainly in females (n = 7). According to the probability analysis, it is estimated that 56% of consumers can comply with purchase practices and safe consumption of sausage. Meanwhile, consumption of expired sausage is observed as a risk factor for loss of safety and an increased risk of gastrointestinal infections (Fig. 1c).

In Mexico, the most preferred cooked meat product is sausage (492,578 tons/year), whose production is projected to increase nationally [24]. Given that the safety of this food has been questioned in Mexico [6–8], it is relevant to determine the hygienic practices of consumers. Currently, consumer responsibility to maintain food safety assurance is a focus [16, 17].

The acquisition of sausages in the surveyed population is mainly for convenience. Among the factors that can condition the hygienic practices for food handling by the consumer are the gender, educational level, socioeconomic stratum, and knowledge habits [30, 31]. In the study, both genders preferably practice safe shopping and consumption habits. However, some populations (25–28%) have risky practices that guarantee the safety of sausages. Ruby et al. [31] pointed out that women tend to maintain better hygienic practices for the handling of food in comparison with men and that these practices are acquired first by the mother, school, and television [16]. This aspect is an opportunity to generate strategies and communication channels for consumer education.

Regarding sausage buying habits, most respondents (80%) opt for products in their original packaging. The main function of sausage packaging is to ensure safety and protect its attributes. On the other hand, bulk buying is a practice of commerce and buying habit in the Mexican

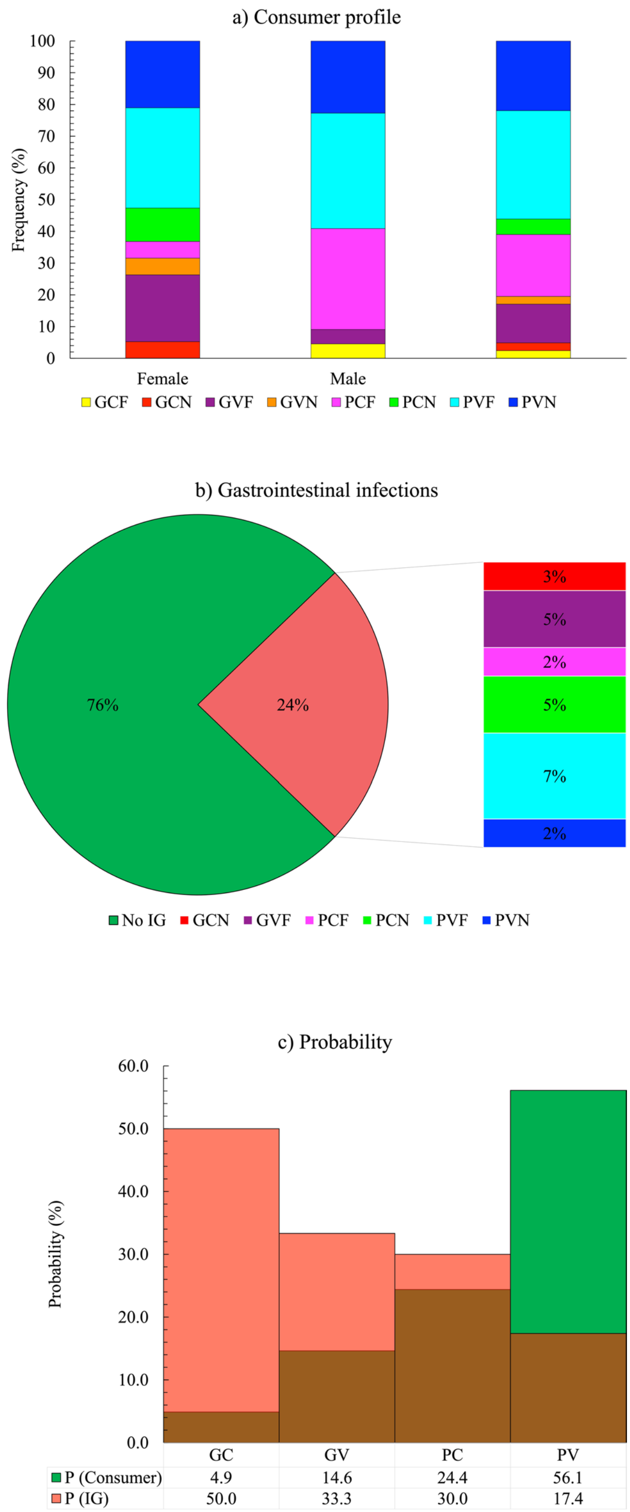


Fig. 1 Frequency (**a**, **b**) and probability (**c**) of the profiles of consumed meat products and gastrointestinal infections according to the surveyed population. The letters mean the following: G, bulk; P, package; V, current; C, expired; F, with cooking; N, without cooking; GI, gastrointestinal infections; P, probability

population. But this habit increases the risk of fecal contamination due to the loss of hygiene during the sale [7].

An interesting habit determined in the respondents (29%) is the consumption of the sausage even after a week of refrigerated storage, presumably due to ignorance of the shelf life or the health implications of the consumption of an expired food. The United States Department of Agriculture recommends that the average refrigeration storage time (4–5 °C) of sausages in open and closed package is 1 and 2 weeks, respectively [32]. In Mexico, the regulations indicate the storage temperature (4 °C) of the sausage and suggest consulting the shelf life according to the manufacturer [33].

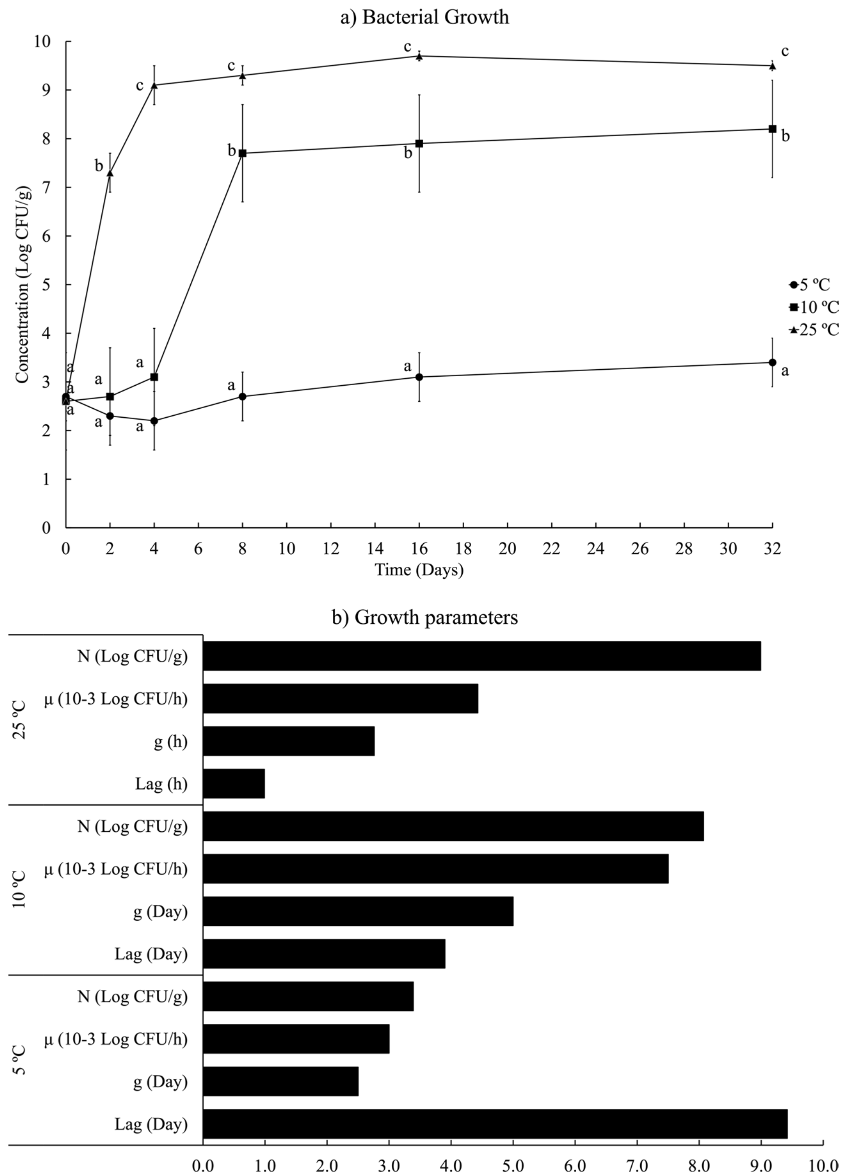
Although cooked sausage is a ready-to-eat product, the Mexican population prefers to cook the sausage prior to ingestion (68%, 28/41). This practice is recommended for the consumption of sausages in Mexico, given the evidence of fecal contamination and *L. monocytogenes* in sausage marketed in packages in Mexico [7]. The application of heat treatments [32] or microwaves [25] to sausages prior to consumption is an ideal strategy to preserve the food safety and minimize the risk of infectious diseases, including listeriosis.

A high probability of gastrointestinal infections (30–50%) was observed when a consumer purchased in bulk or consumed expired sausages. However, the probability that an individual will comply with safety practices and get sick is 17.4%, suggesting the involvement of other factors that favor this scenario. An important aspect was the identification of women as the vulnerable population of gastrointestinal infections, a fact that is corroborated by the cases of intestinal infections and food intoxications reported for this gender by the DGE in Mexico [34].

Survival of *L. monocytogenes* in sausages

The baseline population of *L. monocytogenes* inoculated in sausage samples was 2.6 Log CFU/g for all temperatures ($P > 0.05$). Meanwhile, the final concentration (Log CFU/g) of *L. monocytogenes* observed fluctuated between the temperatures evaluated ($P = 0.000$): 3.4, 8.2, and 9.5 for 5 °C, 10 °C, and 25 °C, respectively. The results showed that storage time and temperature are predictors of bacterial growth ($P = 0.000$), and the bacterium increases its concentration gradually with increasing temperature during the storage period. At 5 °C, the concentration of *L. monocytogenes* remains stable until day 16 and subsequently increases by 0.7 Log CFU/g on day 32. For temperatures of 10 °C and 25 °C, the bacterial concentration was increased 2 and 2.5 times by day 8, respectively (Fig. 2a). The growth parameters calculated from the Gompertz equation indicate that the decrease in storage temperature slows down the adaptation time and the generation time and decreases the exponential growth

Fig. 2 Behavior (**a**) and parameters (**b**) of growth of *L. monocytogenes* in sausage stored at 5 °C, 10 °C, and 25 °C. Values that do not share a letter are statistically significant ($P < 0.05$). The letters mean the following: N, maximum concentration; μ, growth rate; g, generation time; and Lag, adaptation phase



rate: $\mu_{5\,°C} = 0.0026 < \mu_{10\,°C} = 0.075 < \mu_{25\,°C} = 4.43$ CFU/h (Fig. 2b).

The food industry has adopted the zero-tolerance policy of *L. monocytogenes* in cooked meat products [33]. However, in Mexico, the presence of *L. monocytogenes* in sausage marketed in package or bulk [6–8] has been demonstrated in the country exposing a health risk. The ability of *L. monocytogenes* to grow (10 °C and 25 °C) and survive (5 °C) in sausage warns of the importance of cold chain preservation in the food industry and households.

Temperature is the main factor regulating the rate of growth of a microorganism [18]. Sausage is a food whose composition, processing, and storage can influence the growth of *L. monocytogenes* [19]. Our study supports that turkey sausage is a matrix that allows the growth of *L. monocytogenes* up to 32 days, and whose population can grow 0.7 (5 °C), 5.6 (10 °C), or 6.9 (25 °C) Log depending on the storage condition. Previous studies have indicated that *L. monocytogenes* can increase its concentration (>5 Log) on sausages stored in abuse of temperature and time [18–21] or prolong its survival in the sausage stored in suitable refrigeration [18].

The Gompertz model is a non-logistic model used as a tool to describe the behavior of a microorganism on a food matrix [18]. Gompertz's analysis allowed to describe the influence of temperature on the behavior of the bacterium in the sausage. The abuse of temperature (10 and 25 °C) causes the bacterium to establish adaptation periods and short generation times, which allows it to increase its population quickly (Fig. 2). Meanwhile, storage at 5 °C is observed as a safe practice for microbiological control of food for up to 9.4 days, a fact that coincides with the shelf life of the sausage (7 days) [32]. Particularly, the abuse of temperature (15 to 21 °C) for the management of sausage has implications in the deterioration, microbiological risk, and reduction of shelf life (2.6 to 5 days) of the sausage [35].

QMRA

Table 3 shows the risk (event and annual) and the number of estimated cases of listeriosis associated with the exposure of *L. monocytogenes* by the consumption of sausage stored in optimal refrigeration conditions (5 °C) and in temperature abuse (10 and 25 °C). The dose-response model estimated a low probability of acquiring listeriosis (5.53×10^{-8} to 1.42×10^{-5}) by consumption of sausage stored at 5 °C in the study population, which infers an annual risk of 3.50×10^{-7} to 1.52×10^{-6}, and the estimate of 32–92 cases of listeriosis in Mexico. Meanwhile, the risk of acquiring listeriosis from consumption of sausage stored at incorrect temperatures increased according to the increase in temperature and susceptibility of the population stratum (older adults and pregnant women): 0.111 to 0.00616 (10 °C) and 0.109 to 1.00 (25 °C).

The study presents a dose-response model based on the use of *L. monocytogenes* to estimate the risks of acquiring listeriosis by consumption of sausage stored at different temperatures, and the interpretation of the results is limited to the values of the concentrations of *L. monocytogenes* determined for each temperature and under the sausage consumption scenario proposed in Table 1. This study is the first report of the risk of listeriosis due to sausage consumption in Mexico and warns about the use of storage temperature as a factor for the risk of acquiring some type of listeriosis.

Falk et al. [36] predicted the risk of *L. monocytogenes* infection associated with turkey meat products, which ranges from 1.4×10^{-6} to 7.3×10^{-9} depending on the population stratum, being the most vulnerable population with pregnant women (3.0×10^{-7}) and people with cancer (1.4×10^{-6}). In addition, these authors showed that the probability of infection by *L. monocytogenes* associated with the consumption of turkey sausage could be 0.11. The variation in risk estimation depends on the data, scenario, study population, and model used.

The sausage storage scenarios (Table 3) indicated that storage of sausage at 5 °C coincides with the global incidence of listeriosis (0.1 to 11 cases/1,000,000 population) reported by WHO [1], meaning that the estimated annual risk of *L. monocytogenes* in the population aged 5–59 years (3.50×10^{-7}), older adults (6.05×10^{-6}), and pregnant women (1.52×10^{-5}) implies 0.4, 6.1, and 15 cases/1,000,000 people in Mexico, respectively. But if the food is stored under temperatures of abuse, the risk increases mainly in pregnant women according to the temperature of abuse (0.58 to 0.665).

The source infections of cases associated with listeriosis remain unclear in Mexico. On the other hand, the DGE states that intestinal infections (2,885,735 cases) are the third cause of morbidity in Mexico [34], and sausages that have lost the cold chain could be a potential vehicle of infection based on the growth of bacteria in food (Fig. 2) and the estimation of the risk of listeriosis determined (Table 3). The QMRA for consumption of poorly stored sausage has epidemiological relevance to justify the intentional search for the bacterium in suspected cases and propose education campaigns for the hygienic handling and storage of the product by the consumer and manufacturer. In addition, the formulation of sausages and type of packaging could be pathways for microbiological control [37].

Conclusion

The turkey sausage is one of the main sausages consumed in Mexico, whose purchase in packaging is observed as a safe habit in most of the population. However, storage time and consumption without prior cooking could be risk factors for violating food safety and consumer health. The sausage stored in a temperature range of 5–25 °C is a matrix that supports the growth of *L. monocytogenes*, which is modulated by the increase in temperature and storage time. The optimal refrigeration practice (5 ± 1 °C) for the storage of the sausage favors the control of *L. monocytogenes* (up to 9.4 days). Likewise, the abuse of the temperature (10–25 °C) and the extension of the shelf life of the sausage should be avoided to minimize the potential growth of the bacteria.

Table 3 Risk and case estimate of listeriosis by sausage intake in Mexico

Population	Risk per event			Annual risk			Annual cases by population		
	5 °C	10 °C	25 °C	5 °C	10 °C	25 °C	5 °C	10 °C	25 °C
General population	5.53×10^{-8}	6.16×10^{-3}	1.09×10^{-1}	3.50×10^{-7}	3.83×10^{-2}	4.98×10^{-1}	35	3,851,076	50,074,048
Elderly population	1.05×10^{-6}	1.11×10^{-1}	8.88×10^{-1}	6.05×10^{-6}	4.72×10^{-1}	9.95×10^{-1}	92	7,137,432	15,046,075
Pregnant woman	1.42×10^{-5}	7.95×10^{-1}	1.00×10	1.52×10^{-5}	5.80×10^{-1}	6.65×10^{-1}	32	1,213,484	1,392,652

General population (5–59 years) in 2020: 100,550,297 inhabitants. Elderly population in 2020: 15,121,683 inhabitants. Population of pregnant women in 2020: 2,092,214 inhabitants

The QMRA identifies the incorrect storage of sausage as an important cause of cases of listeriosis in Mexico.

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Author contribution All authors read, understood, and approved the final manuscript.

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Data availability The data are available from the corresponding author on request.

Declarations

Conflict of interest The authors declare no competing interests.

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