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POSGRADO EN PRODUCCIÓN ANIMAL

LA CADENA DE FRÍO Y SU RELEVANCIA EN INOCUIDAD Y VIDA DE ANAQUEL DE PRODUCTOS CÁRNICOS

TESIS

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P R E S E N T A

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Bajo la supervisión de: **Ema De Jesús Maldonado Simán, Dra.**

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LA CADENA DE FRÍO Y SU RELEVANCIA EN INOCUIDAD Y VIDA DE ANAQUEL DE PRODUCTOS CÁRNICOS

Tesis realizada por **PEDRO ARRIAGA LORENZO**, bajo la supervisión del Comité Asesor indicado, aprobada por el mismo y aceptada como requisito parcial para obtener el grado de:

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CONTENIDO

LISTA DE CUADROS

LISTA DE FIGURAS

DEDICATORIA

A mis padres **Pedro** y **Juliana**, por ser mi guía incondicional. Gracias por enseñarme, no solo con palabras, sino con el ejemplo, la importancia del esfuerzo, la constancia y el valor de los sueños. Este logro es tan suyo como mío, porque sin su apoyo inquebrantable, sus sacrificios y su confianza en mí, no habría sido posible llegar hasta aquí.

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RESUMEN GENERAL

LA CADENA DE FRÍO Y SU RELEVANCIA EN INOCUIDAD Y VIDA DE ANAQUEL DE PRODUCTOS CÁRNICOS[1]

Los cárnicos requieren temperatura controlada para maximizar su vida de anaquel. Esta puede verse afectada por el manejo *ante-mortem* y *post-mortem*, prácticas aplicadas durante la cadena de suministro, por la presencia de microorganismos, entre otros. La revisión de literatura determinó que los últimos eslabones de la cadena de frío suelen ser los de mayor problema. Una gestión inadecuada puede resultar en brotes de enfermedades. La implementación de buenas prácticas de higiene y manufactura son esenciales para la seguridad e inocuidad alimentaria. Las gestiones realizadas dentro de la venta minorista de perecederos requieren de estrictos monitoreos para corroborar su adecuando funcionamiento. La normatividad mexicana menciona que los establecimientos que comercializan productos cárnicos deben mantenerlos a máximo 4 °C. Sin embargo, evaluaciones de campo mostraron supermercados que rompieron la cadena de frío, temperaturas superiores al límite se observaron durante el año y dentro del refrigerador al evaluar la localización de los cárnicos. Análisis del nivel de higiene del personal de dichos establecimientos, mostraron que requieren mejorar el uso de uniforme adecuado; malas prácticas de higiene ponen en riesgo la inocuidad de los alimentos. Este aspecto se evaluó tomando muestras de carne para detectar contaminación por mesófilos, coliformes, *E. coli*, y *Salmonella.* Todos los supermercados mostraron al menos una muestra con *Salmonella*. Sin embargo, no se determinó la especie. Se encontraron cargas bacterianas de *E. coli* que cumplen la normatividad mexicana, no se realizaron pruebas para determinar serotipos de mayor peligro como el O157:H7, posteriores estudios son necesarios. Por otro lado, la normatividad no contempla límites para mesófilos y coliformes. Sin embargo, las cargas que se encontraron en las muestras no cumplen con lineamientos internacionales como los europeos o estadounidenses; México debería considerar regular de forma más certera la calidad microbiológica de los cárnicos, debido a la gran cantidad de microrganismos de riesgo que pueden contener.

Palabras clave: Inocuidad, carne, cadena de frío, higiene, microbiología.

[1] Tesis de Doctorado en Ciencias en Innovación Ganadera, Posgrado en Producción Animal, Universidad Autónoma Chapingo.

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GENERAL ABSTRACT

COLD CHAIN AND ITS RELEVANCE TO FOOD SAFETY AND SHELF LIFE OF MEAT PRODUCTS[2]

Meat products require temperature control to maximize their shelf life. It can be affected by ante-mortem and post-mortem handling, practices applied throughout supply chain, presence of microorganisms, among others. The literature review showed that the last links of the cold chain were usually the weakest. Improper management can result in disease outbreaks. Implementing good hygienic and manufacturing practices is essential for food safety and security. Perishable retailing operations require strict monitoring to corroborate their proper functioning. Mexican regulations specify that stores marketing meat products must keep them at a maximum 4 °C. However, field evaluations showed supermarkets that broke the cold chain; temperatures above the limit were observed during the year and inside the refrigerator when evaluating the location of the meat products. Analysis of the hygiene level of personnel in these establishments showed they need to improve the use of appropriate uniforms; poor hygiene practices endanger food safety. This aspect was evaluated by taking meat samples to detect contamination by mesophiles, coliforms, *E. coli*, and *Salmonella*. All supermarkets showed at least one sample with *Salmonella*. Nonetheless, no species was determined. Bacterial loads of *E. coli* were found to comply with Mexican regulations, but no tests were performed to determine serotypes of greater danger, such as O157:H7; further studies are necessary. On the other hand, these norms do not contemplate limits for mesophiles and coliforms. Nevertheless, loads found in the samples do not comply with international guidelines such as those of Europe or the USA; Mexico should consider regulating the microbiological quality of meat products more accurately, given the large number of microorganisms of risk that they may contain.

Keywords: Food safety, meat, cold chain, hygiene, microbiology.

[2] Doctoral Thesis in Livestock Innovation, Graduate Program in Animal Production, Universidad Autónoma Chapingo
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1. INTRODUCCIÓN GENERAL

Los humanos consumen una amplia variedad de productos alimenticios, los cuales requieren de diferentes cuidados dependiendo de sus características. Los productos cárnicos, lácteos, frutas y verduras, entre otros, son considerados alimentos perecederos; por lo cual, se deben mantener en un rango de temperatura establecido y sin interrupciones para lograr conservarlos con características óptimas para el consumo humano. Los incrementos por arriba del rango de temperatura de almacenaje pueden acelerar el deterioro del producto, ocasionado por el metabolismo del propio alimento o por el crecimiento de patógenos y microorganismos que lo degradan (Mercier et al., 2017).

Dentro de estos productos perecederos, los cárnicos representan una importante fuente de nutrientes, siendo un sustrato potencial para el desarrollo de una variedad de microorganismos que aceleran su degradación, presentando riesgos para la salud humana. Garantizar la entrega a los consumidores finales de un producto inocuo y con altos niveles de calidad, requiere realizar rigurosos procesos de higiene, además de utilizar las diferentes tecnologías disponibles que permitan conservar los alimentos perecederos bajo temperaturas adecuadas (Kaur et al., 2021).

Los microrganismos que pueden estar presentes en el deterioro de productos cárnicos son principalmente bacterias, debido a las características de estos alimentos (Zhang et al., 2019). Pueden encontrarse Bacterias Ácido Lácticas (BAL), especies del género *Pseudomonas*, y miembros de la familia *Enterobacteriaceae*, entre otras (Gram et al., 2002; Wu et al., 2018). Sin embargo, algunas especies de BAL son conocidas por su influencia positiva en la preservación y fermentación de alimentos, por su capacidad de acidificar el ambiente y producir bacteriocinas que previenen el crecimiento de bacterias con potencial para degradar alimentos y de riesgo a la salud humana (Fontana et al., 2005).

Entonces, garantizar la inocuidad de un alimento representa un gran reto para la industria alimentaria. Por ende, es necesario emplear las herramientas que solucionen un problema en específico, como reducir la probabilidad de enfermedades potenciales por la ingesta de alimentos contaminados, algunas de presencia común, ocasionadas por bacterias de la familia *Enterobacteriaceae*, como *Salmonella enterica* serovar Typhi, *Shigella dysenteriae, Yersinia pestis,* y *Escherichia coli* (Wu et al., 2018). Además, existen otros microorganismos capaces de producir toxinas carcinogénicas o promotoras de otras enfermedades (Hanvi et al., 2021; IARC, 1993).

Un producto alimenticio pasa por diferentes etapas desde su producción hasta llegar al consumidor, a esto se le conoce como cadena de suministro de alimentos; cada uno de los eslabones que la componen tiene su nivel de complejidad y durante estos procesos, el manejo de temperatura es un factor esencial en alimentos perecederos. La temperatura resulta ser importante durante la cadena de frío debido a que, sobre ésta recae la confianza de la industria de alimentos, por ser una herramienta efectiva para mantener la inocuidad y calidad de productos perecederos (Kim et al., 2013; Li et al., 2018; Zhang et al., 2019).

Aunque diversos factores pueden influenciar la reducción de la vida de anaquel de productos perecederos, la temperatura es el factor extrínseco de mayor importancia por el impacto que tiene en esta, mostrando efectos con tan sólo un grado centígrado por arriba de lo establecido en las normas (Almonacid-Merino & Torres, 1993; Raab et al., 2011). En México la NOM-251-SSA1-2009 establece que los productos perecederos deben mantenerse a una temperatura igual o menor que 4 °C, a excepción de los productos de pesca, que pueden llegar hasta los 7 °C. El rango de temperatura se define para limitar el crecimiento de microorganismos que deterioran el producto y el de patógenos que ponen en riesgo la salud de los seres humanos, como lo es *E. coli* O157:H7, la cual puede iniciar su crecimiento a 7.2 °C (Vorst et al., 2018).

El control permanente de la temperatura es útil inclusive al momento de la compra de alimentos, debido a que los centros de distribución ofrecen una variada información en sus embalajes; por ejemplo, la fecha de caducidad. La industria de alimentos perecederos etiqueta sus productos con una vida de anaquel basados en la hipótesis de que se mantendrán bajo una temperatura constante y favorable. Sin embargo, si en algún punto de la cadena de frío se presentan variaciones de temperatura desfavorables, es posible que se produzcan alteraciones en el producto y las leyendas de "*consumo preferente antes de*:" proporcionen una información errónea (Gao et al., 2020).

Los retos que enfrenta la industria de alimentos en materia de inocuidad y calidad se direccionan principalmente en reducir las cifras reportadas anualmente de enfermedades transmitidas por alimentos reportadas. El consumo de alimentos contaminados por bacterias, hongos, virus, parásitos, entre otros microorganismos o sustancias químicas, pueden causar al menos 200 posibles enfermedades, las cuales varían desde diarrea hasta cáncer. Cada año se reportan 600 millones de personas que enferman por el consumo de alimentos contaminados, de los cuales mueren 420 (WHO, 2022).

Por otro lado, manejar erróneamente los alimentos durante la cadena de suministro conlleva pérdidas en las diferentes etapas que la componen, la FAO (2011) estimó que aproximadamente un tercio de la producción mundial de alimentos se pierde o se desperdicia, y esto significa unos 1,300 millones de toneladas al año. A pesar de los esfuerzos realizados para reducir estas cifras, el problema de desperdicio de alimentos sigue latente, lo que impacta en la disponibilidad de víveres para una población en crecimiento (Flanagan et al., 2019). Por lo cual, es importante saber si se están tomando las medidas necesarias para enfrentar los problemas que se presentan durante la cadena de frío, en especial durante el eslabón de la distribución.

Hipótesis

El manejo de la cadena de frío e higiene operado por supermercados de la región del noreste del Estado de México que comercializan hacia el consumidor final productos cárnicos no cumple con los requisitos establecidos por la autoridad nacional competente, publicados en las Normas Oficiales Mexicanas que le competen, presentando un posible riesgo para la salud humana por el consumo de alimentos contaminados.

Objetivos

Objetivo general

Analizar la gestión de la cadena de frío y el manejo higiénico de tres tipos de productos cárnicos comercializados al consumidor final en supermercados y su impacto en la vida de anaquel e inocuidad.

Objetivos específicos

- Registrar la temperatura de la superficie de productos cárnicos de pollo, puerco y res ubicados en diferentes posiciones de los refrigeradores de autoservicio en supermercados, para determinar el nivel de gestión de la cadena de frío.
- Verificar el nivel de los parámetros de higiene operado por el personal, el equipo y lugar de distribución de productos cárnicos prevalente en los supermercados evaluados.
- Determinar si existe riesgo a la salud de los consumidores humanos, con base en la presencia de bacterias en la carne de res, que no cumpla con los lineamientos establecidos en la normatividad correspondiente.

El presente documento se compone de **5** capítulos adicionales. En el Capítulo 2 se desarrolla una revisión de literatura sobre la "importancia de la cadena de frío en la inocuidad de productos cárnicos"; en el Capítulo 3 se elaboró un artículo de investigación sobre la "Fluctuación de la temperatura de la carne de res en la comercialización al menudeo"; en el Capítulo 4 se incluye un artículo sobre "la gestión de la cadena de frío de los productos cárnicos comercializados por centros comerciales"; para el Capítulo 5 se incorpora un artículo sobre "las prácticas de higiene de supermercados que impactan en la vida de anaquel de productos cárnicos"; y en el Capítulo 6 se desarrolló un artículo sobre "bacterias potencialmente peligrosas para la salud humana, presentes en la carne de res comercializada en supermercados".

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2. RELEVANCIA DE LA CADENA DE FRÍO EN LA INOCUIDAD DE PRODUCTOS PERECEDEROS

COLD CHAIN RELEVANCE IN THE FOOD SAFETY OF PERISHABLE PRODUCTS

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Cold chain relevance in the food safety of perishable products

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Abstract:
The food cold chain is an effective tool that allows food markets to maintain food quality and reduce losses. Poor logistics may result in foodborne disease outbreaks and greenhouse gas emissions caused by organic matter decay. The ongoing pandemic of COVID-19 makes it necessary to study the chances of SARS-CoV-2 transmissions in food products.
This study reviews cold chain logistics as a handy tool for avoiding food safety risks, including COVID-19.
The cold chain of perishables and its proper management make it possible to maintain quality and safety at any stage of the food supply chain. The technology covers each link of the food chain to prevent microbial spoilage caused by temperature fluctuations and the contamination with SARS-CoV-2 associated with perishable foods. Given the lack of knowledge in this field in Latin America, the region needs new research to determine the impact of the cold chain on perishable foodstuffs.
The perishable cold chain is only as strong as its weakest link, and the national and international markets require new traceability protocols to minimize the effect of COVID-19.

Keywords: Cold chain, meat, food safety, temperature, COVID-19

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INTRODUCTION

Food safety and environmental protection are one of the most important issues in the global scientific and technological agenda, as well as the subjects of the growing concern and awareness of final consumers. An effective farm-to-table cold chain is a tool that provides food safety by uninterrupted refrigeration. This process maintains a controlled temperature of the perishable product in a given time and space, thus promoting a constant heat transfer coefficient and particular temperature of the dissipation medium [1]. Product temperatures have to remain within a certain range to avoid microbial proliferation, tissue damage, and excessive emission of CO_2 caused by inefficient refrigeration devices and food wastage [2, 3]. Therefore, the industries responsible for cold chain logistics must find better alternatives to reduce CO_2 emissions [4, 5] because perishables require appropriate management, equipment, and facilities at each stage of the food supply chain [3].

Efficient cold chain management uses reliable data on temperature modes for various foods: for instance, low temperatures that are suitable for meat products may damage tropical fruits and reduce their sensory quality [6]. Accurate data on optimal storage temperature for each product could reduce the volume of food waste caused by inadequate cold chain management and mitigate the alarming food loss worldwide [7, 8]. The cold chain technology provides various benefits by limiting the proliferation of microorganisms and avoiding food waste. Efficient cold chain logistics extends shelf life, thus providing the final consumer with a safe product with an optimal sensory profile [9]. Therefore, companies must provide the necessary conditions and equipment for the entire cold chain with its weakest links, not only in the manufacturer's facilities, which are often certified by international standards, such as ISO 9001, ISO 22000, or HACCP [10].

During the current pandemic, food supply chains must reinforce their hygiene measures because SARS-CoV-2 might be transmitted by fomites, although few reports are available on this subject [11, 12]. Nevertheless, in Qingdao, SARS-CoV-2 was revealed in the packaging of cod imported to China via the cold food chain, where the low temperature and humidity increased the stability of the virus [13]. Consequently, disinfection strategies were implemented for packaging cold-chain imported products [14]. This paper highlights the effect of temperature fluctuations on the perishable food cold chain, as well as on the potential presence of SARS-CoV-2 in perishable foods.

RESULTS AND DISCUSSION

Food supply chain. Food products require a variety of handling throughout the food supply chain, from the primary production to the consumer's plate, and each stage involves a large number of people. Assessing the number of people in food production is a difficult task by itself. The European Union alone has at least 11 million establishments engaged in food production, including 300 000 food and beverage companies. Their products are purchased by 2.8 million distribution and food service businesses, whose principal objective is to supply products to some 500 million EU citizens [15].

Considerable food losses and waste are unavoidable because every single stage of the food supply chain involves numerous difficulties. An estimated one-third of the global food production is wasted for various reasons. Approximately 1.3 billion tons are reported as waste every year. The ratios usually differ, depending on the food supply chain link and the conditions within each country [8, 16, 17]. The United Nations Environment Program has estimated that about 931 million tons of food waste were generated by retail, food service, and household waste [18]. While food waste reduction is on the global agenda, Latin America can hardly offer any data on food wastage in the region. Only four countries in Latin America can provide information on food loss and waste. They are Belize, Brazil, Mexico, and Colombia [19–21].

Food cold chain. Cold chain is one of the main tools of the food industry. It ensures the optimal conditions for food meant for human consumption. Cold chain is a system that keeps food under a controlled temperature from the moment of its production or harvest until it reaches the final consumer [22–24]. However, the International Dictionary of Refrigeration describes it as "a series of actions and equipment applied to maintain a product within a specified low-temperature range, from harvest/production to consumption" [25].

Highly perishable food products retain acceptable safety and quality throughout the whole supply chain provided that certain factors are maintained, e.g., temperature and relative humidity [24]. Perishables may suffer an adverse variation when the storage temperature is outside the ideal temperature range [23]. Therefore, cold chain monitoring is critical to identify any weaknesses for successful intervention [26]. Consequently, food science develops various ways to monitor the temperature of a product in real-time and access its temperature history throughout the process [23]. Some of the frequently employed options include radio frequency identification (RFID) tags, time and temperature integrators (TTIs), and wireless sensor networks (WSNs) [27, 28].

Several studies (Table 1) used various monitoring tools to test food temperature along the cold chain and registered temperature abuse at all chain stages [9, 23]. Therefore, food distribution is a complex process that takes into account the effect of environmental conditions on the food temperature throughout the cold chain [29]. Transportation, storage, and retail stages demonstrated the highest temperature abuse rate [30–32].

Temperature abuse can happen in all cold chain links, especially at the last stages. The logistics management definitely requires improvement, given that temperature fluctuations may occur during inspection procedures at customs or ports [35, 42]. A uniform temperature distribution in the refrigeration equipment is crucial to avoid disruptions related to product position within the refrigerator [47].

Technologies employed. The farm-to-table food product chain requires significant resources. Both developed and developing countries keep increasing their refrigeration energy consumption in an attempt to reduce food spoilage [51]. Monforti-Ferrario *et al.* estimated that about 30% of the electrical energy used in the European Union food industry is spent on cooling and freezing [52].

Such refrigerants as chlorofluorocarbon and hydrochlorofluorocarbon dominated the refrigeration field in the 1930s, and vapor compression refrigeration gained ground as an alternative throughout the food supply chain. In the 1980s, the growing environmental awareness resulted in a number of international agreements with timescale applications for eliminating hydrochlorofluorocarbon. Later, the European Union proposed introducing regulations on fluorinated gases, including all hydrofluorocarbon refrigerants, e.g., R134A, and mixes containing fluorinated gases, e.g., R407C, R410A and R404A [53].

Multiple compressor refrigeration packs or air-cooled condenser racks are regularly used in commercial refrigeration systems in food distribution centers. In the United Kingdom, modern systems normally use scroll compressors and R404A refrigerants [53]. Supermarkets use open refrigerators that have

Table 1 Temperature fluctuations observed throughout the cold chain

Country	Link	Product	Recommended temperature, °C	Temperature abuse	Sensor	Reference
Belgium	Harvest to restaurant	Endive	0	16°C	Data loggers	[34]
Canada	Processing to retail	Lettuce	≤ 5	7°C	Temperature recorders	[35]
China	Processing to distribution	Meat	≤ 4	8–10°C	Data loggers	[36]
	Transport	Fish	–18 ± 2	≤ 18.6°C	RFID	[37]
Finland	Retail	Fish and meat	≤ 4	≤ 105 min with temperatures above recommended	Data from the inspector's office, data logger, infrared thermometer	[32]
France	All links	Dairy and meat products	≤ 4	9°C	Temperature recorder	[38]
	All links	Smoked salmon	≤ 8	Temperatures above the recommended	Data loggers	[39]
	Transport/storage	Milk	≤ 4	≤ 11.7°C	Data loggers	[40]
Iceland	Transport	Fish	5	The temperature was ≥ 5°C during 31.1% of transportation time	Data loggers	[41]
Japan	Farm to retail	Lettuce	≤ 5	3–15	Data loggers	[42]
Slovenia	Retail	Miscellaneos products	Different temperature ranges	Temperatures above recommended for different products	Infrared thermometer	[31]
South Africa	Cold store to haven	Fruits	2	≤ 81% temperature abuse for 1.5 h	Data loggers	[43, 44]
Spain	Storage	Ham	≤ 5	≤ 12.2°C	Data loggers	[45]
	Retail	Meat, dairy, fishery products and vegetables	2–8	Temperatures above the recommended for different products	Infrared thermometer	[46]
Taiwan	Transport to home	Frozen shrimps	–20	≤ 17.2°C	Data loggers	[47]
Thailand	Transport/storage		–20	≤ 17°C at different times	Infrared thermal camera/ data logger	[48]
USA	Harvest to retail	Live oyster	1.7–10	≤ 14.4°C	Temperature sensors	[49]
	Transport to display	Lettuce	≤ 5	≤ 18.2°C	TempTale4 sensors	[50]
	Transport	Fresh-cut leafy greens	≤ 5	5–10°C	Data loggers	[51]

no physical barrier between goods and people, except for an air screen that keeps out humidity and warm air [54].

A refrigerated container, also called an integral reefer container, is required to transport perishable foodstuffs. It usually refers to a metal box with polyurethane insulation and a refrigeration unit, typically approved by the International Organization on Standardization, i.e., it is of ISO quality [55]. The container comprises three main components: an air circulation system, a microprocessor controller, and a cooling system. The microprocessor controls the refrigeration unit, records the data obtained by the maintenance system, performs diagnostics, and generates the temperature database during transportation. The refrigeration unit must have a power source supplied by land equipment or container vessels [56].

Different alternatives are available throughout the cold chain, some of which are low-cost, whereas others are more complex and sophisticated, depending on the product's link. Economical alternatives, e.g., ice, or more expensive options, e.g., forced air, vacuum cooling, or hydro-cooling systems, can be used for pre-cooling at the production site. Storage usually occurs in cold rooms, in small or large warehouses with traditional refrigeration equipment, in controlled air conditioning systems, e.g., CoolBot™, or in cold evaporation rooms. The food processing stage may include some alternatives, e.g., refrigerators, individual quick freezing (IQF), blast freezing, freeze-drying, etc. The transportations stage usually includes such alternatives as ice, refrigeration units in trailers, evaporative coolers, or passive cooling [57].

Cold chain in transportation. Cold chain food transportation involves land, air, and maritime resources. Until 2005, trucks used to be the most popular land transport vehicle. Estimates suggest that more than 90% of foods are moved by land in the United Kingdom [2, 58]. The distance that vehicles travel to deliver a food product to the retailer is highly variable [37, 59]. A lot of different factors must be considered during food transportation to keep the cold chain undisturbed. Seasonal temperature can strongly affect the food supply chain, being as low as –10°C in winter or as high as 35°C in summer [7].

Trucks must be able to provide favorable temperature for the perishable foodstuffs they transport, considering that they travel up to 2500 km [37, 59, 60]. Many studies report temperature rises during transportation of milk, strawberries, and fresh-cut leafy greens, as well as during the loading and unloading of fish [39, 50, 61, 62]. Additionally, temperature control deficiencies can be potentiated by the impact of the environment on the temperature fluctuations of the transported products [60].

The advantage of air transport is that food can be quickly moved to locations far from being produced or harvested. However, this transportation method is not very popular, except for high-cost foods and products with a short shelf life that must reach their destination quickly [2]. The cold chain by air transport is extremely complex. Only half of the time required is actually the flight time: the other half is spent on the management procedures to load and unload the product into and out of the aircraft, which results in poor temperature control [2, 63].

In contrast to air transport, shipping products by sea is slower, although more profitable in cases of meat, dairy products, fish, fruits, and vegetables. Therefore, the type of transportation generally depends on the type of the product to be moved. Specialized vessels are usually used to transport bananas. For most products, reefer containers are more cost-effective and can provide a better logistics [2, 64, 65].

Transport to home, which is the last transportation link in the cold chain, is often the weakest one, with the highest temperature increase [66]. Passive cooling devices are a viable alternative to avoid this problem, e.g., phase change material in easily portable insulated boxes [67, 68].

Cold chain in warehouses. Achieving that perishable food reaches the last link of the food supply chain in optimal conditions is complex and expensive. The food industry invests millions of dollars in order to attain this goal and avoid having to recall a product due to contamination during the cold chain [69]. A food product can remain stored in distribution centers for many days [70]. Its shelf life depends on the right conditions, and the optimal temperature control is essential. Unfavorable temperature deviation during the storage of perishable products is related to the corresponding link in the supply chain. Derens *et al.* revealed that the biggest temperature problems in France were related to display cabinets, transport to the home, and domestic refrigerator storage [37].

Unfavorable fluctuations occur less frequently during storage at the distribution center. Multiple studies conducted on such perishables as meat, dairy products, and vegetables confirmed temperature records below 4°C at the storage stage in distribution centers [37, 60, 70]. However, these data were obtained from developed countries. Developing countries have less favorable conditions in terms of equipment, energy sources, and environment, which is often due to their geographical location.

Retail cold chain. Derens-Bertheau *et al.* reported that such stages of the cold chain as display, transport to home, and domestic refrigerator storage are also highly problematic. Retail distribution link appears to be one of the main problems, which can be related to various reasons. Firstly, product information often lacks temperature specifications [31]. Secondly, open refrigeration equipment sometimes fails to maintain the required temperature as a result of an uneven distribution of the airflow throughout the rack [45, 71, 72]. The latter occurs when the equipment lacks capacity or configuration to achieve an effective air curtain [73, 74]. Therefore, refrigeration equipment with doors is a viable option to achieve greater efficiency in cooling of perishables and electricity consumption [54].

Some recent studies pointed to the need for improving the cold chain control during retail: they detected adverse temperature deviations in meat products, poultry, and pork [30, 32, 72]. Even within retail distributors, position of the product in the refrigeration equipment might result in temperature fluctuations caused by design, configuration, or services. Baldera *et al.* reported a 25, 40, and 57% shelf-life reduction for cheese, salmon, and chicken because they were positioned at the highest point inside the refrigerator.

Within the retail food industry, refrigeration systems are responsible for a significant amount of greenhouse gas emissions, which could be reduced by using improved equipment [75]. The electricity consumed by a supermarket generates approximately 50% of these emissions [76]. Moreover, some supermarkets still use hydrofluorocarbons as refrigerants. This refrigeration method is responsible for 30% of greenhouse gas emissions caused by refrigerant leakage, but it still remains quite popular in the United Kingdom [77]. As a result, standards have been implemented to decrease its use in favor of natural options, such as CO_2 [78].

Food spoilage induced by microorganisms. Shelf life is the time food keeps its physical, chemical, and microbiological properties and is safe for human consumption. Food spoilage can be associated with environment, composition, packaging, human handling, microorganisms, etc. All these factors reduce shelf life [79, 80]. Potential factors that affect shelf life can be divided into intrinsic and extrinsic. Therefore, a microorganism can be considered an extrinsic factor if it does not belong to the product. Meat products constitute a highly favorable food source for various bacteria since meat has a lot of nutrients and high water activity, which promote microbial growth. As a result, meat products easily acquire unpleasant texture, odor, and flavor [80].

Food contains a great wide variety of microorganisms, e.g., *Campylobacter*, *Pseudomonas*, *Enterococcus*, *Acinetobacter*, *Psychrobacter*, *Moraxella*, etc., as well as numerous kinds of bacteria, fungi, yeasts, protozoa, and viruses [81–85]. Food in general and meat products in particular are susceptible to a wide range of potential spoilage microorganisms. Meat products have been reported as foods with the highest temperature abuse [86]. Therefore, this kind of food must be handled, stored, and transported at a temperature range of 2–7°C, depending on the type of meat product [87].

However, strict temperature control throughout the cold chain is just another tool that minimizes the risk of microbial contamination. Additional measures can help avoid other contamination sources and reduce the chance of microbiological growth. Some psychrotrophs, for example, can grow at temperatures below 7°C [84, 88]. This group of microorganisms includes such high-risk species as *Listeria monocytogenes* and *Yersinia enterocolitica*, both of which can grow at temperatures below 5°C [89]. However, the European Union reports a low incidence of outbreaks related to psychrotrophs compared to bacteria, e.g., *Campylobacter* and *Salmonella* [90]. Meanwhile, a higher incidence of norovirus cases with a meager mortality rate was reported in the USA through 2017. It was followed by *Salmonella* and, with fewer cases, *Listeria*. However, these bacteria could be considered equally dangerous since 3–8 and 3–35 people die from *Salmonella* and *Listeria* each year, respectively [81].

Food loss and waste are not only a concern for economic and environmental reasons, but they also present a high risk of an outbreak due to contaminated food. Pathogens, such as *Salmonella enterica* serovar Typhi, *Shigella dysenteriae*, *Yersinia pestis*, and most *Escherichia coli*, are found within the *Enterobacteriaceae* family [91]. Some of them can grow when temperatures are above 7.2°C, e.g., *E. coli* O157:H7 [82]. Some strains of these bacteria are natural to the digestive tract of warm-blooded animals [92]. However, strains classified as Diarrheal *E. coli* (DEC) are becoming more aggressive as a result of their improved resistance to different antibiotics [93]. They are subdivided by their virulence into shiga toxin-producing *E. coli* (STEC), enteropathogenic *E. coli* (EPEC), enteroaggregative *E. coli* (EAEC), enteroinvasive *E. coli* (EIEC), enterotoxigenic *E. coli* (ETEC), and diffusely adherent *E. coli* (DAEC).

COVID-19 and its relevance to food safety. Throughout 2019, the world faced a danger that severely impacted public health and hit the worldwide economy. Coronavirus disease (COVID-19) is caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). Up to early November 2021, it caused 247 968 227 confirmed cases, of which 5 020 204 deaths were reported in at least 200 countries. Consequently, vaccines are reported to have been applied in 7 027 377 238 doses among the world's population [94]. Vaccination works in conjunction with recommended safety measures, but the number of cases reported vary from region to region in each country.

A 55-day period without viral transmission was achieved in the Beijing region, which was interrupted on June 11, 2022 when a SARS-CoV-2 case was reported and continued to spread. The virus was detected on different surfaces on a wholesale seafood and meat market, particularly on a board used to slice salmon imported from Europe. The virus could be transmitted through food in the cold chain, cross-contamination by workers, or packaging, but the sequences found were consistent with those of infected Chinese citizens who returned from Europe [95, 96].

Moreover, the Chinese Center for Disease Control and Prevention carried out different studies that detected the presence of SARS-CoV-2 nucleic acid in samples of chicken and shrimp imported from South America and marketed in various Chinese cities [97]. Consequently, several studies (Table 2) proved the presence of SARS-CoV-2 in food products and raw materials. Whether food is a direct transmission route remains unclear, which does not eliminate the possibility of cross-contamination [98]. Therefore, strict control measures are required to reduce outbreaks, particularly in large slaughtering and meat-processing companies, where outbreaks have been reported in Portugal, Australia, The United Kingdom, and Ghana [99].

Food products receive little scientific attention in COVID-19 research since they are not considered a potential transmission route of SARS-CoV-2. Studies conducted on fresh vegetables, e.g., cucumbers, revealed that the virus might remain infectious for up to 72 h [107]. Castrica *et al.* commented that researchers are increasing the number of studies on wastewater based on the understanding that monitoring the pathogen in this environment could create a real-time pandemic model [110, 111]. Moreover, communal areas must not be overlooked as a source of contact infection, although no positive samples have been found from different regions, potentially due to adequate sanitation measures [106].

Since the jury is still out on the foodborne transmission of COVID-19, inoculations were carried out on pork, beef, and salmon samples with different concentrations of SARS-CoV-2 to investigate the stability of the virus after controlled cold-chain management (4 and –20°C) [112]. Viral RNA was detected in all samples stored at 4°C for 72 h after infection, with a higher average number of RNA copies in the pork meat at the lowest concentration. At the highest concentration, viral RNA could be detected in all samples up to 216 h after infection. Viral RNA remained detectable up to 20 days after infection in the samples stored at –20°C in both inoculum

Table 2 Detection of SARS-COV-2 virus in food-safety-related samples

Country	Sample	Type of study	Detection method	Reference
USA	Water and wastewater	Persistence evaluation	RT-qPCR and Vero E6 cells	[102]
South Korea	Tap water	Stability in water samples	qRT-PCR	[103]
China	Salmon	Viability of SARS-CoV-2 under different conditions	Vero E6 cells	[104]
Bangladesh	Wastewater	Detection of SARS-CoV-2 genetic material	RT-PCR	[105]
Finland	Wastewater influent	Presence and stability of SARS-CoV-2 RNA	RT-qPCR, N2 assay, ABI BigDye™ v3.1 Chemistry	[106]
Brazil	River water	Viability of SARS-COV-2 under different temperature conditions	Plaque assay	[107]
Canada	Surfaces in food retailers	Detection of SARS-CoV-2 (all of them negative)	RT-qPCR	[108]
	Apple, tomato, cucumber, and lettuce	Preservation of infectivity (HCoV-229E)	Plaque assay (MRC-5 cells)	[109]
France	Zebra mussel	SARS-CoV-2 genome detection in zebra mussels as bioindicators of water contamination	RT-qPCR Genes tested: RdRP: RNA-dependent RNA polymerase gene; E, an envelope protein gene and N, nucleocapsid protein gene	[110]
Italy	Polyethylene and polystyrene food trays	Persistence of SARS-CoV-2 (ATCC® VR-1986HK™)	RNA extracted with QIAamp® Viral RNA Mini Kit RT-qPCR using the VETfinder detection kit	[111]

concentrations, being present to a greater measure in pork and beef, probably because of their fat content and texture.

The actual routes of SARS-CoV-2 transmission are not entirely clear [113, 114]. Currently, the closest relationship is to viruses reported in bats [115]. Given the variety of information about possible COVID-19 transmission routes, people reacted by increasing food safety and hygiene measures, e.g., washing and sanitizing kitchen surfaces, food, and hands [116]. Additionally, animal foods should undergo proper cooking procedures before consumption [117]. Unfortunately, people might fail to link security measures to food safety and give up these practices after the pandemic if their importance is not promoted [118]. Another critical point is the correct washing and disinfecting methods, e.g., using of detergent residues or inefficient disinfecting with vinegar, as was observed in Brazil [119–122].

On the other hand, food could be a transmission route for SARS-CoV-2, as it has been linked to meat processing plants, wherefrom viral particles could be transported to meat through the chain links. Some publications reported worrying data on the survival of viral surrogates, depending on the food and temperature. The SARS-CoV-2 viral surrogates remained in chilled and frozen meat and fish for a long time at refrigeration and freezing temperatures, possibly because the low temperatures allowed the virus to survive [123]. Low temperatures and humidity increased the survival of SARS-CoV-2 and contributed to its long-distance spread during logistics and trade [124]. The widespread recommendation to prevent contamination of food and processing surfaces focuses on disinfection protocols at every stage of food processing.

Another relevant factor indicates that contaminated food and packaging imported from areas of active outbreaks of COVID-19 were located in China [125]. In contrast, low levels of SARS-CoV-2 were detected on stainless steel and cardboard surfaces under room temperature and constant humidity [126, 127]. Frozen foods were reported to carry SARS-CoV-2 without human contact, thus necessitating procedures for safe transport. Scientists reported incidents related to cold chains in frozen meat and fish. An improvement system for food cold chain management includes information detection, chain linkage, and credible traceability [128]. We identified two areas of improved cold chain management practices. The first one focuses on the analysis of requirements for the prediction of transmission risk and temperature ranges. The other concentrates on the documentation regarding critical control points throughout the cold chain, thus implementing objective traceability.

For high-quality food to reach the final chain link, the food industry needs qualified staff who are aware of the relevance of their work. All workers along the cold chain should possess a solid food safety culture, be able to identify the hazards of food mishandling, and understand the importance of hygienic measures both before and after the handling of animal products, tools, etc. [129, 130]. In addition, whole and retail vendors must be tightly supervised by government and non-government certification agencies [131, 132]. However, Nyarugwe *et al.* conducted surveys of employees from diverse areas in food companies located in China, Greece, Tanzania, and Zambia [133]. They found that workers in African compared lacked training and safety culture in comparison to those in China and Greece.

Unfortunately, the statistics of foodborne disease outbreaks in developing countries are scarce, and adequate product resources for safe food are few [134]. Therefore, the safety culture and personal training identified by Nyarugwe *et al.* in African companies could be extrapolated to those in Latin America [133]. In addition, the challenges of the COVID-19 pandemic require better hygiene practices in the general population. For instance, male workers were reported to have a greater sense of risk of contracting SARS-CoV-2, but they took fewer safety measures to protect themselves, compared to female employees [118].

Mohammadi-Nasrabadi *et al.* assessed the knowledge on health and food safety during the COVID-19 pandemic in restaurant personnel only to discover that none of them had received any training on this topic [135]. The authors classified the level of COVID-19 awareness in restaurant workers as low (17%), moderate (35.2%), and good (47.2%). After the training, these percentages increased.

CONCLUSION

Food safety has the potential to have a strong impact on different sectors of each nation. By supplying healthy food to the population, governments can reduce the occurrence of foodborne diseases. Companies that produce, transport, or trade in perishables should raise the awareness of their employees about refrigeration equipment, its maintenance, calibration, and temperature monitoring. This simple measure is especially important in developing countries, where it could improve food handling at each supply chain step.

The present work stresses the need to use refrigeration equipment that ensures temperature control at each stage of the cold chain because various potential microorganisms may affect meat products' safety and shelf life. An appropriate cold chain management could reduce food wastage, especially in developing countries, thus decreasing carbon print. An effective cold chain possesses a reliable traceability and contributes to international efforts against the COVID-19 pandemic. Therefore, effective food cold chain management standards increase food safety and prevent the spread of SARS-CoV-2.

CONTRIBUTION

P. Arriaga-Lorenzo compiled the bibliography and initiated the research. P. Arriaga-Lorenzo, E. de Jesús Maldonado-Simán, R. Ramírez-Valverde, P.A. Martínez-Hernández, D.N. Tirado-González, and L.A. Saavedra-Jiménez participated in the analysis and discussion of each topic. All the authors approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

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3. EVALUACIÓN DE LA CADENA DE FRÍO EN CORTES DE RES VENDIDA EN SUPERMERCADOS

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EN

Assessment of the cold chain for cuts of beef sold in supermarkets

ES

Evaluación de la cadena de frío en cortes de res vendida en supermercados

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Abstract

The demand for food at global level has constantly increased, and particularly for perishable products that require a specialized management to assure their safety when they reach the final consumer. The cold chain is a useful tool for achieving this objective. However, there are problems in the different links that can affect the product quality. Retailing is a weak link, for this, the cold chain needs to be monitored to assure there are no fluctuations in temperature that negatively affect the food quality and safety. In this study, the cold chain management for beef sold by four supermarkets in the State of Mexico, was assessed, considering those that use open fridges. The surface temperature of the product placed in different parts of the fridge, was recorded. Data obtained were analyzed with a mixed model with repeated measurements over time under a completely random design. It was determined that two of the four supermarkets showed management problems in the cold chain during the assessed months, breaching the provisions of the NOM-213-SSA1-2018 standard. This represents a risk for human consumers, due to the possible growth of microorganisms caused by the temperature increase, in addition of decreasing the shelf life and subsequent waste of food, generating economic losses.

Key words: Meat, beef, temperature, safety, food spoilage.

Resumen

La demanda de alimentos a nivel mundial ha mantenido un constante crecimiento, y en particular los productos perecederos que requieren de manejo especializado para asegurar su inocuidad al llegar con el consumidor final. La cadena de frío es una importante herramienta para lograr este objetivo. Sin embargo, existen problemas en los distintos eslabones que pueden afectar la calidad del producto. La venta al menudeo resulta ser un eslabón débil, por lo que la cadena de frío necesita ser monitoreado para asegurar que no se presenten fluctuaciones de temperaturas que afecten negativamente la calidad e inocuidad de los alimentos. En esta investigación, se evaluó la gestión de cadena de frío de carne de res vendida en cuatro supermercados del estado de México,

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considerando aquellos que utilizan refrigeradores de tipo abierto. Se registró la temperatura superficial del producto localizado en diferentes posiciones del refrigerador. Los datos obtenidos se analizaron con un modelo mixto con mediciones repetidas en el tiempo bajo un diseño completamente al azar. Se determinó que dos de los cuatro supermercados, presentaron problemas de gestión de la cadena de frío durante los meses evaluados, incumpliendo lo estipulado en la norma NOM-213-SSA1-2018. Esto representa un riesgo para el consumo humano, por la posible proliferación de microorganismos causada por el aumento de temperatura, además de reducir la vida de anaquel y posterior desperdicio de alimentos, generando pérdidas económicas.

Palabras clave: Carne, bovino, temperatura, inocuo, deterioro de alimentos.

Introduction

In the human diet, the main source of protein comes from the animal products, for this, it is important to consider that meat products, such as beef, that being a highly perishable food, can be a risk for human health if there is an inappropriate management in some links of the supply chain (Syahputri and Sucipto, 2021). It is estimated that, during 2021, about 55 843 000 t of meat were consumed at global level, from which, 1 987 245 were consumed in Mexico (Consejo Mexicano de la Carne, 2022). Therefore, in order to assure that this food reaches the final consumer in good condition, it is essential that beef stay under cold chain.

Highly perishable food products need refrigeration or freeze processes during all the links of the supply chain, since the post-harvest/sacrifice until they reach the final consumer, which is achieved under cold chain logistics (Hu et al., 2020). All this on the understanding that, the refrigeration of highly perishable products is one of the main and effective options to increase the shelf life (Ding et al., 2016; Feng et al., 2019; Pichaya et al., 2012). However, it is estimated that of a production of 1 661 million tons of food that should be refrigerated, only 47 % is refrigerated, which generates a global food loss up to 13 %, mainly in developing countries with lack of refrigeration units (International Institute of Refrigeration, 2020).

On the other side, with the beginning of the COVID-19 pandemic, the importance of hygiene measures, both personal and in food for daily consumption, was highlighted. Although there is no evidence that food transmits del SARS-CoV-2, viral particles have been detected in materials related to food under cold chain (Chen and Duan, 2020; Normile, 2020; Yang et al., 2021). This as consequence that the stability of the SARS-CoV-2 benefits from the low temperatures provided by the cold chain (Han et al., 2021; Shi et al., 2020). Nevertheless, it is strictly necessary maintain the perishable food at a temperature not higher than 4 °C, because a sudden increase could cause a quality loss,

Introducción

En la dieta de los humanos, la principal fuente de proteína proviene de los productos de origen animal, por lo que, es importante considerar que los productos cárnicos, como los de res, que al ser un alimento altamente perecedero, puede ser un riesgo para la salud humana si se presenta un manejo inadecuado en algún eslabón de la cadena de suministro (Syahputri y Sucipto, 2021). Se estima que, durante el 2021 se consumieron alrededor de 55 843 000 t de carne de res a nivel mundial, de las cuales, 1 987 245 se consumieron en México (Consejo Mexicano de la Carne, 2022). Por ende, para asegurar que dicho alimento llegue en buen estado hasta el consumidor final, es crucial que la carne de res se mantenga bajo cadena de frío.

Los productos alimenticios altamente perecederos requieren de procesos de refrigeración o congelación durante todos los eslabones de la cadena de suministro, desde la post-cosecha/sacrificio hasta llegar al consumidor final, lo cual se logra bajo la logística de la cadena de frío (Hu et al., 2020). Esto en el entendido de que, la refrigeración en los productos altamente perecederos es una de las principales y eficaces alternativas para maximizar la vida de anaquel (Ding et al., 2016; Feng et al., 2019; Pichaya et al., 2012). Sin embargo, se estima que de una producción de 1 661 millones de toneladas de alimentos que deberían ser refrigerados, únicamente se refrigera 47 %, lo que genera una pérdida mundial de alimentos de hasta 13 %, principalmente por países en desarrollo con falta de equipos de refrigeración (International Institute of Refrigeration, 2020).

Por otro lado, con la llegada de la pandemia del COVID-19 se resaltó la importancia de medidas de higiene, tanto personales como en los alimentos de consumo cotidiano. A pesar de que no se ha demostrado que los alimentos sean una ruta de transmisión del SARS-CoV-2, se han detectado partículas virales en materiales asociados con alimentos bajo cadena de frío (Chen y Duan, 2020; Normile, 2020; Yang et al., 2021). Esto como growth of microorganisms and, therefore, economic losses before the expiration date (Ndraha et al., 2018; Neisyafitri and Ongkunaruk, 2020; Rizou et al., 2020).

The temperature variations, also called disruptions, abuses or fluctuations, are produced through the food management and generally in the cooling before its transport, during the delivery at different points of the supply chain, in the process of loading and unloading the products. These alterations cause delay in the transport of the product in contact with the room air, in addition of the interruptions or incorrect calibration of the refrigeration system during the retailing (Brenner, 2015; Mercier et al., 2017; Syahputri and Sucipto, 2021). As a consequence, the aim of this study was to assess the cold chain for beef sold in supermarkets, in order to detect if there is a risk of microbiological contamination due to temperature increases.

Methodology

From January to May 2022, we took surface temperature records for the cuts of beef loin and rib eye steak packaged and marketed in four supermarkets from the northeast of the State of Mexico. Samplings were conducted each week between 12:00 – 14:00 hr. In each supermarket, the temperature of the products placed in the front, middle and back position of open fridges, was recorded. During the study, a room temperature between 15 – 26 °C was recorded in the zone. The generated database collected 12 records by supermarket/month, obtaining a total of 240 records. The temperature readings were obtained with an infrared thermometer (MASIONE GM320).

To analyze the temperature database, a mixed model with repeated measurements over time was used, with the SAS software (SAS, 2013). Through a completely random design, the positions within the fridge, the four supermarkets and five months of the year (January to May), were considered as independent variables. The room temperature was deemed as a covariate with linear and quadratic effect. Measurements were grouped through the Student's t-test. The temperature means obtained from the statistical analysis were compared with what is stipulated in the NOM-213-SSA1-2018 for meat products.

Results and discussion

Front position

In the front position (Table 1) of the open fridges, it was found that, during the five sampled months, severe management problems in the cold chain were presented in the two supermarkets assessed (1 and 3),

consecuencia de que la estabilidad del SARS-CoV-2 se beneficia de las bajas temperaturas propiciadas por la cadena de frío (Han et al., 2021; Shi et al., 2020). No obstante, es estrictamente necesario mantener los alimentos perecederos a una temperatura no mayor a 4 °C, ya que un aumento repentino, puede provocar que antes de la fecha de caducidad se produzca una pérdida de calidad, proliferación de microorganismos y, por consiguiente, pérdidas económicas (Ndraha et al., 2018; Neisyafitri y Ongkunaruk, 2020; Rizou et al., 2020).

Las variaciones de temperatura, también llamadas disrupciones, abusos o fluctuaciones, se producen durante el manejo de los alimentos y generalmente en el enfriamiento previo a su movilización, durante la entrega en los diferentes puntos de la cadena de suministro, en el proceso de carga y descarga de los productos. Estas alteraciones causan demoras en la movilización del producto entrando en contacto con el aire ambiental, además de las interrupciones o incorrecta calibración del sistema de refrigeración durante la venta al menudeo (Brenner, 2015; Mercier et al., 2017; Syahputri y Sucipto, 2021). En consecuencia, el objetivo de este estudio fue evaluar la cadena de frío en cortes de carne de res vendida en supermercados, con el fin de detectar si existe riesgo de contaminación microbiológica por aumentos de temperatura.

Metodología

Durante los meses de enero a mayo de 2022, se tomaron registros de temperatura superficial de cortes de carne de res de lomo y rib eye steak empaquetada y comercializada en cuatro supermercados localizados en el noreste del Estado de México. Los muestreos se realizaron de forma semanal entre las 12:00 – 14:00 hr. En cada supermercado se registró la temperatura de los productos localizados en la posición frontal, media y posterior de refrigeradores abiertos. Durante el estudio se registró una temperatura ambiente entre 15 – 26 oC en la zona. La base de datos generada acumuló 12 registros por supermercado/mes, obteniendo 240 registros en total. Las lecturas de la temperatura fueron obtenidas utilizando un termómetro infrarrojo (MASIONE GM320).

Para analizar la base de datos de temperaturas, se empleó un modelo mixto con medidas repetidas en el tiempo, usando el software SAS (SAS, 2013) mediante un diseño completamente aleatorizado; se consideraron como variables independientes las posiciones dentro del refrigerador, los cuatro supermercados y cinco meses del año (enero a mayo). La temperatura ambiental fue considerada como una covariable con efecto lineal y cuadrática. Las medias se agruparon mediante la prueba t de Student.

Table 1. Estimated temperatures (°C) for cuts of beef placed in the front position of the fridge.
Cuadro 1. Temperaturas estimadas (°C) en cortes de res localizados en la posición frontal del refrigerador.

Supermarket / Supermercado	Month/Mes					
	January / Enero	February / Febrero	March / Marzo	April / Abril	May / Mayo	Mean / Media
1	10.17±0.58	9.78±0.41	10.16±0.48	8.91±0.30	9.71±0.41	9.75±0.21[a]
2	4.83±0.77	3.31±0.60	3.59±0.39	3.38±0.49	4.11±0.33	3.84±0.26[b]
3	6.81±0.58	7.18±1.74	12.84±3.20	8.36±2.99	9.37±1.08	8.91±0.92[a]
4	2.99±0.73	3.78±0.78	4.24±1.21	5.63±1.07	4.45±0.50	4.22±0.39[b]
Mean / Media	6.2±0.68	6.01±0.82	7.71±1.28	6.57±0.92	6.91±0.67	

Means with the same literal, do not show significant statistical differences (P>0.05) /
Medias con la misma literal, no muestran diferencias estadísticas significativas (P>0.05)

showing temperature abuse of up to 8 °C above the limit allowed by the NOM-213-SSA1-2018 standard, which sates a temperature not higher than 4 °C for refrigerated foods. Supermarkets 2 and 4 showed a better temperature management, although in some months, there are temperature increases slightly above what is stipulated by the standard. The analysis of the environmental temperature as covariate, did not show lineal or quadratic influence (P>0.05).

Middle position

Supermarkets that did not maintain a good temperature management for the cuts of beef placed in the front position of the fridge, showed the same trend in the middle position (Table 2), with temperatures up to 6 °C above what is stipulated. On the other side, the variations showed by the supermarkets 2 and 4, were reduced and practically disappeared. Also, it was observed that the temperature of the meat products placed in this position within the fridge, showed an influence of the room temperature with quadratic effect.

Back position

Data obtained from the analysis of the various positions in the fridge show that there are temperature variations in respect of the position in which meat products are placed. In this research, it is showed that in the back position (Table 3), the assessed refrigeration units maintained a better temperature

Las medias de temperatura obtenidas del análisis estadístico se compararon con lo estipulado en la NOM-213-SSA1-2018 para los productos cárnicos.

Resultados y discusión

Posición frontal

En la posición frontal (Cuadro 1) de los refrigeradores abiertos, se encontró que, durante los cinco meses muestreados se presentaron severos problemas en el manejo de la cadena de frío en dos de los supermercados evaluados (1 y 3), presentando abusos de temperatura de hasta 8 °C por arriba del límite permitido por la norma NOM-213-SSA1-2018, la cual indica una temperatura no mayor a 4 °C para alimentos refrigerados. Los supermercados 2 y 4 presentaron un mejor manejo de la temperatura, aunque se observan en algunos meses incrementos de temperatura ligeramente por arriba de lo estipulado por la norma. El análisis de la temperatura ambiental como covariable, no mostró influencia (P>0.05) lineal o cuadrática.

Posición media

Los supermercados que no lograron mantener una buena gestión de la temperatura de los cortes de res localizados en la parte frontal del refrigerador, mostraron la misma tendencia en la posición media (Cuadro 2), con temperaturas hasta 6 °C por arriba

Table 2. Estimated temperatures (°C) for cuts of beef placed in the middle position of the fridge.
Cuadro 2. Temperaturas estimadas (°C) en cortes de res localizados en la posición media del refrigerador.

Supermarket / Supermercado	Month / Mes					
	January / Enero	February / Febrero	March / Marzo	April / Abril	May / Mayo	Mean / Media
1	10.35±0.56	10.79±0.50	9.33±0.86	7.19±0.47	8.64±0.57	9.26±0.34[a]
2	4.75±0.83	3.76±0.88	3.55±0.23	2.72±0.29	2.30±0.38	3.42±0.30[c]
3	4.99±1.03	7.00±1.49	7.65±3.73	6.19±1.54	5.98±0.90	6.37±0.78[b]
4	1.83±0.57	2.16±0.57	3.00±0.25	3.81±0.82	2.38±0.81	2.64±0.33[c]
Mean / Media	5.48±0.79	5.93±0.95	5.89±1.10	4.98±0.62	4.83±0.69	

Means with the same literal, do not show significant statistical differences (*P*>0.05) /
Medias con la misma literal, no muestran diferencias estadísticas significativas (*P*>0.05)

Table 3. Estimated temperatures (°C) for cuts of beef placed in the back position of the fridge.
Cuadro 3. Temperaturas estimadas (°C) en cortes de res localizados en la posición posterior del refrigerador.

Supermarket / Supermercado	Month / Mes					
	January / Enero	February / Febrero	March / Marzo	April / Abril	May / Mayo	Mean / Media
1	5.80±0.89	5.54±0.68	4.61±0.16	3.07±0.22	4.79±0.63	4.76±0.29[a]
2	1.74±1.39	0.51±0.69	-0.01±0.47	-0.33±1.03	0.39±0.81	0.45±0.41[b]
3	1.84±0.71	2.61±1.57	7.00±4.03	4.35±2.24	4.13±4.54	3.99±0.96[a]
4	-2.14±0.40	-0.64±0.49	0.03±0.42	-0.2±0.72	-1.15±1.18	-0.82±0.37[b]
Mean / Media	1.81±0.77	2.00±0.74	2.91±1.20	1.72±0.78	2.04±0.76	

Means with the same literal, do not show significant statistical differences (*P*>0.05) /
Medias con la misma literal, no muestran diferencias estadísticas significativas (*P*>0.05)

control. However, although the temperatures in the four supermarkets are observed to be lower than in the front and middle positions, supermarkets 1 and 3 still presented temperatures above what is allowed for three months. On the other side, supermarkets 2 and 4 maintained a good control of the cold chain during the five months assessed.

de lo estipulado. Por otro lado, las variaciones que presentaban los supermercados 2 y 4, se redujeron y prácticamente desaparecieron. Además, se observó que la temperatura de los productos cárnicos localizados en esta posición dentro del refrigerador presentó una influencia de la temperatura ambiental con efecto cuadrático.

General discussion

According to the temperature means of the different supermarkets, it is observed that, when they are compared with the Mexican legislation, there are problems with the cold chain management in the distinct positions of the open fridges. These findings are similar to the results obtained by Baldera et al. (2016) in Spain, where it was determined that the temperature fluctuations occurred more frequently at the top of the fridge. In another study developed by Eriksson et al. (2016), they point out that, to extend the shelf life of the perishable foods, a more important activity is to reduce the storage temperature, that leads to a reduction of food waste in supermarkets. On the other hand, in Mexico, and in other countries, it is imperative to have databases that show the correct operation of the refrigeration units. However, the corresponding authority needs a strict system to monitor and verify that data is correct, in order to avoid discrepancies between the database and real temperatures, like those detected in retail establishments by Lundén et al. (2014).

It is important to point out that the temperature abuses are not limited to the link considered in this study, since managing the cold chain turns out to be complicated during transport, storage, and retailing, besides that it is not limited to a specific product. Ndraha et al. (2018) show the fluctuations recorded by different European countries such as Spain, Finland, France, Iceland, and Slovenia. Due to the high temperatures estimated in this study, it is possible to infer that the food waste increases, because of a significant reduction of the shelf life, as it was observed in the province of Granada, Spain, with reductions from 25 to 40 % during the summer season (Baldera et al., 2016).

On the other side, the safety food production during and after the COVID-19 pandemic, the fluctuation and temperature abuse in the cold chain, currently represent a crucial factor. This is because, by applying an appropriate temperature during transport or storage, in each type of food stipulated in the standards, it leads to achieving the desired quality of food products, and therefore reduces food waste and loss. (Skawińska and Zalewski, 2022). In the initial period of the COVID-19, a shock scheme between the supply and demand at global level was presented due to the applied coordination and climatic conditions, highlighting in particular the role of applied temperature in food storage (Davis et al., 2020; Hobbs, 2020). There is a systemic research and information gap about the

Posición posterior

Los datos obtenidos del análisis de las distintas posiciones del refrigerador muestran que existen variaciones de temperatura en cuanto a la posición en la que se colocan los productos cárnicos. En esta investigación se muestra que en la posición posterior (Cuadro 3), los equipos de refrigeración evaluados mantuvieron un mejor control de la temperatura. No obstante, a pesar de que las temperaturas en los cuatro supermercados se observan más bajas que en las posiciones frontal y media, los supermercados 1 y 3 continuaron presentando temperaturas por arriba de lo permitido durante tres meses. Por otro lado, los supermercados 2 y 4 mantuvieron un buen control de la cadena de frío durante los cinco meses evaluados.

Discusión general

De acuerdo con las medias de temperatura de los diferentes supermercados, se observa que, al comparar con la legislación mexicana, existen problemas con la gestión de la cadena de frío en las distintas posiciones de los refrigeradores abiertos. Estos hallazgos son similares con los resultados obtenidos por Baldera et al. (2016) en España, donde determinaron que las fluctuaciones de temperatura ocurrieron con mayor frecuencia en la parte superior del anaquel. En otro estudio hecho por Eriksson et al. (2016) indican que, para lograr prolongar la vida útil de los productos perecederos, una actividad de mayor importancia es reducir la temperatura de almacenamiento, que conlleva a una reducción de desperdicio de alimentos en supermercado. Por otra parte, en México, como en otros países, es obligatorio contar con bases de datos que demuestren el correcto funcionamiento de los equipos de refrigeración. Sin embargo, la autoridad correspondiente requiere de un estricto sistema para monitorear y verificar que los datos sean correctos, con el fin de evitar discrepancias entre la base de datos y las temperaturas reales, como las detectadas en establecimientos minoristas por Lundén et al. (2014).

Es importante señalar que los abusos de temperatura no se limitan al eslabón considerado en este estudio, ya que gestionar la cadena de frío resulta ser complicado durante el transporte, almacenaje y venta al menudeo, además de que no se limita a un producto en específico. Ndraha et al. (2018) muestran las fluctuaciones registradas en diversos países europeos como España, Finlandia, Francia, Islandia, y Eslovenia. Debido a las altas temperaturas estimadas en este estudio, es posible inferir que se aumenta el desperdicio de alimentos, como consecuencia de una reducción considerable de la vida de anaquel, como temperature fluctuations in foods throughout the supply chain (Skawińska and Zalewski, 2022).

On the other hand, the types of refrigeration units used in the retailing supermarkets play a key role in the cold chain control, as well as in the supermarkets considered in this study, called open fridges. For example, in the study developed by Morelli et al. (2012), they suggest performing the appropriate corrections for the calibration to reach the target temperature, in addition of the correct unit management on the part of the retail staff. As consequence, and according to the temperature issues in food products in France, two main reasons were identified: poor professional practices and poor refrigerator design. The recommendations proposed for the first problems are focused on reducing the periods of food preparation and putting it quickly to the cooling process, to avoid the development of *Listeria monocytogenes* in those sensitive products. While the unit design is focused on the manufacturers in order to identify limitations and promote an optimum performance of the units.

On the other side, maintaining meat foods at low temperatures hinders the growth of pathogenic bacteria during the stages of storage and retail sales in supermarkets. (Castro-Ibáñez et al., 2017). Also, if the proper temperatures are not maintained for the food refrigeration, the proliferation of pathogenic bacteria that are already present in the products, occurs (Zeng et al., 2014). For example, the raw meat is one of the foods that has a lower stability, because it has a large amount of nutrients for microorganisms. For this, the temperature control becomes an essential tool to protect the quality of the meat products (Xiong, 2023). Although the cold chain maintenance represents a crucial point in the safety and quality of the products, the supervision and exclusion of sick workers becomes more important (Alegbeleye et al., 2018). The detection of a high rate of pathogens in fresh meat has been reported, Staphylococcus, Salmonella, Shigella, Enterococci, Escherichia, Acinetobacter, and Corynebacterium spp. in carcasses or cuts of pork (Van Ba et al., 2019), while in beef carcasses there is a presence of Clostridium, Brochothrix thermosphacta, lactic bacteria and Pseudomonas spp. (Reid et al., 2017). In another research, Xiaofeng and Xuelai, (2021) point out the relevance of moisture and temperature to guarantee the meat safety, specially to inhibit the growth of bacteria. Therefore, the cold chain, together with the moisture control, favor a visible improvement in the quality and safety, as well as the shelf life of the products (Fikiin et al., 2020). Then, the combination of an elevated temperature and high moisture facilitate the bacterial growth (Yu et al., 2001), although there

se observó en la provincia de Granada, España, con reducciones del 25 hasta el 40 % en la época de verano (Baldera et al., 2016).

Por otro lado, la producción de alimentos inocuos durante y después de la pandemia COVID-19, la fluctuación y abuso de temperatura en la cadena de frío, representa hoy en día un factor crucial. Esto se debe a que, al aplicar una temperatura apropiada durante el transporte o almacenamiento, en cada tipo de alimentos estipulada en los estándares, conlleva a lograr la calidad deseada de los productos alimenticios, y por ende reduce el desperdicio y pérdida de alimentos (Skawińska y Zalewski, 2022). En el periodo inicial del COVID-19 se presentó un esquema de choque a nivel mundial entre la demanda y la oferta, a causa de la logística aplicada y las condiciones climáticas, resaltando en especial el papel de la temperatura aplicada en el almacenamiento de alimentos (Davis et al., 2020; Hobbs, 2020). Existe un vacío de información e investigación sistemática sobre las fluctuaciones de temperatura presentes en los alimentos a lo largo de toda la cadena de suministro (Skawińska y Zalewski, 2022).

Por otro lado, los tipos de equipos de refrigeración que se emplean en los supermercados de venta al menudeo juegan un papel crucial en el control de la cadena de frío, como en los supermercados considerados en este estudio, nombrados refrigeradores abiertos. Por ejemplo, en el estudio realizado por Morelli et al. (2012), sugieren efectuar las correcciones pertinentes en la calibración, para lograr la temperatura objetivo, además del correcto manejo de los equipos por parte de personal del minorista. Como consecuencia, y de acuerdo con los problemas de temperatura en productos alimenticios en Francia, donde se identificaron dos razones principales: prácticas profesionales deficientes y un mal diseño de los refrigeradores. Las recomendaciones que proponen para el primer problema se enfocan en reducir los períodos de preparación de los alimentos y someterlos rápidamente al proceso de enfriamiento, para evitar el desarrollo de Listeria monocytogenes en aquellos productos sensibles. Mientras que, el diseño de equipos, está orientado hacia los fabricantes, con el fin de identificar las limitaciones y propiciar un rendimiento óptimo de los equipos.

Por otro lado, el mantener los alimentos cárnicos a bajas temperaturas dificultan la proliferación de bacterias patógenas durante las etapas de almacenamiento y ventas al menudeo en supermercados (Castro-Ibáñez et al., 2017). Además, si no se mantienen las temperaturas adecuadas para la refrigeración de los alimentos, se presenta la proliferación de bacterias is also the presence of active bacteria even with low temperatures in the cold chain (Duffy et al., 2001).

Conclusions

The cold chain management for food, particularly for meat products is essential to reach the proper quality and safety for consumption. In this study, important fluctuations were recorded for meat products in the assessed supermarkets, which have a significant impact in foods. Also, these alterations favor the microbiological growth and negative changes in organoleptic characteristics. Thus, it is important a greater training and application of systems to adequately monitor the temperature, jointly adjust the maintenance and calibration systems of refrigeration units. Finally, when applying the temperature stated in the standard for this type of products, the shelf life increases and safe products suitable for consumption are generated, and the food waste is also reduced.

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patógenas que ya están presentes en los productos (Zeng et al., 2014). Por ejemplo, la carne cruda es uno de los alimentos que tienen menor estabilidad, ya que cuenta con una gran cantidad de nutrientes para los microorganismos. Por tal razón, el control de la temperatura se convierte en una herramienta esencial para proteger la calidad de los productos cárnicos (Xiong, 2023). Si bien el mantenimiento de la cadena de frío representa un punto crucial en la inocuidad y calidad de los productos, adquiere mayor importancia la supervisión y exclusión de los trabajadores enfermos (Alegbeleye et al., 2018). Se ha reportado la detección de una tasa elevada de patógenos en carne fresca, de Staphylococcus, Salmonella, Shigella, Enterococci, Escherichia, Acinetobacter y Corynebacteriwn spp. en canales o cortes de porcino (Van Ba et al., 2019), mientras que en canales de bovino se señala la presencia Clostridium, Brochothrix thermosphacta, bacterias lácticas y Pseudomonas spp. (Reid et al., 2017). En otra investigación Xiaofeng y Xuelai, (2021) señalan la importancia de la humedad y temperatura para garantizar la inocuidad de los cárnicos, en especial para inhibir el crecimiento de bacterias. Por consiguiente, la cadena de frío, en combinación con el control de la humedad, propicia una mejora notable en la calidad e inocuidad, así como la vida de anaquel de los productos (Fikiin et al., 2020). Luego entonces, la combinación de una alta temperatura y elevada humdad propicia el crecimiento bacteriano (Yu et al., 2001), aunque también existe la presencia de bactarias activas aún con bajas temperaturas en la cadena de frío (Duffy et al., 2001).

Conclusión

El manejo de la cadena de frío en alimentos, en especial en productos cárnicos es de vital importancia para lograr la calidad e inocuidad adecuada para el consumo. En este estudio se registraron fluctuaciones importantes en productos cárnicos en los supermercados evaluados, las cuales tienen un impacto relevante en los alimentos. Además, estas alteraciones propician el crecimiento microbilógico y cambios negativos en las características organolépticas. Por lo tanto, es importante mayor capacitación y aplicar sistemas para monitorizar adecuadamente la temperatura, ajustar conjuntamente los sistemas de mantenimiento y calibración de los equipos de refrigeración. Finalmente, al aplicar la temperatura estipulada en la norma para este tipo de productos, se aumenta la vida de anaquel y generan productos inocuos aptos para el consumo, y también se reduce el desperdicio de alimentos.

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4. GESTIÓN DE LA CADENA DE FRÍO EN SUPERMERCADOS MEXICANOS

MEAT COLD CHAIN MANAGEMENT IN MEXICAN SUPERMARKETS

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MEAT COLD CHAIN MANAGEMENT IN MEXICAN SUPERMARKETS

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Keywords: *food safety, supermarkets, meat, cold chain, retail, temperature*

Abstract
The cold chain represents an important opportunity for the food industry to offer food safety and quality of perishable foodstuffs, mainly by maximizing shelf life through limiting bacterial growth. Especially meat products have a short shelf life due to their cold chain requirements. Refrigeration equipment must always be appropriately calibrated and monitored to provide the right temperature and ensure its correct performance. This study aimed to evaluate the cold chain at the retail link in supermarkets of the major commercial chains in Mexico during 2021 and 2022 by recording the surface temperature of pork, poultry, and beef cuts in open coolers. A general linear model was used for the statistical analysis in a completely randomized design. The study considered several factors, such as supermarket, season of the year, position inside the refrigerator, type of meat and environmental temperature. Cold chain breaks were detected in certain seasons of the year, in supermarkets, and even within the refrigerator; there were differences between positions where products were placed. The persistence of these variations in the cold chain represents a public health risk caused by the consumption of foods because a temperature increase can lead to a rise in the microbial load of meat products. Thus, meat cold chain requires integrated logistics management in order to maintain high quality of foods.

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Introduction

Delivering safe foods with acceptable organoleptic characteristics is a food industry challenge due to the complexity of the food supply chain. Around one-third of the world's food production is wasted for different reasons, which adds up to about 1300 million tons per year [1,2]. Food supply chain involves stages that can be categorized as primary production, postharvest and storage, processing, distribution, and consumption [3]. Food wastage varies according to a link in the supply chain; for example, wastage of up to 931 million tons has been estimated for retail, households, and food services [4]. To minimize food wastage, shelf life of highly perishable foods can be extended by employing different packaging techniques. Nevertheless, usually they always need to be kept at a correct temperature [5]. Improper cold chain management results in a negative impact on food safety and a significant reduction in quality, which is reflected in economic losses, health risk, and lack of food availability [6].

Several observations in the retail sector indicate that cold chain management in facilities appears to be the weakest due to reported temperature abuses in food [7]. Having the time-temperature history is essential for food safety, as it can be used in identifying perishable foods that have been subjected to temperature control abuses and gives an opportunity to timely remove them from food displays [8] to minimize meat wastage caused by quality loss due to improper storage [9]. Since some years ago, different technologies have been developed which help in the cold chain monitoring, obtaining a large amount of data used to take pertinent actions. In this context, using the Internet of Things (IoT) allows the implementation of monitoring and traceability protocols by means of wireless sensors and RFID tags, which provide data in real time [10,11].

From animal slaughter to retail sales, meat products require adequate facilities and equipment to guarantee quality and safety [12]. They are achieved through refrigeration or freezing processes throughout the distribution chain after slaughter until reaching the final consumer [13]. The cold chain is one of the main tools of the food industry, limiting bacterial growth, maximizing shelf life, and reducing food waste. This is relevant in the sanitary, environmental, and economic areas [14,15,16]. Strict monitoring must be implemented to preserve the cold chain integrity of sensitive food products, considering the temperature heterogeneity within the refrigeration display [8]. However, the cold chain must be implemented in conjunction with strict hygiene measures during handling of meat products to reduce contamination with microorganisms that may proliferate even under proper refrigeration temperatures, such as *Campylobacter jejuni* commonly found in poultry [17].

Temperature disturbance at any step of the food production chain represents a hazard that leads to product spoilage. The causes are various, such as interruptions of the refrigeration system itself, irregular temperature distribution due to uneven air distribution, exposure to ambient air, and everything related to incorrect settings in refrigeration systems. Maintaining control of the cold chain ensures the prolongation of the shelf life of fresh meat, so it is essential to avoid temperature fluctuations that lead to spoilage [18]. As a consequence, food spoilage leads to an unacceptable level of quality caused, in many cases, by a break in the cold chain [8]. These temperature variations promote the proliferation of a wide variety of microorganisms associated with a meat product type, which may include *Pseudomonas*, *Campylobacter*, *Moraxella*, *Enterococcus*, *Psychrobacter*, *Salmonella*, *Escherichia coli*, among other agents responsible for food-borne diseases [19].

Therefore, it is essential to consider a type of food within cold chain management so that refrigeration equipment provides the appropriate storage temperature [10]. To ensure the quality and safety of meat products, the Mexican authority established that meat products should be kept under refrigeration at all times at a temperature no higher than 4 °C according to NOM-213-SSA1–2018, which coincides with the Canadian, USDA, and FDA temperature limit [20,21,22,23]. Derens-Bertheau et al. [24] indicated that, along the cold chain, retail is one of the last three stages with the highest incidences of temperature violations. These temperature violations are caused by the lack of information and personnel training on the requirements of the products they handle [25].

In the face of various breaks in the cold chain, it has been indicated that the low efficiency of refrigeration equipment can influence maintaining the target temperature, as has been observed in open-type refrigerators [26]. Supermarkets widely use this type of equipment to display meat products in such a way as to make them accessible to consumers, because these refrigerators have no physical barriers and operate only with an air curtain that should maintain the proper temperature of products [27]. However, it is necessary to have properly calibrated equipment and monitor its performance to avoid temperature violations as a result of irregular distribution of airflow [28,29,30]. Despite the importance of monitoring throughout the cold chain, there needs to be more scientific evidence in Mexico that specifies the state of temperature management in supermarket refrigerators. Therefore, this research describes the temperature analysis in refrigerated open displays operated by some major chain supermarkets in Mexico to offer meat products to customers.

Objects and methods

Meat products, which temperatures were monitored in this research, were pork, poultry, and beef exhibited in refrigerated open displays for consumers' pick-up in four supermarkets located in an urban area to the northeast of the State of Mexico, Mexico. Pork and beef were in slices, while poultry was in whole pieces: breasts, legs, and thighs. Temperature was measured at three positions within the open display refrigerator: front, middle, and rear. Temperature recording was weekly at the same time for each supermarket for two consecutive years: 2021 and 2022. For each type of meat, 606 temperature records were obtained for an overall total of 3636 records during the whole monitoring. An infrared thermometer (GM320 MASIONE®, China) was used to record the temperature, pointing to the surface of the specific meat product. When temperatures in supermarket displays were taken, outside environmental temperature was collected from records of a nearby federal weather station (00015125 TEXCOCO [DGE]).

Statistical Analysis

The effects of year's season (winter, spring, summer, and autumn), meat type (pork, poultry, and beef), supermarket (1, 2, 3, and 4), position inside the refrigerator (front, middle, and rear), and their respective interactions were analyzed. The statistical analyses were performed using online SAS software. The analysis of variance (ANOVA) was performed considering season, position, supermarket, and meat as fixed effects under a general linear model, using a completely randomized design. A comparison of mean differences ($p < 0.05$) was performed with the LSMEANS function adjusted to Tukey. Environmental temperature was considered as a covariate using PROC Mixed and SGPLOT to obtain the effect on predicted and observed temperature in meat products. An orthogonal polynomial test was carried out to evaluate the linear and quadratic tendencies of the covariate (Proc Mixed) [31].

Results and discussion

All four variation sources included in the study influenced ($p < 0.05$) surface meat temperature (Table 1). Statistically significant differences were found for the effect of year's season ($p < 0.001$); winter, followed by summer, were the seasons with the highest temperatures in the products. Regarding the supermarket effect, differences in the cold chain management were highly marked between supermarket 1 and the rest with more than 5 °C differences. In other words, the temperature in supermarket 1 was around 1.3 times higher than the mean temperature in the other three supermarkets. These results of variability are relevant, considering that all supermarkets evaluated in this study use the same type of refrigerator (open cabinet).

On the other hand, despite statistically significant temperature differences found between different meat types, they were tiny, showing cold chain breaks in beef. However, this is the statistical interpretation according to the temperature means. It can be observed in the minimum and maximum temperature data that the three meat types showed temperatures above 4 °C; the time during which the products were subjected to these conditions is unknown. Deficient cold chain management increases the growth risk of possible bacteria present in the different types of meat. Furthermore, it is necessary to consider the ability of different microorganisms including pathogens to grow at refrigeration temperature (4 °C), as is the case of *C. jejuni*, which causes gastroenteritis and is the main cause of Guillain-Barre Syndrome [32,33]. Upon the interpretation of statistical analysis, an effect of meat type was found to be very close to non-significant ($p = 0.05$). On the contrary, an effect of the meat product position in the refrigerator was significant. Temperature was rising from the rear to the front with the highest mean temperature of 5.84 °C.

Table 1. Single-effect temperature means

Variation source	Levels	Mean	Min — Max	S.E.	Significant differences
Season	Winter	4.18	–15.90 — 15.40	0.11	a
	Spring	3.95	–5.60 — 22.20	0.09	ab
	Summer	4.09	–6.10 — 26.00	0.09	a
	Autumn	3.73	–5.30 — 13.40	0.09	b
Supermarket					
	1	6.92	–1.50 — 14.40	0.09	a
	2	2.68	–5.60 — 9.20	0.09	c
	3	3.56	–6.10 — 26.00	0.09	b
	4	2.80	–5.90 — 12.70	0.09	c
Meat type					
	Pork	3.84	–6.10 — 22.20	0.08	b
	Poultry	4.00	–5.20 — 26.00	0.08	ab
	Beef	4.12	–5.90 — 20.30	0.08	a
Position					
	Front	5.84	–3.90 — 22.20	0.08	a
	Middle	4.58	–3.90 — 26.00	0.08	b
	Rear	1.54	–6.10 — 18.70	0.08	c

S.E. = standard error; means within the variation source with at least one literal in common are not statistically different

As for the seasonal effect on product temperature reported in this study, the highest temperature was in winter followed by summer. It is partially consistent with the results reported in the previous study by Baldera et al. [28], where fresh meat temperatures were higher during summer instead of winter.

Regarding open-type refrigerators, this study conducted in Mexico reports differences between refrigerators used by the supermarkets evaluated. However, the stores evaluated by Talbot et al. [34] use different refrigerator types. They mention that the global temperature means of various positions in the refrigerator did not show significant differences, but there were differences among the refrigerator types.

An effect of a supermarket on a temperature of meat products was analyzed. Cold chain management applied in supermarket 1 showed concerns in the three meat types with statistical differences; beef showed the highest temperature (Figure 1). The records indicate that this supermarket's maximum limit of 4 °C was not achieved in any meat type ($p < 0.01$). In contrast, none of the other supermarkets recorded violations of the temperature limit specified in the recommendations by NOM-213-SSA1–2018 in the tested meat types [20].

The results showed violations of current regulations concerning the permitted temperature for perishable foods such as meat in the Mexican supermarkets evaluated. In the same way Lundén, Vanhanen, Myllymäki, et al. [35] reported a higher rate of temperature violations in fish compared to minced meat, which shows that it is crucial to consider a product type to implement the proper refrigeration equipment and configuration consistently to achieve the right temperature. Therefore, according to Mexican legislation regarding temperature requirements for meat products, some supermarkets evaluated in this study sell meat that does not comply with the regulations, and as [8,36] point out, there is a high probability that a significant bacterial load can represent a health risk. Besides, shelf life of products is reduced with each degree of temperature above recommended.

Similarly, an effect of the position in the refrigerator was analyzed at different retail stores. Supermarkets 1, 3, and 4 presented temperatures above 4 °C in the front position. Whereas supermarkets 3 and 4 ensured the cold chain in the middle and rear positions, supermarket 1 did not achieve proper temperature in any position, contrary to supermarket 2, which successfully managed temperature in all three positions in the refrigerator (Figure 2). At the same time, the front and middle positions in the refrigerator showed temperature fluctuations that were out of the norm in all-year seasons (Figure 3). Based on this observation, it has been confirmed that monitoring of refrigeration equipment is essential to verify that it is correctly calibrated, since uniform temperature distribution is crucial to avoid disruption of the cold chain [37].

Temperature deviations in meat products can drastically affect food quality and safety, influencing meat structure, fracturing muscle fibers, and water loss [38]. It is of greater relevance, considering that various pathogens can be present in meat products, including *E. coli* [39]. In a study conducted in Slovakia, where the microbiological quality of ready-to-eat foods was evaluated, Lopašovský et al. [40] indicate that one of the main concerns in reducing food losses and public health risks focuses on maintaining control of refrigeration at all stages of the cold chain, thereby preserving control of food safety and quality. Due

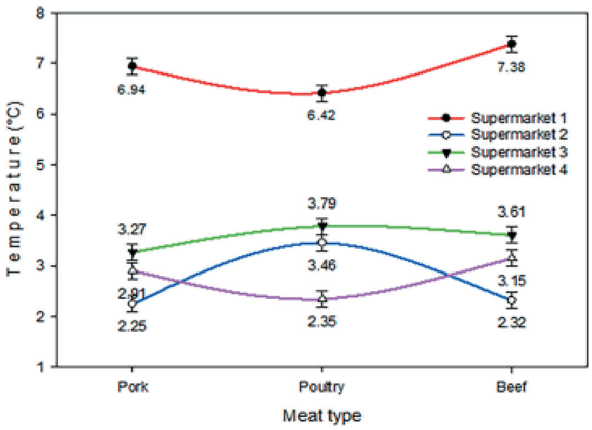

Figure 1. Temperature means of the three meat types in the supermarkets

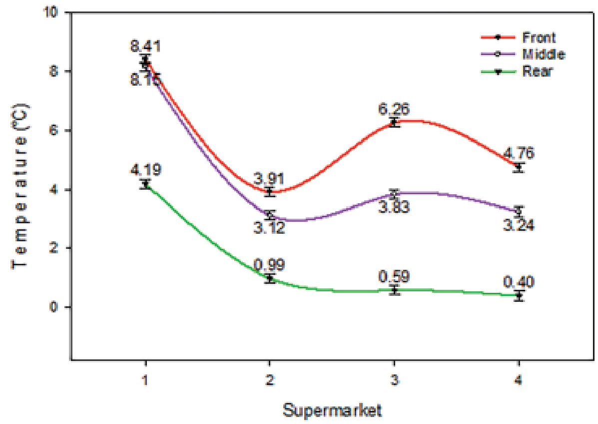

Figure 2. Temperature means of the three meat types in different positions in the refrigerator in the supermarkets

to cold chain breakage, bacteria colonies increase, and the product's spoilage is accelerated. It is reasonable to assume that there is the probability of cross-contamination during different stages of carcass processing after slaughter [41].

Cold chain breaks at retail distribution, particularly by supermarkets, can be attributed to a refrigerator type. Supermarkets often use open refrigerators, such as those examined in this study. This equipment facilitates consumer access to the products. An air curtain flow is used to prevent heat transfer from the environment. However, in many cases, it proves inefficient, having problems with maintaining the correct temperature at the front position as it is in the rear. Therefore, using refrigerators with doors, in many cases, helps to reduce this problem [27]. Likar and Jevšnik [42] reported that despite temperature fluctuations during food storage, retail stores did not have the corresponding documentation and system to control the cold chain. At the same time, this study shows that retailers are not well-informed about the importance of the food cold chain.

The cold chain monitoring in the three meat types showed breaks due to diverse factors related to a supermarket. With the reference 4 °C limit for meat products [20], a significant violation of up to 3.48 °C was reported for supermarket 1 during autumn; nevertheless, temperature fluctuations were observed during all seasons of the year (Figure 4). In this scenario, supermarket 3 had problems with maintaining its cold chain during the winter and spring. Considering the influence of the environmental temperature used as a covariate in the present study, it is possible to affirm its impact since it was found to have a linear effect ($p < 0.0001$), where it is predicted that for each 1 °C increase in environmental temperature, the meat products increase their temperature by 0.93 °C. However, a quadratic effect was also found, where the maximum point is predicted at 20.4 °C, and subsequently, meat product temperature is reduced by –0.02 °C for each 1 °C increase in ambient temperature. This phenomenon was observed in the four supermarkets (Figure 5). Figure 5 shows the general panorama that varied in each supermarket only in the temperature values of meat products kept, exceeding the values predicted and permitted by Mexican regulations.

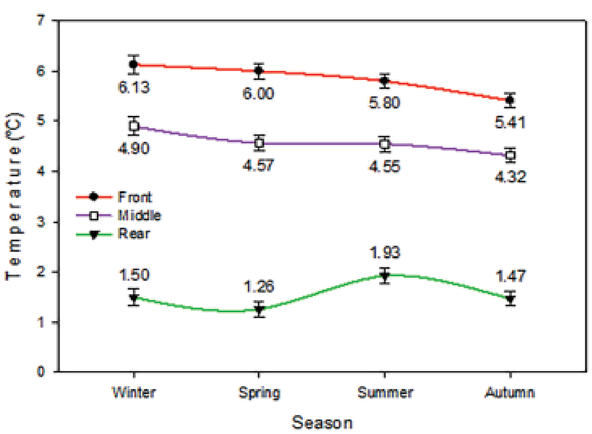

Figure 3. Temperature means of the three meat types in different positions in the refrigerator throughout the year

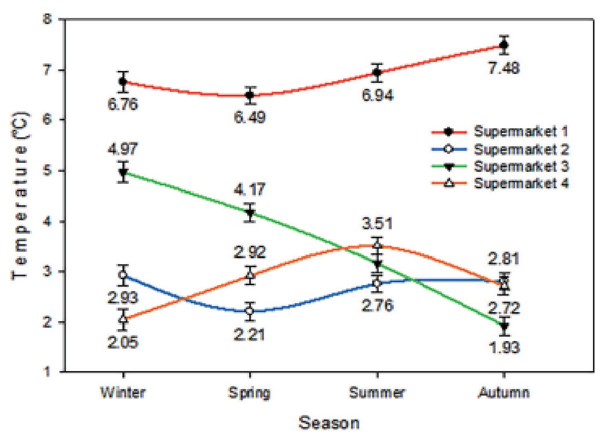

Figure 4. Temperature means of the three meat types in year seasons in the supermarkets

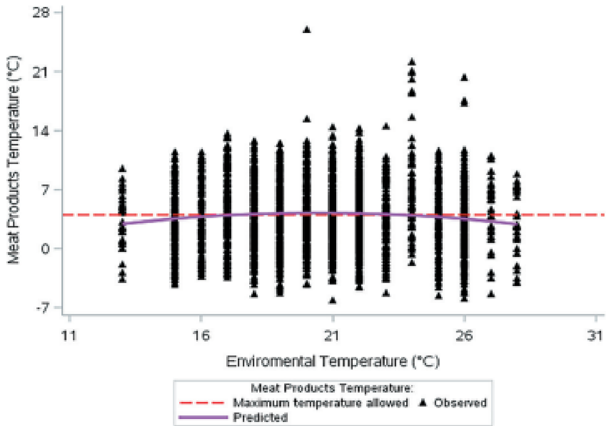

Figure 5. Effect of environmental temperature on meat products

This study did not evaluate an effect of a type of refrigerator used in the supermarkets (open or closed) on the cold chain. However, the difference in temperature control can be observed in the present study, given that supermarket 3 changed its open refrigerator display for refrigeration equipment with doors in the poultry (Figure 6A) and beef (Figure 6B) section at the beginning of August 2022. It can be observed that, after this date, the maximum temperature limit of 4 °C established by Mexican regulations was not exceeded during the rest of the study contrary to pork (Figure 6C), which remained on open shelves and showed temperature violations throughout the monitoring period. Bruckner et al. [43] noted that short temperature increases in fresh pork and poultry meat led to spoilage patterns that reduced shelf life during storage and influenced the growth of *Pseudomonas* spp. in these types of meat.

Consequently, it is necessary to have continuous temperature monitoring and temperature data exchange throughout the supply chain of products that are highly perishable to predict the remaining shelf life [44]. Nastasijević et al. [45] highlighted that meat is a fresh product with a short shelf life, so cold chain management is crucial to maintain quality and safety. To achieve successful management, retail establishments require special attention to weak points, such as the size and capacity of cold rooms, the initial temperature of incoming meat, the dimensions of cabinets, the procedures applied in meat handling, environmental temperatures, location of refrigeration equipment, light, and ventilation, among others [45]. Poor cold chain management can result in food waste and economic losses [46]. In the case of developing countries, food wastage may be mainly due to poor refrigeration infrastructure. Therefore, investment in better refrigeration can improve food availability and quality [46].

As for developed countries, large percentages of food waste are reported at the consumption stage [46]. However, it is estimated that 12% of the production of countries such as the USA, Canada, Australia, and New Zealand needs to be recovered during distribution and retailing [47]. For

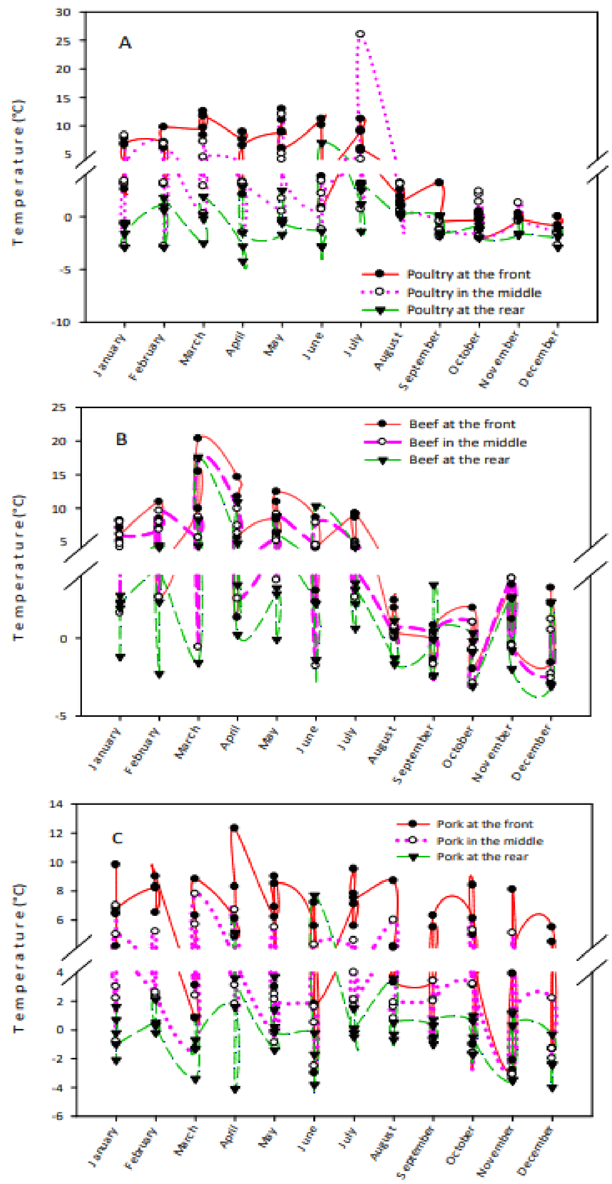

Figure 6. Effect of the change of refrigeration equipment in supermarket 3

food business operators to maintain effective temperature control of refrigeration equipment, it is necessary to know precisely about the type of equipment operating in the centers and, equally, the temperature parameters of the product, equipment alerts, and the situation, in which they are activated to solve the problem promptly [35]. Then, temperature monitoring must be performed on both the refrigeration equipment and the product it contains because there may be unfavorable variability between them [25].

Thus, temperature control in retail store refrigeration equipment is essential to avoid violations, particularly in the most sensitive products that require low temperatures in storage processes. Undoubtedly, the use of an open refrigeration equipment represents a challenge to maintain proper temperatures [48], in addition to their inefficient use of electrical energy [49]. Therefore, a poor design of the equipment causes difficulties in maintaining the cold chain of every product and induces instability in temperature management in this type of equipment. Thereby, regular maintenance is required to ensure the recommended long-term performance.

It should be remembered that the cold chain not only is a tool to limit the growth of pathogenic bacteria, but also reduces the growth of microorganisms that deteriorate the product, thus maximizing its shelf life and reducing food wastage [50]. The magnitude of food waste produced worldwide has already been discussed, and its control has been a topic of great interest during the last decades because it can contribute to achieving another sustainable development objective [1]. However, food wastage needs to be addressed according to a geographic region, given that wastage exists worldwide but at different stages and magnitudes. In the case of Latin America, large amounts of food are lost in production, handling and storage, distribution, and consumption [51], attributed mainly to inadequate handling practices and food knowledge [52], such as the case of deficient cold chain management observed in this study.

Furthermore, climate change greatly influences food wastage at different stages. For the cold chain, the main impact is related to higher environmental temperatures, given that, at higher temperatures, it is a greater challenge to maintain the temperature within the established limits [53]. This problem is prevalent in developing countries, where infrastructure deficiencies such as refrigeration equipment have been detected [52]. Finally, it is important to highlight that several supermarkets use open refrigerators in the meat product areas, which do not have doors and, therefore, operate with an air curtain that prevents air and humidity from coming into contact with the products. Nevertheless, they could be inefficient in maintaining the cold chain and power consumption compared to equipment with doors, allowing for energy savings of 20 to 70% [27]. A suggestion put forward by Ashraf and Alanezi [54] indicate that a smart refrigerator would have the possibility to provide concrete information on food safety and leftovers.

Conclusion

This study detected significant temperature increases in major supermarket chains operating in Mexico. Only supermarket 2 achieved temperature means that complied with the Mexican regulations in force regarding different effects considered in the statistical analysis. All the other supermarkets showed temperature abuses for at least one season of the year, position in the refrigerator, or meat type. Particularly, the front position in the refrigerator showed the highest temperature abuses. The season of the year, related to the environmental temperature, may affect the performance of refrigeration equipment, and can lead to an accelerated growth of microorganisms. Finally, retailers face challenges in adequately managing refrigeration systems to guarantee the safety and quality of meat products. Knowledge of the product´s temperature range is necessary to choose the appropriate refrigeration equipment to ensure the cold chain integrity. In general, refrigerators with doors are recommended for better temperature control, as observed in supermarket 3, or the constant monitoring of open refrigerators to calibrate whenever necessary. High-quality meat products require integrated cold chain management.

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5. PRÁCTICAS DE LIMPIEZA E HIGIENE EN ÁREAS DE PRODUCTOS CÁRNICOS EN SUPERMERCADOS MEXICANOS

CLEANING AND HYGIENE PRACTICES IN MEAT PRODUCT AREA OF MEXICAN RETAIL SUPERMARKETS

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Cleaning and Hygiene Practices in Meat Product Area of Mexican Retail Supermarkets

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ABSTRACT

The management of good hygiene and sanitation practices plays a fundamental role in the quality and safety of fresh meat products. An evaluation related to hygiene and sanitation was conducted in situ in four Mexican retail supermarkets, by visual assessment using a 5-level Likert scale. Statistical analysis used a completely randomized experimental design with the chi-square statistical test. The results showed that there were significant temperature fluctuations in the meat self-service area and service areas. Another essential parameter addressed was associated with employees in the proper use and cleanliness of the work uniform. Therefore, it was suggested to conduct training programs for employees and implement activities leading to the maintenance and calibration of cooling equipment to control the food deterioration. Finally, the combined participation of governmental authorities and retail enterprises is necessary to make safe and maintain the quality Mexican food products available by consumers.

Keywords

Supermarkets, hygiene, meat, retail, cold chain.

INTRODUCTION

Foodborne diseases have become a public health problem worldwide and have been linked to poor food handling and sanitation practices among food handlers, and other factors (1). Abdullahi et al. (2) noted that animal products originate from many foodborne diseases. Consequently, hygiene practices and the health status of personnel handling these food products represent the most relevant factors in this problem (3). Animal foods, such as meat, represent an essential source of nutrients, but their composition provides a suitable medium for the growth of many microorganisms. The prevalence of inadequate food handling practices among food handlers puts food safety at risk. In order to increase the sanitation levels of each practice, it is essential to improve the attitude and practice of food handlers (4).

Then, handlers must know the necessary and positive attitude to perform their work, with the application of systematic supervision and the required infrastructure of sanitary facilities to improve food safety practices in meat retail outlets (4). All actors involved in every food supply chain stage have the primary task of ensuring food safety, especially processors and retail outlets, which become crucial safeguards to achieving this objective (5). An essential factor focuses on improving and enhancing food safety in managing meat products, following hygienic-sanitary regulations in conjunction with the cold chain (6). To this purpose, the implementation of prerequisite programs in food retail outlets ensures the operation of good hygienic practices associated with point-of-sale cleaning and disinfection and staff hygiene (7). However, a prerequisite is that these practices must be closely monitored, verified and validated to obtain results that meet the standard and are valid in the long term (8).

For a retail meat center to offer safe and high-quality meat products, specific training programs are required at all levels, from management to staff working directly in the meat handling areas, as well as evaluation processes for all activities. Training in good food safety and hygiene practices should give staff the knowledge, attitude and skills necessary to carry out their work successfully (9). It is relevant to highlight that food hygiene after COVID-19 has become a cutting-edge issue (10), requiring effective sanitation methods in conjunction with visual inspections and microbiological data to ensure that these are effective (11,12).

For this reason, it is essential for all food handlers to receive responsible food hygiene practices training, as they often need more information and training on the subject (13), to ensure at all times, that persons of enterprises handling foodstuffs must correctly implement the hygiene regulations in force (14). Johns and Johns (15) mention two important variables to guarantee that staff meets personal hygiene requirements. The first relates to the work performed by the food staff, including protective clothing, and follows the prevailing quality of the working environment and equipment. Therefore, the objective of this research was to investigate through on-site inspection the compliance degree of parameters related to cleanliness, hygienic practices, and cold chain in the meat product areas of the major retail commercial chains operating in Mexico.

MATERIALS AND METHODS

Distinct aspects of cleanliness and hygiene practices were evaluated in the points of sale and self-service display of meat products in supermarkets of major chains in the State of Mexico, Mexico. The study was conducted weekly from January 2021 to December 2022; during this time, the evaluation was carried out by visual assessment of cleanliness, using a 5-level Likert scale where 1= very bad, 2= bad, 3= average, 4= good, and 5= very good. The parameters assessed included cleanliness around the service area, employee, handling room, equipment in the service area, service area, self-service area; and the temperature of meat products displayed on the shelves. Data were compared with that established by NOM-213-SSA1-2018 (16) to assign the score by Likert scale.

For statistical analysis, data were analyzed as categorical data with the chi-square statistical test, using a completely randomized experimental design. The clustering of percentages for hygiene levels was analyzed with confidence intervals with the formula:

$$(Porcentaje \pm \sqrt{\frac{Percentage * (100 - percentage)}{Number\ of\ records\ for\ percentage}})$$

These were calculated for each category at a probability of $p<0.05$.

RESULTS AND DISCUSSIONS

For the analysis of the hygienic-sanitary parameters in this study, six categories involved in managing fresh meat products from four retail supermarkets were incorporated (Table 1). From the results obtained, the self-service areas indicated that the performance of the open refrigerated meat shelves was poor (60.2%) since they did not show compliance with the temperature limit of 4 °C established by the NOM-213-SSA1-2018 (16), even though the cleanliness factor showed good management (>75%). However, it was required to increase the wearing of appropriate clothing in the working area (52%) and in appropriate conditions (>58%), as required by current regulations, for the development of their food management activities (16). In contrast, the remaining categories associated with equipment management, meat handling rooms, service areas, and their cleanliness, all had positive performance percentages. However, they still presented significant areas of improvement by the four retail supermarkets. In this connection, Bhandari et al. (17) argue that inadequate hygiene protocols in retail meat handling severely affect food safety. In addition, retail meat in developing countries is exposed to extensive handling by staff and a range of pathogen contacts. Therefore, these factors affect food safety, quality, and shelf life; coupled with economic losses, caused by foodborne illnesses that pose a potential public health hazard that leads to morbidity and mortality, making it essential to establish a visible and permanent commitment to all links of the food chain (18).

Table 1. General distribution (%) of ranks in the degree of cleanliness in different areas of the supermarkets evaluated (N=4)

General	Hygienic-sanitary parameters				
Category (pr > Chi Sq)	**1 very bad**	**2 bad**	**3 moderate**	**4 good**	**5 Very good**
Service area cleanliness					
Cleanliness (Floor, surface)		1.23±4.95[b]	7.43±4.79[b]	90.35±1.55[a]	0.99±4.95[b]
Products in cold chain	0.25± 4.99[c]	1.73±4.93[c]	27.73±4.23[b]	67.57±2.83[a]	2.72± 4.90[c]
Employee cleanliness					
If in uniform	0.74±4.95[d]	14.60±4.60[c]	32.67±4.08[b]	49.76±3.53[a]	2.23±4.92[d]
Condition of uniform		1.24±4.95[c]	40.10±3.85[b]	58.66±3.20[a]	
Cleanliness			13.37±4.63[b]	86.63±1.82[a]	
Handling room					
If order of tools and materials exists		3.11±4.92[c]	18.18±4.42[b]	78.71±2.30[a]	
Number of meat pieces exposed at one time		5.20±4.85[c]	17.32±4.52[b]	77.48±2.36[a]	
Equipment					
Cleanliness			4.46±4.87[b]	95.54±1.05[a]	
Service area					
Cleanliness		0.50±4.99[b]	5.44±4.84[b]	94.06±1.21[a]	
Self-service area					
Cleanliness	0.50±4.99[c]	5.20±4.85[c]	14.10±4.61[b]	79.70±2.24[a]	0.50±4.99[c]
Working of cold displays	7.93±4.77[b]	22.52±4.38[a]	29.70±4.17[a]	29.70±4.17[a]	10.15±4.72[b]

Means in the same row with at least one literal in common are not different (P < 0.0001).

Consequently, prerequisites for all activities related to hygiene and sanitation in meat retail centers must be closely monitored, verified and validated to obtain results that meet the standard and are valid in the long term (8). Furthermore, Santos et al. (19) confirm that food handlers must maintain a high level of personal hygiene and intrinsically safety-related behavior. Therefore, to achieve the competencies required by staff, they need knowledge and updates related to food safety, for which the educational level must be accompanied by instruments of proven validity and accuracy (20).

Regarding the results of the individual analyses of the four retail supermarkets of fresh meat products on the hygienic-sanitary parameters, the four categories involved are detailed in Table 2. Firstly, in all four supermarkets, the parameters related to management aspects and related activities in the handling room, equipment conditions, and those prevailing in the service area recorded good management and condition status. On this issue, Nyamakwere et al. (21) argue that typified areas as the most susceptible to contamination and spread of pathogens are the handling room, which is characterized by intensive handling tasks.

The main recommendations to retail outlets are to point out as fundamental activities those related to the prevailing hygiene in the handling room, as well as the cleanliness of equipment, floors, walls, and ceilings structured with appropriate materials, operability in the control of the cold chain and the strategic use of the necessary utensils to handle the products. In an Ethiopian study, 85% reports using appropriate clothing when handling produce, 91% washed their hands at least once before handling produce, 88% used soap when washing their hands, and only 14% received training (22). Nee and Sani (23) also indicate that a high level of personal cleanliness with clean and appropriate protective clothing and protective equipment for employees in food handling areas is critical to ensure food safety.

In terms of the results of this study (Table 2), supermarket S2 was the only one that recorded better cold chain management in the meat self-service areas. Nevertheless, most worrying results were recorded in S1 (89.11%), S3 (25.79%) and S4 (6.93%), in which poor cold chain management was observed in the racks containing meat to be pick-up for sale. In addition, supermarket S3 recorded (21.79%) deficient hygiene where meat products were placed, mainly with fluids from the meat, which were a suitable medium for bacterial growth (24,25).

Table 2. Specific distribution (%) of ranks of cleanliness and hygiene practices recorded in four meat areas of four Mexican retail outlets.

Supermarket	Handling room		Equipment	Service area	Self-service area		*Hygienic-sanitary parameters
	IO	NM	CL	CL	CL	WCH	
S1						21.78±8.80^{b}	1
		1.98±9.85^{b}				67.33±5.69^{a}	2
	7.92±9.55^{b}	12.87±9.29^{b}	0.99±9.9^{b}	3.96±9.75^{b}	1.98±9.85^{b}	9.90±9.44^{c}	3
	92.08±2.80^{a}	85.15±3.83^{a}	99.01±0.99^{a}	96.04±1.98^{a}	98.02±1.40^{a}		4
						0.99±9.90^{c}	5
S2							1
	2.97±9.80^{c}	11.88±9.34^{b}					2
	27.72±8.46^{b}	28.71±8.40^{b}	4.95±9.70^{b}	1.98±9.85^{b}	0.99±9.90^{b}	21.78±8.80^{b}	3
	69.31±5.51^{a}	59.41±6.34^{a}	95.05±2.21^{a}	98.02±1.40^{a}	99.01±0.99^{a}	61.39±6.18^{a}	4
						16.83±9.07^{b}	5
S3					1.99±9.85^{c}	8.91±9.50^{bc}	1
	6.93±9.60^{c}	3.96±9.75^{c}		1.98±9.85^{b}	19.8b±8.91^{c}	16.83±9.07^{b}	2
	35.64±7.98^{b}	25.74±8.57^{b}	10.99±9.43^{b}	12.87±9.29^{b}	42.57±7.54^{a}	52.48±6.86^{a}	3
	57.43±6.49^{a}	70.30±5.42^{a}	89.11±3.28^{a}	85.15±3.83^{a}	33.66±8.10^{ab}	4.95±9.70^{c}	4
					1.98±9.85^{c}	16.83±9.07^{b}	5
S4						0.99±9.90^{c}	1
		2.97±9.80^{b}			0.99±9.90^{c}	5.94±9.65^{c}	2
	3.96 9.75^{b}	1.98±9.85^{b}	0.99±9.90^{b}	2.97±9.80^{b}	10.89±9.39^{b}	34.65±8.04^{b}	3
	96.04±1.98^{a}	95.05±2.21^{a}	99.01±0.99^{a}	97.03±1.71^{a}	88.12±3.43^{a}	52.48±6.67^{a}	4
						5.94±9.65^{c}	5

IO= if the order of tools and materials exists; NM= number of meat pieces exposed at one time; CL= cleanliness; WCH= working of cold displays. *Hygienic-sanitary parameters scores: 1= very bad; 2= bad; 3= moderate; 4= good; 5= very good. Different superscript letters in columns within supermarket indicated significant differences ($p<0.05$).

To guarantee the cold chain, it is essential to implement permanent improvements in temperature control devices in the refrigerated open displays of meat products (6). Enterprises in developing countries are obliged to sensitize their employees on the handling of refrigeration equipment to reduce the problems of microorganism growth in food (26). In addition, Lundén et al. (27) also indicate the need for close monitoring by food business operators and management of relevant factors closely related to food safety, such as cleanliness and temperature of refrigeration equipment. It is also appropriate to mention that most fresh foods are highly vulnerable, especially those of animal origin (28,29), which leads to microbial contamination and intoxication (30). Thus, promoting hygienic food handling practices and cold chain management are plausible and potentially compelling strategies to protect consumers from public health risks (31).

The categories linked to the activities referred to service area cleanliness and those fulfilled by the staff are detailed in Table 3. Initially, it may be specified that in supermarket S2, the employees handling food were found not to wear an adequate uniform or to wear it incompletely during working hours (50.5%) and to use it with moderate cleanliness (>80%). Jianu and Goleţ (32) suggested that the lack of proper protective clothing and failure to use gloves and disinfectants are typified as poor hygienic practices in meat handling areas, leading to food contamination and the spread of disease. Moreover, regarding cleaning of the service area in this study, in supermarket S3, it was identified that meat products remained out of the cold chain in this area for prolonged periods while waiting to be packaged for retail sale (61.4%), with poor cleaning in the same room sporadically (17.8%).

In contrast, supermarkets S1, S2, and S4 showed good cleanliness levels in the service areas. There are intrinsic and extrinsic factors that affect microbial growth (33); one factor in the latter group is temperature, which alters the shelf life of foods, representing one of the main problems for industry (34). As the cold chain is a temperature-controlled supply necessary for food safety, the correct application of temperature monitoring and management is required to maintain a sustainable and uninterrupted cold chain (35). The disruption in meat products reduces shelf life, quality and safety, causing microbial growth that leads to spoilage, loss of sensory and nutritional qualities, and increasing food wastage or food poisoning if consumed (36,37).

Another factor that influences the occurrence of temperature fluctuations is the storage arrangement of the foodstuff products, especially for those more susceptible to degradation (38). Therefore, for companies and governments, improving the quality supervision and management system of the cold chain logistics process is a significant concern (39). Consequently, when offering perishable products to consumers, it is imperative to apply temperature control and management by current regulations, thus ensuring the safety and quality of meat products for consumption to reduce legal conflicts (40).

Table 3. Specific distribution (%) of ranks of cleanliness and hygiene practices recorded in two meat areas of four Mexican retail outlets.

Supermarket	Service area cleanliness			Employee		*Hygienic-sanitary parameters
	CL	CCH	IU	C	CL	
S1						1
		0.99c±9.9^{c}	1.98±9.85^{c}			2
	5.94±9.65^{b}	19.80b±8.91^{b}	17.82±9.02^{b}	18.81±8.97^{b}	8.91±9.50^{b}	3
	94.06±2.43^{a}	79.21±4.54^{a}	74.26±5.05^{a}	81.19±4.32^{a}	91.09±2.97^{a}	4
			5.94±9.65^{bc}			5
S2			1.98±9.85^{b}			1
			48.51±7.14^{a}	3.96±9.75^{b}		2
	5.94±9.65^{b}	16.83±9.07^{b}	42.57±7.54^{a}	80.2±4.43^{a}	17.82±9.02^{b}	3
	93.07±2.62^{a}	81.19±4.32^{a}	6.94±9.60^{b}	15.84±9.13^{b}	82.18±4.20^{a}	4
	0.99±9.90^{b}	1.98±9.85^{b}				5
S3		0.99±9.90^{c}				1
	4.95±9.70^{b}	5.94±9.65^{c}	2.97±9.80^{c}			2
	12.87±9.29^{b}	55.45±6.64^{a}	40.59±7.67^{b}	34.65±8.04^{b}	14.85±9.18^{b}	3
	81.19±4.32^{a}	34.65±8.04^{b}	55.45±6.64^{a}	65.35±5.86^{a}	85.15±3.83^{a}	4
	0.99±9.90^{b}	2.97±9.80^{c}	0.99±9.90^{c}			5
S4			0.99±9.90^{c}			1
			4.95±9.70^{c}	0.99±9.90^{c}		2
	4.95±9.70^{b}	18.81±8.97^{b}	29.70±8.34^{b}	26.72±8.51^{b}	11.88±9.34^{b}	3
	93.07±2.62^{a}	75.25±4.95^{a}	62.38±6.10^{a}	72.29±5.24^{a}	88.12±3.43^{a}	4
	1.98±4.02^{b}	5.94±9.65^{b}	1.98±9.85^{c}			5

CL= cleanliness; CCH= products in cold chain; IU= if in uniform; C= condition of uniform. *Hygienic-sanitary parameters scores: 1= very bad; 2= bad; 3= moderate; 4= good; 5= very good. Different superscript letters in columns within supermarket indicated significant differences ($p<0.05$).

Besides, the main food contamination risks are associated with food management practices on the body of the staff, which are transferred to the food during processes in the preparation of meat products (41). For example, the Canadian Food Inspection Agency (42) recommendation focuses on scheduled training of food handlers to update and reinforce key concepts. Specially, meat products are associated with risks caused by biological agents. Similarly, Gutema et al. (43) point out poor hygienic practices lead to contamination and cross-contamination. They also indicate that it is indispensable to train staff in food safety and significantly improve hygienic practices to remedy the problems. In particular, training must emphasize that the origin of this type of food represents an essential pathway for transmitting pathogens to ready-to-eat food (44).

A preliminary study in Mexico (6) reported that among the hygienic-sanitary activities carried out in Mexican supermarkets in the management of ground meat, the cleanliness and condition of employee clothing, especially protective clothing, were reported as deficient activities that could be improved. A study by Odetokun et al. (5) indicate a low level of hygienic practices related to the sale of meat in retail outlets in Nigeria. Therefore, they showed that these purchasing centers must implement operating actions directly. There are also reports that meat handling training courses are urgently needed in two districts of Jammu and Kashmir, India, to improve the viability and safety of consumer protection systems in these regions. Furthermore, Santos et al. (19) confirm that food handlers must maintain a high level of personal hygiene and intrinsically safety-related behavior. Therefore, to achieve the competencies required by staff, they need knowledge and updates related to food safety, for which the educational level must be accompanied by instruments of proven validity and accuracy (20).

Food poisoning outbreaks include three fundamental factors linked to the knowledge level, attitude and practice of personnel involved in food management (45). Bello and Bello (46) suggested that the unsafety of meat could be linked to pathogenic bacteria implicated in different activities during food processing and sale. These operations are associated with poor hygiene of retail and processing staff, contaminated equipment in food handling, poor workplace hygiene, and contaminated materials in packaging. Problems associated with inadequate hygienic procedures can lead to reduced shelf life of food products and increased risks of illness due to the presence of pathogens (47). Oluwafemi et al. (9) confirmed that the involvement of government and private agents in the meat product production chain is indispensable for achieving quality at the point of sale. Their role is addressed in compliance with current regulations to ensure safe and quality meat for consumers. To this end, promoting hygienic practices in their employees is essential to implement and operate them in retail meat sales centers.

Consequently, the food safety of consumer products is essential at the retail point of sale (48). Studies highlight unfavorable scenarios in the hygiene conditions of food trade, particularly in developing countries, which are concerning and dangerous for consumers. They also expressed the multiple challenges for meat supply, as there is a discrepancy between the official standards of each country and what is relevant in each place where meat is produced, processed, and traded (49). Definitively, routine activities that are closely monitored, verified, and validated to achieve results that meet each country's regulations and are valid in the long term must be incorporated (8). Nowadays, retailers must be responsible for providing safe food to consumers (50), not least because foodborne disease outbreaks in developing countries have a hard impact on health and socio-economic development (51). Then, for this goal, a significant increase in investment is needed (52). Therefore, food processors and retailers must ensure food safety due to the increased demands of developing country markets. This is achieved through hygienic strategies applied during process management, using safety management systems for each type of food (53). For example, Okpala et al. (54) identified that consumers have recently increased their demands and expectations for safe animal products due to population growth and urbanization in developing countries. Nevertheless, the demand for safe food remains an issue of concern in developed countries. However, this demand is even more critical in developing countries, as production and processing conditions often lack the necessary hygienic requirements for a baseline (55).

CONCLUSIONS

The results firstly show that the series of operations carried out in the self-service areas, as well as in the service area of the meat products, fluctuate in temperature, which implies that they do not comply with the current Mexican regulations, that indicate keeping the meat products ≤4 °C, and at the same time, it is essential to improve the cleanliness in both areas mentioned significantly. Another relevant factor recorded relates to the employees, who require clear and precise instructions on using the work uniform and an appropriate design for the functions to be carried out in the handling of meat products. On this point in this study, some supermarkets also fail to comply with the same regulation. Therefore, it suggested to design staff training courses on good hygiene and manufacturing practices. At the same time, it is necessary to implement strategies for monitoring, recording, and maintaining the equipment responsible for refrigerating ready-to-sell meat products to avoid significant temperature fluctuations that impact the quality and safety of meat foodstuffs. Finally, the active participation of government authorities and companies in all these processes is also indispensable for ensuring the safety and quality of meat products in Mexican supermarkets.

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USE OF AI-ARTIFICIAL INTELLIGENCE

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6. ANÁLISIS MICROBIOLÓGICO DE CARNE DE RES EN SUPERMERCADOS MEXICANOS: DETERMINACIÓN DE MESÓFILOS AEROBIOS, COLIFORMES, *ESCHERICHIA COLI* Y *SALMONELLA*

Microbiological analysis of beef in Mexican supermarkets: Determination of aerobic mesophiles, coliforms, *Escherichia coli* and *Salmonella*

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Scientific article

Microbiology of beef in Mexican supermarkets: Analysis of aerobic mesophiles, coliforms, *Escherichia coli* and *Salmonella*

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Abstract

Foodborne illnesses cause millions of deaths worldwide. Mexican law establishes criteria that the food industry must apply to minimize outbreaks of disease caused by several pathogens. This study analyzed beet from different establishments to verify compliance with these regulations. Beef cuts were bought from randomly selected places of refrigerators from three supermarkets in Mexico. Aerobic mesophilic, total coliforms, *Escherichia coli*, and *Salmonella* loads were analyzed twice at 0, 3, 6, 9, and 12 d after 27 meat samples were bought. The three supermarkets evaluated showed at least one meat sample in which *Salmonella* spp. was detected. On the other hand, aerobic mesophilic bacterial load showed ranges of 4.90 to 6.55 Log_{10} CFU (colony-forming units). Furthermore, the total coliform count was detected between 1.60 and 3.25 Log_{10} of CFU/g of meat. Some samples were free of *E. coli*. However, most showed bacterial loads ranging from 28.9 to 94.7 CFU/g of meat. The results show that the samples analyzed comply with the guidelines of current Mexican regulations. However, further analysis is necessary to determine the serotypes present. All the microorganisms evaluated in the study were analyzed at different points during shelf-life post-purchase; as expected, the bacterial load increased during the following days. In compliance with Mexican regulations, evaluated supermarkets must improve their management practices to minimize the proliferation of microorganisms that can endanger consumers' health. Implementing strict monitoring tools is required to verify compliance with current regulations.

Keywords:

Meat

Bacteria

Food Safety

Salmonella

Escherichia coli

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Introduction

Determining the presence of microorganisms in foods is one objective that highlights food safety and security to safeguard global health, mainly when pathogens that endanger human welfare are detected [1]. Highly perishable foods require careful management to ensure quality and safety throughout the supply chain. Meat products that require skin removal, such as bovine, have a high risk of contamination with pathogenic and spoilage-associated microorganisms [2,3]. The meat is an essential source of nutrients not only for humans but also for a wide variety of microorganisms that can adapt perfectly due to the amount of water present in the meat and its physicochemical characteristics [4,5]. In addition to protein, complex B vitamins, minerals and amino acids can be found [6].

Food safety is affected by the transmission of microorganisms considered relevant disease-causing pathogens due to the presence of vegetative pathogens or their toxins in food consumed by animals and subsequently consumed by humans [7]. Inadequate handling and sanitation practices occur during the supply chain of meat products, resulting in bacterial growth [8], leading to food safety disruption [9]. Furthermore, it is important to consider that these products experience changes such as oxidation, which modify their pigmentation, flavor, texture and, therefore, reduce consumer acceptance [10]. The main routes of exposure for consumers to zoonotic bacteria are the consumption of meat, dairy products, and eggs, foods in which *Salmonella* spp. can be found, which is considered one of the primary zoonotic pathogens due to its toxins generated [7]. Consequently, numerous cases of foodborne illness are reported annually. *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella* spp. have been detected in fresh meat or ready-to-eat foods in the United States for over a decade [11].

The Centers for Disease Control and Prevention (CDC) [12] reported that outbreaks resolved during 2021 caused 2,047 illnesses. In the United States, approximately 128,000 people are annually hospitalized due to foodborne illness [13]. In the European Union, 5,763 outbreaks were reported during 2022 [14], while in Mexico, there were more than 23,000 cases of food poisoning caused by bacteria [15,16]. Although foodborne infections are familiar worldwide, regional incidences are variable [17].

With the variety of microorganisms that can contaminate food and the magnitude of annual disease outbreaks, food companies continue to face the challenge of delivering food free of pathogenic microorganisms. The meat industry mainly focuses on preventing contamination with Shiga toxin-producing *Escherichia coli* (STEC) and *Salmonella* [18]. This approach is due to the high number of reports of foodborne illnesses caused by these bacteria [12]. However, other problem microorganisms such as *Bacillus cereus*, *Brucella* spp., *Campylobacter* spp., *Clostridium botulinum*, *C. perfringens*, and STEC non-O157 are also considered [19]. Consequently, to minimize the risk of contamination of meat with pathogenic bacteria and food spoilage, it is required that the practices performed in slaughtering and meat processing are carried out with strict hygiene [5].

In Mexico, specific standards, NOM-194-SSA1-2004 and NOM-213-SSA1-2018, guarantee the quality and safety of meat products. Various establishments for food handling must adhere to these regulations [20,21].

Regarding food retail establishments, risk factors associated with foodborne illness are related to cooking and holding temperature, cross-contamination, hygiene practices, and suppliers [22]. Therefore, food management in the processing sector of food products, including those of animal origin, is indispensable to reduce contamination risks and avoid the spread of pathogens [23]. In addition, along with good hygiene practices and the handling of meat products, maintaining refrigeration temperatures under 4 °C is a primary tool in the food industry to maximize the shelf life of highly perishable foods. Good management practices ensure a supply chain for over 90 days [24].

The incidence of foodborne illness reveals a significant food safety problem in Mexico [15,16]. The objective of this study was to analyze beef sold by the leading commercial chains in the northwest region of the State of Mexico to detect whether the guidelines stipulated by current regulations on microbiological issues are met by the counting of colony-forming units (CFU) of aerobic mesophiles, *E. coli*, coliforms, and detection of *Salmonella*.

Materials and methods

Inclusion and exclusion criteria and sampling methods

Beef cuts marketed as brochette (Figure 7) were bought in three supermarkets' self-service refrigerators (open refrigerators) in the northeastern area of the State of Mexico, Mexico. On nine occasions among three months, samples of 320 g were randomly picked from the front, middle, and rear sections of each supermarket's refrigerator. Each sample was conserved at a controlled temperature (≤4 °C) for 12 d during the analysis procedures (once each sample was analyzed in its totality, the next was acquired and processed similarly). At the end, 27 samples were bought and analyzed.

Figure 1. Beef brochette.

Sample analysis

To avoid external contamination, all samples were processed in a laminar flow cabinet with a Bunsen burner. The aseptic environment was checked by pouring Plate Count Agar (BD Bioxon), letting it solidify with the Petri dishes open, and turning the laminar flow cabinet and burner on. Subsequently, the dishes were monitored to verify growth (no cultures were detected).

Samples were analyzed by duplicate at 0 (day of purchase), 3, 6, 9, and 12 d; 25 g of the meat sample was subsampled in a sterile container with 250 mL of peptone water at 0.1% (w/v) to be homogenized. From the homogenized suspension, 10 mL were disposed of in a sterile test tube for serial dilutions in peptone water at 0.1%. Aliquots of 1 mL were taken and spread homogeneously with a sterile Drigalski scraper in Petri dishes with Agar culture medium for standard methods (BD Bioxon) and incubated at 35 °C for 48 h. Plantings were done by duplicate. CFU counts were performed with a Quebec-type colony counter; calculations were made to obtain the CFU/g of aerobic mesophiles in meat.

To determine *Salmonella*, *E. coli*, and coliforms, 3M^{TM} Petrifilm® plates were used; the processing and reading of results were done according to the manufacturer's specifications.

Environmental temperature conditions

Daily data on minimal and maximum temperatures (TMIN and TMAX) were retrieved from Weather Spark's website (2024). Temperatures were registered, and the daily differential was calculated (DifT=Ti-T0).

Statistical analysis

Analysis was done using the Statistical Analysis System software [26].

Normality tests

The probability distributions of the variables were tested using Chi-square tests (Proc Univariate) to ensure that all continuous and binomial variables were approximated to a normalized distribution (when N≥230 observations).

Variance analysis (ANOVA)

Models 1 and 2 considered the effects of time, market, and position from meat sampled and the differential of TMIN and TMAX as autoregressive parametric covariables. Analysis was performed using general linear models and mixed procedures (Proc GLM and Mixed). Adjusted means (LsMeans instruction) were compared using the Last Minimal Difference (LSD=0.05) calculated from Standard Errors (SE).

Model (1)

$$\mathrm{Yijkl} = \mu + \mathrm{T(Rep)ij} + \mathrm{Mk} + \mathrm{Pl} + (\mathrm{M} * \mathrm{P})\mathrm{kl} + \varepsilon\mathrm{ijkl}$$

Model (2)

$$\mathrm{Yij} = \mu + \mathrm{Ti} + \mathrm{Cov}(\beta\mathrm{i} - \beta0) + \varepsilon\mathrm{ijkl}$$

Where: Y=Log_{10} (CFU of mesophiles, *E. coli*, Coliforms); T_i= effect of i-th sampling time; $T(Rep)_{ij}$= effect of i-th time into j-th run; M_k= effect of k-th market; P_l=effect of l-th refrigerator position; $(M*P)_{kl}$= interaction among M and P factors; Cov= DifTmin and DifTmax; ε_{ijkl}= random error.

Orthogonal polynomial analysis
Linear, quadratic, and cubic trends of microorganisms across time (d) (Proc Nlin) was done.
Correlations. Pearson's correlations (Proc Corr) were tested to relate the microorganism's growth with environmental variables.
Multiple linear regression models were obtained using the Stepwise method (Proc Reg), including variables with P<0.15 (Forward).
Validity of models. All models were discriminated through Mallow (Mallow's CP) and Akaike criteria (AIC), and determination coefficient (R^2) and adjusted (adj-R^2).

Results and discussion

Microorganisms across markets and refrigerators' positions
Table 10 shows the total microorganisms in meat sampled in different refrigerator positions of markets. Statistical analyses revealed bacterial loads ranged for 4.90 to 6.55, 4.97 to 5.54, and 5.40 to 5.62 Log_{10} CFU of aerobic mesophiles/g of meat from supermarkets 1, 2, and 3, respectively (**¡Error! No se encuentra el origen de la referencia.**). Although there were differences among the refrigerator positions where meat was placed across the markets (P<0.05), NOM-213-SSA1-2018 in Mexico does not contemplate mesophile load in raw products; this parameter is only evaluated for cooked meat products [20]. On the other hand, the European Union established a maximum limit of 5 log CFU/cm^2 in daily mean for minced meat or 3.7 Log_{10} for meat preparations. Thus, it is assumed that meat products with higher bacterial loads had deficient hygienic measures in slaughtering and subsequent processes [27]. Therefore, it is possible to mention that the meat evaluated in this study does not comply with this parameter.

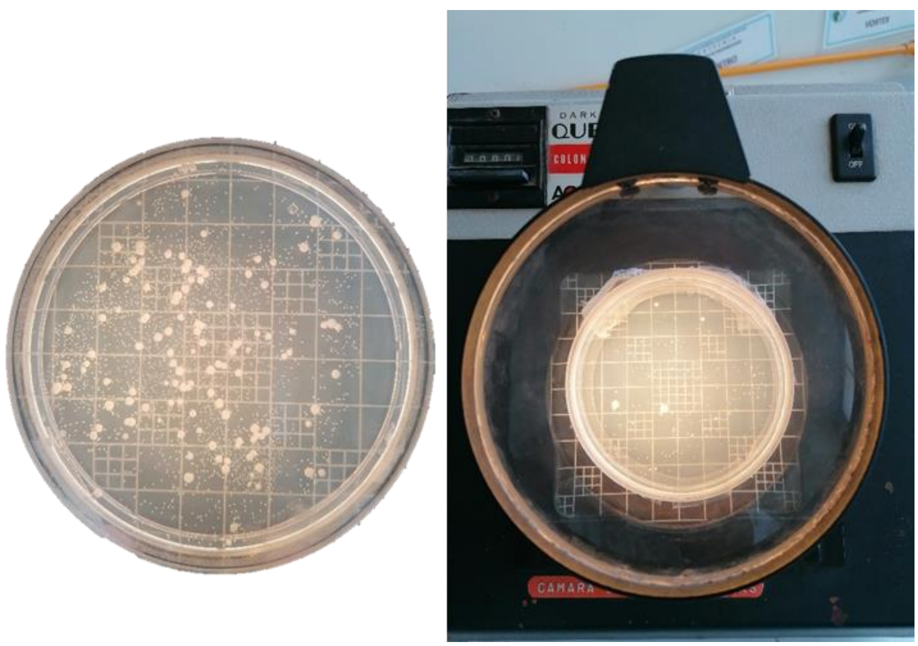

Figure 2. Aerobic mesophiles counting.

Regarding microorganisms of greater sanitary relevance, such as pathogenic bacteria, **Table 10** shows at least one meat sample in all supermarkets with *Salmonella* spp. placed at the bottom, medium, or front section of refrigerators was found (**¡Error! No se encuentra el origen de la referencia.**). This study's methodology to detect these bacteria is limited to the genus and does not differentiate the species or serotypes. However, only two species are considered to exist to date: *S. bongori* and *S. enterica*. Many serotypes have been identified; those of greater importance for their risk of animal to human transmission and cause infections are *S. enterica* serotype Enteriditis and *S. enterica* serotype Typhimurium, without mentioning those of lower risk for presenting less severe clinical symptoms [28,29]. Therefore, it is impossible to affirm that the analyzed meat contains bacteria in this study that can produce disease outbreaks. However, there is a high risk, and it does not comply with national regulations. Nonetheless, the isolates must be serotyped.

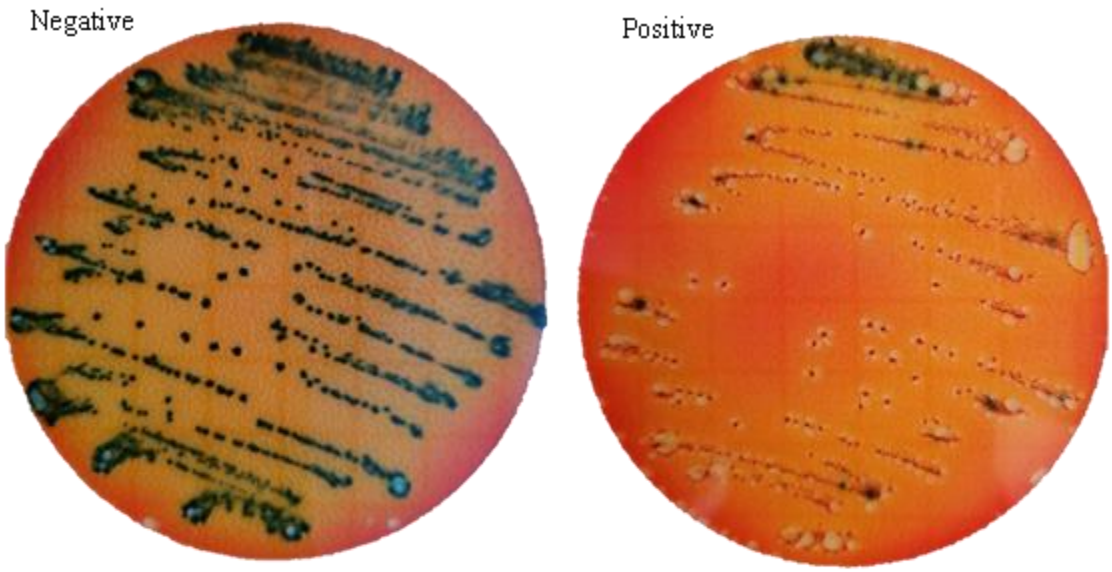

Figure 3. Petrifilms for *Salmonella* spp.

Safety and hygiene measures during food processing and distribution should be improved to reduce the contamination that has so far been confirmed. Heredia et al. [30] performed similar research in Mexico; they detected *Salmonella* spp. in 76% of the samples and determined that the microbiological quality of the ground meat analyzed was poor, which led to food poisoning. In another study conducted in Jalisco, Mexico, on the microbiological quality of ground meat in retail centers, they reported that *Salmonella* was present in 56.7% of the samples. They suggest that the contamination points may have been during the production and grinding process, along with poor hygiene, inappropriate temperature management, and cross-contamination during the mincing process [31].

Additionally, although some specific positions in the refrigerators were free from *E. coli*, most samples showed mean values from 28.9 to 94.7 CFU/g of meat (**Figure 10**). Petrifilms plates for the detection and quantification of *E. col*i and total coliforms have similar limitations as those for *Salmonella* mentioned above; it does not detect specific serotypes, such as O157:H7. These results show that all analyzed samples meet the permissible limits for *E. coli* of different standards [20,27]. However, it is only at the species level that supermarkets must maintain strict control of hygiene and cold chain to avoid the emergence of any *E. coli* risk to health by meat handling failures since open refrigerators often present problems in maintaining the proper temperature [32].

Supermarkets are reported to be one of the places where Mexican consumers buy ground beef. As a result, in a study conducted in Monterrey, Mexico, on the microbiological contamination level of this meat type, it was reported that 40% of the samples contained 10^6 total coliforms per g, which implies an unsatisfactory level of hygiene, representing a health risk. Subsequently, *E. coli* were reported in most of the samples [30]. These coliform concentrations differ widely from those found in the present study, so it is essential to determine why they vary greatly. A study conducted in Mexico (Culiacan, Sinaloa) showed positive results for *E. Coli* in meat but negative for the serotype O157:H7; additionally, the higher incidence was in summer. Consequently, it is recommended that good manufacturing practices be implemented, together with a rigorous sanitary control program [33]. Other studies also report positive results of *E. coli* O157:H7 in meat, with a higher incidence in spring and summer due to the prevalence of higher temperatures in these seasons, leading to microbial growth [22,34].

Microbiological quality assessment of different foods or beverages is often done by determining fecal indicator bacteria, including members of the Enterobacteriaceae family, mainly *E. coli*/coliforms (**Figure 10**), which can be an indicator of the level of hygiene in the different processes of the meat supply chain [35,36]. Consequently, coliform concentrations in this study ranging from 1.60 to 3.25 Log_{10}/g of meat can be observed in **Table 10**. The Mexican regulation does not establish a maximum limit for coliforms present in meat [20]. Nevertheless, some values found slightly exceed the 3 Log_{10} (1000 CFU/g of meat) limit established by USA standards [37,38]. Although coliform levels do not far exceed those standards, Mexico should consider including this parameter in its regulations to have greater hygiene control.

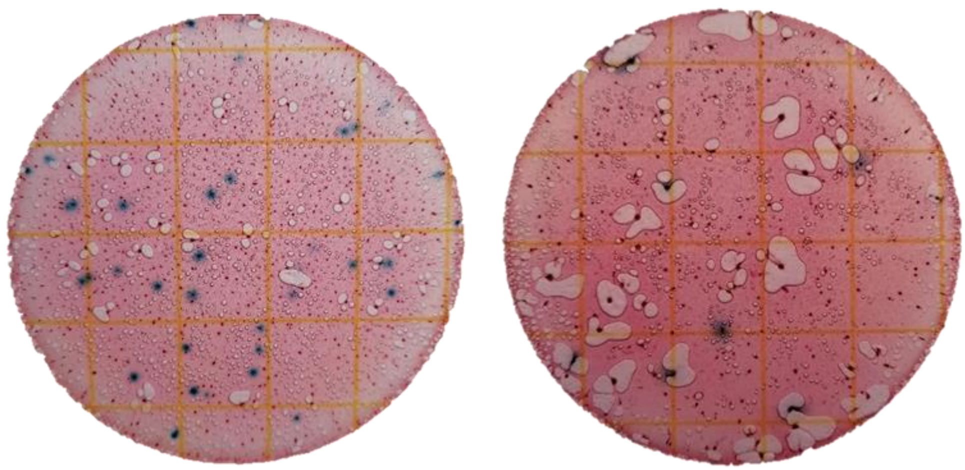

Figure 4. Red colony with gas = coliform, blue colony with gas = E. coli.

Table 1. Means of aerobic mesophiles, E. coli, coliforms, and Salmonella in meat sampled in different markets.

Market	Position	Aerobic mesophiles**	*E. Coli*^{2}	*Salmonella**	Coliforms**
1	Front	6.55^a	94.7^a	1.01^b	3.25^a
	Middle	5.58^b	63.9^a	1.01^b	2.57^{bc}
	Rear	4.90^c	0^c	1.39^a	2.38^c
2	Front	5.17^{bc}	37.0^{bc}	1.39^a	2.14^c
	Middle	4.97^c	0^c	1.39^a	1.60^d
	Rear	5.54^b	28.9^{bc}	1.01^b	2.20^c
3	Front	5.56^b	47.8^b	1.01^b	2.96^a
	Middle	5.62^b	49.7^b	1.01^b	2.71^b
	Rear	5.40^b	0^c	1.39^a	3.04^{ab}
			P-value		
Market		0.08	0.13	0.02	<0.0001
Position		0.05	0.005	0.02	0.0005

M*P		0.0009	0.05	<0.0001	0.006
SE.		0.35	27.1	0.09	0.21
LSD 0.05=		0.57	44.4	0.15	0.34

*****Values >1 are interpreted as at least one sample with *Salmonella*; M, market; P, position (place on the refrigerator); S.E., standard error; LSD, last significant difference. **Log_{10}CFU/g of meat. [2]CFU/g of meat

Microorganisms across time

Ranges from 2.97 to 7.05 Log_{10} CFU, 10.1 to 81.4 CFU, and 2.11 to 2.9 Log_{10} CFU were observed for mesophiles, *E. coli*, and coliforms, respectively (**Table 11. Means of aerobic mesophiles, E. coli, coliforms, and Salmonella in meat across the time after being on the marketTable**). All those variables varied across days after the meat was bought (P<0.002). Analysis on sixth d post-purchase revealed a reduction in microbial load, showing it is possible to attribute a higher count of microorganisms on purchase day to the fact that open refrigerators often have disruptions to the cold chain [39,40], microbial load reduction once the analysis has started could be explained by the efficiency of keeping the samples at the right temperature in the laboratory, demonstrating that the cold chain is the primary tool to limit bacterial growth [41].

The DifT minimum and maximum affected the mesophiles and *E. coli* (P<0.05). However, maximum temperature variations affected almost all variables (P<0.05). Aerobic mesophiles, *E. coli*, and Coliforms showed linear trends (P<0.03); moreover, they also had quadratic tendencies with an inflection point on third d (P<0.05), and *E. coli* that showed quadratic and cubic effects had inflection points 3 and 6 d after brought meat from markets (P<0.01).

Table 11. Means of aerobic mesophiles, *E. coli*, coliforms, and *Salmonella* in meat across the time after being on the market

Time (d)	**Aerobic mesophiles****	***E. coli* [2]**	***Salmonella****	**Coliforms****
0	2.97^{d}	48.0^{b}	1.15	2.11^{c}
3	5.65^{bc}	81.4^{a}	1.15	2.71^{b}
6	5.24^{c}	46.7^{b}	1.15	2.72^{b}
9	6.07^{b}	4.50^{c}	1.15	2.90^{a}
12	7.05^{a}	10.1^{c}	1.15	2.72^{b}
	P-value			
D[1]	<0.0001	0.001	0.9	0.001
Diff Tmin	<0.0001	0.05	0.9	0.85
Diff Tmax	0.0003	0.003	0.63	0.05
Trend Effects				
Linear	<0.0001	0.05	0.99	0.03
Quadratic	0.003	0.01	0.98	0.05
Cubic	0.99	0.001	0.99	0.63
SE	0.27	19.1	0.07	0.17
LSD 0.05=	0.44	31.5	0.12	0.28

[1]trends of microorganisms across time; *****Values >1 are interpreted as at least one sample with *Salmonella*; S.E., standard error; LSD, last significant difference. **Log_{10}CFU/g of meat. [2]CFU/g of meat.

Correlation and regression models

Table 13 shows the simple correlations. Aerobic mesophiles correlated with the total counting of microorganisms, *E. coli*, and Coliforms (r=0.4, 0.17, 0.27, respectively; P<0.009). Those variables also correlated with increasing environmental Tmin and Tmax across the time of storage and sampling (r=0.15 to 0.39; P<0.02).

Although *Salmonella* incidence negatively correlated with Coliforms (r=-0.17 and -0.26; P<0.008), it was not related to increasing minimum or maximum environmental temperatures across the time of storage and sampling. Similarly, Rangel-Vargas et al. [42] found no correlation between coliforms and *Salmonella*, neither between *E. coli* and *Salmonella* in alfalfa sprout samples, given that *Salmonella* was isolated in samples that were determined negative for *E. coli* in the same way as in bean samples [43].

Table 3. Pearson's simple correlations among microorganisms and environmental analyzed variables.

	E. coli	***Salmonella***	**Coliforms**	**Storage (1st d)**		**Storage (2nd d)**		**Sampling (3th d)**	
				Tmin	**Tmax**	**Tmin2**	**Tmax2**	**Tmin3**	**Tmax3**
Mesophiles	-0.03	0.25	0.27	0.31	0.39	0.23	0.39	0.33	0.33
P-value	NS	NS	0.009	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001
E. coli		-0.15	0.23	0.17	0.15	0.03	0.23	0.19	0.21
P-value		0.02	0.0004	0.01	0.02	NS	0.0004	0.003	0.001
Salmonella			-0.26	-0.04	0.11	0.14	0.06	-0.14	0.08
P-value			<0.0001	NS	NS	NS	NS	0.04	NS
Coliforms				0	0.24	0.31	0.22	0.07	0.24
P-value				NS	0.0002	<0.0001	0.0009	NS	0.0002

TMIN, temperature minimum; TMAX, temperature maximum

Perspectives and suggestions

Many pathogenic bacteria exist in food-producing animals [7]. Beef is easily contaminated along the production chain. Although contamination is variable among countries, proper cold storage might reduce the presence of pathogenic bacteria [44]. *E. coli* and *Salmonella*, among others, are the primary agents causing illnesses and deaths from food of animal origin. Their zoonotic occurrence affects the public health and economic sectors [7].

Infestations can vary widely for different reasons, mainly due to the level of hygiene during the supply chain. Saad et al. [45] recorded a *Salmonella* infestation rate of 8% in beef luncheons; in contrast, high infestation rates were reported by Elbayoumi et al. [46] at 27.5% and Hassanien et al. [47] at 26.67% in kofta samples.

According to Bugarel et al. [48], *Salmonella* is one of the leading agents recognized as causing diseases that significantly affect consumers. Transmission of salmonellosis can occur when feed and water are contaminated with *Salmonella* in feces [49], as well as poor hygienic conditions, storage temperature, equipment, and personal hygiene [50]. Additionally, the lack of control of critical points in the quality management of meat products leads to changes in organoleptic characteristics and a significant decrease in product quality [51], primarily due to the proliferation of pathogenic microorganisms leading to the outbreak of diseases [52]. There are worrying findings about the risks to consumers concerning the quality and safety of beef sold in retail involved in the production and distribution processes. In order to maintain the quality and safety of meat products, it is essential to manage the continuous training of food handling staff [53].

Factors that impact food safety and contribute to the emergence of foodborne illnesses include low compliance with good personal and equipment hygiene practices, interruption of the cold chain, and inadequate cooking. These factors are most prevalent in the later stages of the food chain, such as retail, which are particularly critical to ensuring food safety for the consumer [54]. Although some Mexican regulatory laws about counting and presence of microorganisms in the analyzed samples were not exceeded, some reported values may not be allowed in other countries, showing that it is essential to implement cold chain safety measures during handling and distribution, as well as to structure handling and packaging programs at the point of sale [55].

Conclusions

1. Regardless of the refrigerators' sampling places, all markets sampled in a region of Northeastern State of Mexico showed the counting and presence of *E. coli*, *Salmonella*, and Coliforms in bovine beef that might not be allowed in other Countries.

2. Across days, all variables showed linear effects, but *E. coli* and coliforms showed quadratic trends, with an inflection point 3 d after the meat was bought.
3. Aerobic mesophiles and *E. coli* were affected by environmental maximum temperature variations (differentials), mostly suggesting a poor of cold chain management.
4. *Salmonella* negatively correlated with aerobic mesophiles and coliforms. However, it was not related to increasing environmental minimum and maximum temperatures, suggesting good hygienic practices, disrupting the food cold chain, or contaminated equipment.

Author contributions

P.A.L. searched all the supporting bibliography for this article and initiated the writing of the article. The analysis and discussion of each topic oversaw all the authors: P.A.L., E.M.S., R.R.V., P.A.M.H., D.N.T.G., and L.A.S.J., and they also finally reviewed and approved the final paper.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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7. DISCUSIÓN GENERAL

La industria alimentaria constantemente ha buscado alternativas para maximizar la vida de anaquel de alimentos perecederos, al mismo tiempo que cumpla con las expectativas de calidad de los consumidores y sean seguros para el consumo. La revisión de literatura en este estudio indicó que en todos los eslabones de la cadena de frío se han presentado incrementos de temperatura por arriba del límite establecido. Por ello, a pesar de que la cadena de frío es la principal herramienta de este mercado, alternativas como cubiertas de acetato de polivinilo en limones, indican que es posible reducir la tasa de respiración y producción de etileno en limones sin presentar riesgos a la salud para el consumidor (Chinchkar et al., 2025).

En el mismo sentido, los productos cárnicos tienen mayor susceptibilidad a microorganismos patógenos, además de aquellos que promueven el deterioro. Entonces, un estudio recientemente demostró que la aplicación de emulsiones con extractos del alga *Furcellaria lumbricalis*, quitosano, aceites esenciales y péptidos bioactivos logró maximizar la vida útil de carne de cerdo más de 5 días al reducir el crecimiento de diversos microorganismos, siempre y cuando se mantengan en refrigeración de máximo 4 °C (Kulawik et al., 2025). Estas determinaciones se acoplan con los objetivos de diversas investigaciones recabadas en el presente estudio, la inocuidad alimentaria participa directa e indirectamente en la reducción de enfermedades, desperdicio de alimentos, economía e inclusive en la producción de gases de efecto invernadero.

Considerando entonces la importancia de la refrigeración de alimentos perecederos, se confirmó que al igual que sucede en diversos países y eslabones de la cadena de frío (Arriaga-Lorenzo et al., 2023), la venta de cárnicos al menudeo en la zona muestreada presenta serios problemas de gestión de la temperatura, destacando que las rupturas de la cadena de frío pueden ser influenciadas por la época del año, el centro de distribución y la posición en la que se encuentre el producto dentro del refrigerador. Estos fenómenos fueron similares a los encontrados por Baldera et al. (2016), quienes detectaron las rupturas durante el verano y en la posición superior del refrigerador, mientras que en el presente estudio fue el invierno y la posición frontal.

El aumento de la temperatura de la carne representa un importante riesgo a la salud humana, durante esta investigación se observaron temperaturas de más de 2 °C por arriba de lo que estable la normatividad mexicana (DOF, 2019), la sensibilidad de los posibles microorganismos presentes en los cárnicos les permite reproducirse y reducir la vida de anaquel con cada grado centígrado que aumenta; el riesgo a la salud del consumidor es latente al asumir la presencia de patógenos, por lo que el monitoreo y estricto control de la cadena de frío debe realizarse en todos los eslabones (Almonacid-Merino & Torres, 1993; Raab et al., 2011).

Analizando de forma visual las diferentes áreas de los centros de distribución considerados en esta investigación, fue evidente la deficiente gestión de la temperatura, pero para la limpieza en su mayoría si se encontró en buenas condiciones. No obstante, la inocuidad y calidad de los alimentos no depende de sólo un factor, es necesario poner atención en los puntos débiles encontrados, como lo es aumentar el uso de ropa en condiciones adecuadas. Trabajar bajo condiciones inadecuadas vulnera considerablemente la inocuidad de los alimentos (Umoh & Mosimabale, 2002). El personal que manipula alimentos requiere ser consciente de la importancia de realizar sus labores con la mayor higiene posible (Santos et al., 2017), en especial en las áreas de manipulación directa como las salas de despacho, donde existe mayor riesgo de contaminación de los alimentos (Nyamakwere et al., 2017), en las cuales se detectaron malas prácticas en algunos de los sitios muestreados.

La contaminación de los cárnicos además de las salas de despacho puede ocurrir en diferentes eslabones de la cadena, y la diversidad de microorganismos que pueden colonizar es amplia. Aquellos de interés zoonótico se esparcen principalmente por la leche, carne, huevo, etc., e incluyen a *Salmonella* spp., *E. coli* O157:H7, *Listeria monocytogenes*, y se detectan brotes con mayor frecuencia

(Abebe et al., 2020; Sofos, 2008). Sin embargo, existe el riesgo de contaminación con *Bacillus cereus*, *Brucella* spp., *Clostridium botulinum*, *C. perfringens* y otros (Scallan et al., 2011).

Muestras de carne de res que fueron analizadas en este estudio, revelaron cargas bacterianas de 4.90 a 6.55 Log_{10} CFU de mesófilos aerobios, y aunque la normatividad mexicana (DOF, 2019) no determina un límite máximo para estos microorganismos, en la Unión Europea si se considera como un aspecto para determinar en nivel de higiene de la carne (Official Journal of the European Union, 2005), por lo que en México existe la posibilidad que se estén comercializando productos con mayor riesgo a la salud que en otros países.

Microorganismos que sí se consideran en la normatividad mexicana y que se evaluaron en este estudio son *E. coli* y *Salmonella*; esta última fue encontrada en todos los supermercados evaluados, pero no en todas las muestras. Un aspecto importante para mencionar es que no se detectó a nivel de especie. No obstante, la normatividad no especifica presencia de especies, además de que muy pocas especies de este género se han descrito, por lo que el riesgo está presente (Wang et al., 2024). México requiere mejorar sus prácticas de manejo, debido a que en distintos puntos se han realizado detecciones de esta bacteria en alimentos, presentado un riesgo a la salud de la población (Cabrera-Diaz et al., 2013; Heredia et al., 2001).

Por otro lado, México establece un límite máximo para el coliforme *E. coli*, mismo que todas las muestras analizadas no rebasaron. Sin embargo, también se dictamina que no debe haber presencia de *E. coli* O157:H7; la metodología utilizada en este estudio no permitió identificar hasta el nivel serotipo, por lo que estudios posteriores se requieren para aclarar esa interrogante. Variaciones en la concentración de *E. coli* en carne han sido encontradas en México, aunque en otro estudio no se detectó la presencia del serotipo O157:H7, pero sí detectaron la relación de mayor carga bacteriana con el aumento de la temperatura, lo que sugiere la necesidad de mejorar los sistemas de refrigeración o monitoreo (Jiménez et al., 2012).

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8. APÉNDICE

A continuación, se presentan los resultados obtenidos de las actividades de retribución social realizadas durante el doctorado.

Article

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English version

Relevance of cold chain for meat products focusing on pork meat

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Abstract

Cold chain systems, as well as food safety and quality management systems, constitute tools used to prolong the shelf life of perishable products. Refrigerated storage conditions avoid development of pathogenic bacteria and other microorganisms that are associated with meat spoilage. This study aimed to determine cold chain management of fresh pork meat in four supermarkets located in Texcoco de Mora, Mexico. The surface temperature of the product located in different positions inside the self-service refrigerators of the supermarkets was recorded. A mixed model with repeated measurements over time and a completely randomized experimental design was used to analyze data. Results indicated that three of the four supermarkets that were evaluated exceeded the limits of temperature established by the Mexican regulation NOM-213-SSA1-2018. Low efficiency of refrigeration equipment and poor implementation of good management practices by the operator can be related to these temperature abuses. Non-compliant supermarkets are not able to ensure the quality of their products, essentially in terms of food safety.

Keywords: Bacteria, food safety, quality, spoilage, temperature.

Introduction

Perishable products, such as fruits, vegetables, and meat products, have a relatively short shelf life if there are not properly handled and stored. The conditions prevailing during these stages are determinant on the type of microorganisms responsible for product spoilage (Koutsoumanis and Sofos, 2004). According to FAO and WHO (2003), the main outbreaks of foodborne diseases are mainly related to pathogenic microorganisms. Storage temperature is considered as the main factor affecting safety and quality in meat products, because it prevents bacterial growth and, therefore, sensory characteristics associated with spoilage (Casaburi, et al., 2015; Mercier, et al., 2017).

Controlling temperature, keeping it within the appropriate range for each product from processing to consumption, is the basis of the cold chain (Mercier et al., 2017; Taoukis et al., 2016). Bacterial growth dynamics are subject to the temperature range required for optimal growth. Thus, some species have the ability to reproduce even under refrigerated conditions, as is the case of some strains of *Pseudomonas*, becoming one of the main groups responsible for meat spoilage under these storage conditions (Rawat, 2015).

NOM-213-SSA1-2018 establishes that meat products with a moisture content greater than 35% must be kept at a temperature lower than 4 °C. Retail distribution centers are considered a critical control point in many cold chain

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management systems, because the displays in these types of establishments generally have low efficiency in maintaining the proper temperature. This promotes temperature abuses at the recommended limit, which, in turn, generates product weight losses, decreased quality and shelf life (James and James, 2014; Mercier et al., 2017). Therefore, the objective of this research was to determine the cold chain management in fresh pork meat in four supermarkets in Texcoco de Mora, Mexico.

Materials and Methods

Temperature measurements

A total of 288 temperature records of fresh pork meat located in the self-service refrigerators of four supermarkets in the city of Texcoco de Mora, Mexico, were taken on Sundays from July to December 2021. Twelve measurements were taken each month, per supermarket, each one measured on the surface of the pork packaging, whose locations inside the refrigeration equipment were front, middle, and rear. Temperature was measured using an infrared thermometer (MASIONE GM320).

Data analysis

Mean differences between refrigerator positions were aggregated using the Student's t-test. The average temperature was determined and compared to the temperature requirement for meat products stipulated in NOM-213-SSA1-2018.

Results and Discussion

Monthly temperatures for the front, middle and rear positions are shown in Tables 1, 2 and 3, respectively. Mean temperatures were compared with the NOM-213-SSA1-2018 standard, which indicates that fresh meat products should be kept at a storage temperature no higher than 4 °C.

Table 1 corresponds to the frontal position. Mean monthly temperature reports indicate that, of the supermarkets analyzed, supermarkets 1, 3 and 4 failed to maintain the cold chain, since in all three cases the temperature was found to be higher than 4 °C. Supermarket 2 was the only one that had a lower risk level, because, although it was found outside the permitted range, its temperature was very close to that specified in NOM-213-SSA1-2018, and lower compared to the other supermarkets ($P < 0.05$), especially with the one identified as 1, which was found to be 5 °C above the established requirement.

As for the middle position (Table 2), temperatures of supermarkets 2 and 4 indicated they met the standard properly. Even when there were no statistically significant differences between supermarkets 2, 3 and 4 ($P > 0.05$), the mean of supermarket 3 was 0.18 °C above the allowed temperature level because, for three of the six months sampled, it was at least 1 °C above the reference document. However, its risk level was lower than that of supermarket 1, because its average was almost 6 °C above the maximum allowed.

Finally, Table 3, corresponding to the rear position, shows that, according to the mean of the supermarkets per month, most of the establishments evaluated correctly maintained the cold chain, because they maintained the temperature specified in the standard. However, according to the mean temperature of supermarket 1, it showed the highest temperature ($P < 0.05$), compared to the other supermarkets, because it was outside the range, with 1.39 °C above the permitted limit. Temperature was only maintained within the required range in the month of September.

Table 1. Monthly surface temperature (°C) of pork meat exposed in the front position of four supermarkets in Texcoco de Mora, Mexico, from July to December 2021.

Supermarket	Month						Mean
	July	August	September	October	November	December	
1	10.65± 0.58	8.78± 1.05	7.9± 1.21	10.04± 1.04	9.83± 0.90	9.53±1.19	9.45 a
2	2.88± 0.86	4.02± 0.41	4.28± 1.39	4.24± 0.38	4.73± 0.28	4.4± 0.35	4.08 b
3	7.68± 1.42	5.02± 2.18	7.83± 1.46	7.64± 1.44	8.75± 0.95	3.03± 1.14	6.65 c
4	5.60± 1.22	6.52± 1.34	4.30± 1.83	4.56± 0.76	5.43± 0.60	5.60± 1.72	5.33 bc
Mean	6.70	6.08	6.07	6.62	7.18	5.64	

Means with at least one letter in common are not statistically different ($P < 0.05$)

Table 2. Monthly pork surface temperature (°C) placed in the average position of four supermarkets in Texcoco de Mora, Mexico, from July to December 2021.

Supermarket	Month						Mean
	July	August	September	October	November	December	
1	11.23± 0.69	9.84± 0.79	8.25± 1.11	10.36± 1.30	9.75± 0.33	10.13± 1.14	9.93 a
2	1.43± 1.79	2.76+ 0.91	4.22± 1.11	2.84± 0.66	2.3± 1.51	3.10± 0.98	2.78 b
3	3.38± 2.66	2.98± 1.07	5.55± 1.68	5.12± 1.30	5.33± 0.93	2.75± 0.49	4.18 b
4	0.88± 2.28	2.28± 1.92	3.45± 1.97	1.96± 1.53	2.53± 2.14	4.65± 1.77	2.62 b
Mean	4.23	4.47	5.37	5.07	4.98	5.16	

Means with at least one letter in common are not statistically different ($P < 0.05$)

Table 3. Monthly temperature (°C) of the pork surface exposed in the back position of four supermarkets in Texcoco de Mora, Mexico, from July to December 2021.

Supermarket	Month						Mean
	July	August	September	October	November	December	
1	6.48± 0.82	4.70± 0.94	3.48± 1.13	6.0± 1.08	5.65± 0.76	6.05± 1.25	5.39 a
2	-0.03± 1.8	0.86± 1.11	0.80± 0.95	1.70± 0.85	0.38± 1.48	1.73± 1.04	0.91 b
3	-1.90± 2.18	-0.88± 0.98	0.30± 1.39	0.50± 0.65	0.55± 0.79	-1.13± 0.89	-0.43 b
4	-0.68± 1.26	0.22± 1.11	1.25± 1.86	1.26± 1.08	1.95± 0.47	0.35± 2.21	0.73 b
Mean	0.97	1.23	1.46	2.37	2.13	1.75	

Means with at least one letter in common are not statistically different ($P < 0.05$)

Similar results from this research have been reported in other studies regarding retail establishments selling perishable products, which correspond to one of the weakest elements in the cold chain. This is because the refrigerators where the products are exhibited are generally not the most efficient to preserve them, allowing temperature abuses over the recommended limit (Mercier et al., 2017; Nychas, Skandamis, et al., 2008). Authors from different countries have also confirmed this. Derens-Bertheau, et al., (2015), Morelli, et al., (2012) and Villeneuve, et al., (2002) conducted different studies in France, reporting that position, shape, and size of the product influence temperature variation in retail stores, with abuses of up to 6 °C above the established limit. In these studies, variations have been associated with the efficiency of refrigerators and handling by store employees. On the other hand, Likar and Jevšnik (2006), in Slovenia, noted that in retail establishments, greater preference is given to the appearance of the product over the processes that ensure its quality, emphasizing hygiene and management of the cold chain.

The position of products inside the refrigerator has been the subject of study due to its impact on product temperature differences. Baldera Zubeldia, et al., (2016) obtained similar data to the present research after analyzing the temperature of fresh meat during winter and summer in different supermarkets in Andalusia, Spain. The authors found that the season of the year and the position inside the refrigerator are highly related to temperature abuses and that 38.5 % of the analyzed sites did not meet the requirements in the "top" position during summer, while in winter it decreased to 16.7 %. Meanwhile, the "lower" and "middle" positions had smaller deviations.

These studies have highlighted that the front position is the one that shows the greatest deviation from the adequate range. These data coincide with the results obtained in the front position of this research (Table 1), where three of the four supermarkets analyzed were above the established limit. On the other hand, the middle and rear positions also showed deviations, although of smaller proportion than the front position.

Morelli et al. (2012) associated the relationship of temperature variation to type and use of the refrigerator and to the handling practices carried out by workers directly on the product. In the present investigation, the refrigerators analyzed corresponded to the "open display" or "multi-story cooling cabinet" type, which are in contact with the environment next to the refrigerator. Hundy, et al. (2016) highlighted that this type of refrigerators are based on an air curtain that maintains the products at a temperature determined by the operator. However, even with good management, they are not the most efficient, because they tend to have deviations due to temperature gains from the environment.

Temperature abuses have several implications on perishable products, mainly on their quality. According to Yang, et al. (2021), the increase in temperature favors the degradation of muscle proteins, decreasing water retention capacity and, consequently, increasing fluid loss. Huff-Lonergan (2009) indicated that this phenomenon is particularly important because it modifies the visual acceptance by the consumer and reduces the nutritional quality of the product, since water, iron and proteins are lost in this liquid, mainly associated with the color of the meat.

On the other hand, Nychas et al. (2008) indicated that temperature abuses contribute to spoilage by microorganisms. Studies by Bruckner, et al. (2012), Koutsoumanis, et al. (2006) and Tang et al. (2013) agreed that storage temperature variations greater than 4 °C considerably decrease the shelf life of products, due to increased bacterial growth. These studies highlighted that, under these conditions, *Pseudomonas* is the main bacteria that dominates over *Brochothrix thermosphata*, lactic acid bacteria and *Enterobacteriaceae*. According to Casaburi et al. (2015) different species of the genus *Pseudomonas* produce a wide range of volatile organic compounds (VOCs), associated with the characteristic odor of spoiled meat, which in turn lead to the rejection of the product by the consumer.

The presence of pathogenic bacteria associated with foodborne illnesses can also occur following temperature abuses. Maintaining the cold chain reduces biological risks by these bacteria; however, it is essential to use a preventive approach by properly implementing good hygienic and distribution practices (Betic, et al., 2019). According to Raab, et al. (2011), staff training on issues related to quality and safety of perishable products is essential. In addition, temperature management, monitoring and control is equally relevant, using alternatives that facilitate its implementation, for example, the use of temperature indicators over time, or wireless technologies or the radio frequency identification system (RFID). Michael and McCathie (2005) reported that the use of the RFID system contributes to greater efficiency in temperature, bacterial growth, and quality monitoring processes. Furthermore, this system assures the use or consumption of products before the end of their shelf life.

Conclusions

The four supermarkets evaluated must correctly manage their cold chain, because they are not fulfilling the terms established by NOM-213-SSA1-2018, specifically in the section corresponding to storage conditions. These supermarkets showed temperature abuses during the commercialization of fresh pork, showing that the rear area of the refrigerator is the safest in terms of maintaining the temperature within the appropriate range. It is suggested to continue the research with the objective of determining causes and possible corrective actions for these temperature abuses that occur in these meat retail centers.

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UNIVERSIDAD AUTÓNOMA CHAPINGO

DEPARTAMENTO DE ZOOTECNIA

POSGRADO EN PRODUCCIÓN ANIMAL

Doctorado en Ciencias en Innovación Ganadera

Taller de capacitación en Buenas Prácticas de Higiene

Chapingo, Estado de México, 2024

UNIVERSIDAD AUTÓNOMA CHAPINGO

DEPARTAMENTO DE ZOOTECNIA

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Chapingo, Estado de México, 2024

CONTENIDO

1. ÁMBITO DE APLICACIÓN

- Este documento proporciona conocimientos al personal que participa en la producción de alimentos y al público en general.
- La información del manual apoya en la producción de alimentos para que no causen daño al consumidor.
- Las prácticas y controles de higiene son necesarias durante todas las etapas de producción de los alimentos.

2. INTRODUCCIÓN

Este manual contiene la información necesaria que requieren las personas dedicadas a la producción de alimentos en general. Es indispensable que este grupo ponga en práctica las acciones propuestas en este folleto para garantizar que los alimentos en venta sean seguros para los consumidores.

Uno de los principales problemas de salud pública son las enfermedades transmitidas por alimentos. Para evitar la contaminación de alimentos deben aplicarse medidas sencillas de forma higiénica por parte de los empleados. En este manual se proporciona el conocimiento necesario que se deben aplicar durante la preparación de alimentos. Para ello, se discute información base en la inocuidad de los alimentos, con conceptos generales y prácticos.

3. OBJETIVO

Este manual está diseñado para personal que maneja alimentos y tiene como objetivo proporcionar herramientas necesarias y con principios básicos de las buenas prácticas de higiene.

4. DEFINICIONES

- **Autoridad competente**: Organismo oficial del gobierno que aplica leyes de inocuidad en los alimentos, y organiza controles oficiales.
- **Contaminante:** Cualquier agente biológico, químico o físico, materia extraña u otras sustancias no añadidas intencionalmente a los alimentos que puedan afectar la inocuidad de los alimentos.
- **Contaminación**: Introducción o presencia de un contaminante en un alimento o en el entorno alimentario
- **Inocuidad:** Garantía de que los alimentos no causarán efectos dañinos a la salud del consumidor.
- **Desinfección**: Reducción de la cantidad de microorganismos vivos en las superficies, agua o aire a niveles que no afecten la inocuidad de un alimento.
- **Limpieza**: Eliminación de tierra, residuos de alimentos, suciedad, grasa u otros materiales que deben ser retirados antes de realizar la desinfección.
- **Contaminación cruzada:** Transferencia de contaminantes de un alimento contaminado, a otro que no tiene ninguno.
- **Desinfectar:** Eliminación de contaminantes no visible de las superficies al usar productos químicos desinfectantes, agua caliente, vapor.
  Superficie de contacto: Todo lo que está en contacto con productos alimenticios, incluyendo equipos, utensilios, manos del personal durante su manejo.

Evidencia del taller impartido a estudiantes de la Universidad Autónoma Chapingo

Trabajadores de supermercados del área de Texcoco de Mora, México.


Universidad Autónoma Chapingo
Posgrado en Producción Animal
Taller de capacitación en
Buenas Prácticas de Higiene

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Posgrado en Producción Animal

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Ema Maldonado Simán
Pedro Arriaga Lorenzo

1. ÁMBITO DE APLICACIÓN

- ✓ El documento proporciona conocimientos al personal que participa en la producción de alimentos y al público en general.
- ✓ La información apoya en la producción de alimentos para que no causen daño al consumidor.
- ✓ Las prácticas y controles de higiene son necesarias durante todas las etapas de producción de los alimentos.

2. Introducción

1. Los manipuladores de alimentos requieren de información.
2. Realizar acciones de mejora para garantizar que los alimentos en venta sean seguros para los consumidores.

Fuente: 1- Mapfre. (2023). ¿Cómo evitar el Contagio en la Manipulación y Preparación de Alimentos?
2- CSA seguridad alimentaria. (2024). Buenas prácticas para la manipulación de alimentos.

Cinco síntomas severos causados por alimentos contaminados

Fuente: Arlington virginia. 2024. Foodborne Illness (Food Poisoning)

Aplicar medidas higiénicas

Fuente: Unilever Food Solutions. (2024). Personal Hygiene Kitchen Safety Tips.

3. OBJETIVO

- Discutir este manual de buenas prácticas de higiene diseñado para personal que maneja alimentos con:
  - Herramientas necesarias
  - Principios esenciales de las buenas prácticas de higiene
  - Importancia del trabajo del personal

4. Definiciones

1. **Autoridad competente**: Organismo oficial del gobierno que aplica leyes de inocuidad en los alimentos, y organiza controles oficiales.

2. **Inocuidad**: Garantía de que los alimentos no causarán efectos dañinos a la salud del consumidor.

Fuente: 1-Food manufacturing. (2024). FDA, Mexican Counterparts Advance Food Safety Partnership.
2- Encolombia. (2023). Contaminación de los Alimentos y sus Efectos

4. Definiciones

3. **Contaminante**: Peligro por agente biológico, químico o físico, materia extraña u otras sustancias no añadidas intencionalmente a los alimentos.

4. **Contaminación**: Introducción o presencia de un contaminante en un alimento o en el entorno alimentario.

Fuente: 3. Printerest. (2021). Tipos de Contaminantes de Alimentos.
4. Milgar-limpieza profesional. (2022). Contaminación Alimentos!!

4. Definiciones

5. **Desinfección**: Reducción de la cantidad de microorganismos vivos en las superficies, agua, aire o alimentos.

6. **Limpieza**: Eliminación de tierra, residuos de alimentos, suciedad, grasa u otros materiales que deben ser retirados antes de realizar la desinfección.

Fuente: 5- Milgar-limpieza profesional. (2022). ¿Qué es desinfección?
6 -Vikan. (2024). Cleaning equipment and its importance in the control of Listeria in food production.

4. Definiciones

7. **Contaminación cruzada:** Transfencia de contaminantes de un alimento a otro, que no lo está.

8. **Superficie de contacto:** Todo lo que está en contacto con productos alimenticios, incluyendo equipos, utensilios, manos del personal.

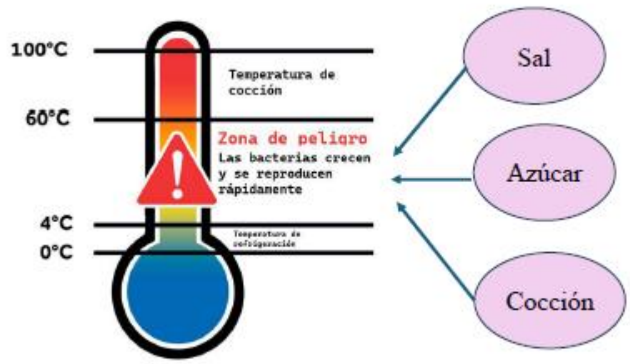
Fuente: 7. Hule & Mantel. (2023). 5 trucos para evitar la contaminación cruzada en las comidas y cenas de Navidad.
8. Kiilto. (2024). Clean and disinfect food contact surfaces in one step - Kiilto Pro Alco-Free WipeDes

5. PELIGROS DE LOS ALIMENTOS

Limitan el crecimiento

a. Peligros biológicos

- Bacterias
- Levaduras
- Hongos
- Virus y parásitos



Fuente: Diccionario gastronómico. (2024). Zona de peligro de los alimentos.

PELIGROS DE ALIMENTOS

¿Cómo llegan microbios a los establecimientos de alimentos?

- Alimentos crudos
- Manipuladores de alimentos (manos, delantales, accesorios)
- Plagas (insectos, ratas, etc.)
- Aire
- Polvo
- Agua

1

2

Fuente: 1-Farmacia J. Lavernia-Salelles. (2023) Peligros Biológicos de los Alimentos .
2- Business Insider. (2022). Nunca te comas un huevo con clara roja: este es el grave riesgo que implica para la salud.

PELIGROS DE ALIMENTOS

Microorganismos

- No se pueden ver
- No se pueden oler
- No se pueden probar

Fuente: MicrobiologyClass.net. (2023). Food spoilage.

ALTO RIESGO	BAJO RIESGO
Alimentos cocidos consumidos en frío o recalentados	Sopas y caldos
Carnes, pescados y mariscos crudos.	Carnes cocidas a la parrilla que se consumen de inmediato
Carnes molidas o en picadillo.	Alimentos fritos que se consumen de inmediato.
Leche y productos lácteos sin pasteurizar.	Alimentos secos, salados, con ácido natural o añadido, o preservados con azúcar.
Flanes y postres con leche y huevo.	Nueces, almendras, avellanas. Almacenados adecuadamente.
Cremas chantillí, pasteleras y otras salsas y cremas.	Panes, galletitas dulces o saladas.
Huevos y alimentos con huevo.	Manteca, margarina o aceites comestibles.
Cereales y legumbres cocidas como por ejemplo arroz, lentejas.	Cereales secos.
Melones cortados y otras frutas poco ácidas mantenidos a temperatura ambiente.	Alimentos enlatados cerrados.
Aderezos para ensaladas con huevo.	
Aderezos con caldos de carne.	
Pastas cocidas.	
Papas horneadas, hervidas o fritas mantenidas a temperatura de riesgo	

Fuente: Food Organización Mundial de la Salud (OMS). (2017). Manual para manipuladores de alimentos.

PELIGROS DE LOS ALIMENTOS

b. Peligros químicos

- Residuos de productos químicos
- Errores en almacenamiento
- Mala ejecución en la desinfección

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

PELIGROS DE LOS ALIMENTOS

c. Peligros físicos

Objetos extraños:
- Trozos de vidrio
- Madera
- Trozos de hueso
- Semillas de la fruta

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

DISCUSIÓN

6. FUENTES DE CONTAMINACIÓN DE ALIMENTOS

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

* Enfermedades transmitidas por alimentos

Fuente: Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

7. BUENAS PRÁCTICAS DE HIGIENE

Fuente: Agencia Chilena para la Inocuidad y Calidad Alimentaria. (2021). Manual para Manipuladores de Alimentos, Basado en el modelo de curriculum estandarizado.

Hábitos higiénicos

a. Hábitos deseables

Lavar utensilios y vajillas antes de usarlos.
Utilizar siempre jabón y agua limpia.

1 

Tomar platos, cubiertos y fuentes por los *bordes*, cubiertos por el mango, vasos por el *fondo* y tasas por el *mango*.

2 

3 

Fuente: 1- Ciencia. (2020). El truco poco conocido para desinfectar los utensilios de cocina.
2-StateFoodSafety Resources. (2024). Consejo para manipulador alimentos: Manos fuera.
3- Reddit. (2024). What specific muscles/tendons are at play when holding a cup as shown?

Hábitos higiénicos deseables

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

b. Hábitos indeseables

- Hurgarse o rascarse la nariz, la boca, el cabello, las orejas, granos, heridas, quemaduras, etc.
- Usar anillos, pulseras, aros, relojes, u otro elemento.
- Manipular alimentos con las manos y no con utensilios.
- Utilizar vestimenta como paño para limpiar o secar.
- Usar el baño con la indumentaria de trabajo puesta.


1


2


3


4


5

Fuentes:

1. BBC. (2022). Why do we pick our nose?
2. Bienestar. Consejos de Salud. (2023). ¿Los anillos, relojes y pulseras pueden transportar el coronavirus?
3. Semana. Vida Moderna (2024). ¿Lavarse las manos antes de comer? Experimento viral demuestra su importancia y efectividad
4. Eroski Consumer. (2022). Los 10 errores más comunes en seguridad alimentaria.
5. Sutterstock. (2024). Toilet laptop

Fuente: Agencia Chilena para la Inocuidad y Calidad Alimentaria. (2021). Manual para Manipuladores de Alimentos, Basado en el modelo de curriculum estandarizado.

Fuente: Nestlé Professional. (2015). Básicos del manejo higiénico de alimentos.

8. CINCO CLAVES DE INOCUIDAD EN ALIMENTOS

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.

Siete pasos para lavarse las manos correctamente

i. Mojar las manos con agua corriente, aplicar jabón y enjabonar bien

ii. Frotar las manos durante al menos 20 segundos

De palma con palma

Entre los dedos

Dorso de las manos

Base de los pulgares

Dorso de los dedos

Uñas de los dedos

Muñecas

iii. Enjuague bien las manos y séquelas con una toalla de papel limpia o con aire

Fuente: National Environment Agency. Safeguard – Nature - Chrerish. (2016). Handler's Handbook.

Desinfectante de manos

Fuente: University of Mississippi. Institute of Child Nutrition. Resources Training Research. (2020). The 2020 Safe Food Handler.

¿Cómo y cuándo lavar las manos?

¿Conoces esto?

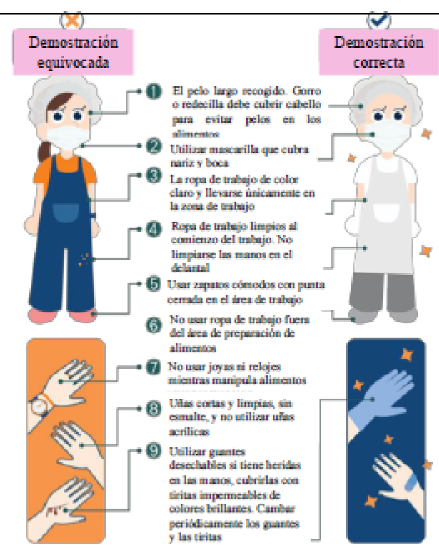
- Sólo 1 de cada 5 personas en todo el mundo lavan sus manos después de ir al baño.
- El dedo gordo, las yemas, uñas y los huecos entre los dedos son las zonas que no se lavan correctamente.

Fuente: Food Organización Mundial de la Salud (OMS). (2017). Manual para manipuladores de alimentos.

Siempre debes lavar tus manos con agua caliente y jabón, frontándolas bien

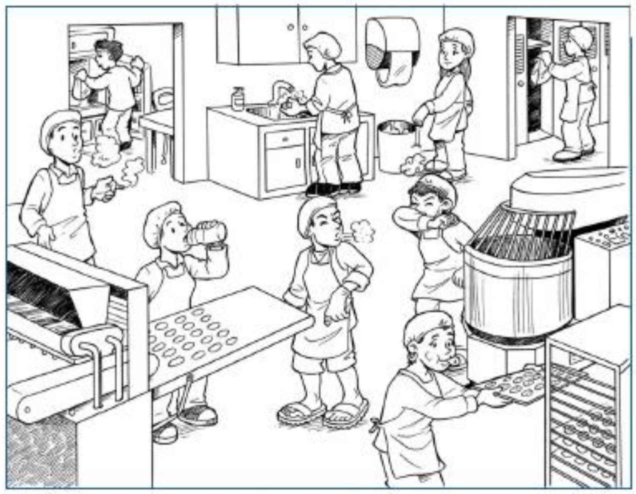
Antes de	Después de
Comer	Ir al baño
Tocar alimentos	Manipular alimentos crudos (carne, pescado, pollo y huevos)
Cocinar	Jugar y tocar mascotas. Sonarse la nariz, estornudar o toser

Propiedades de la ropa de protección



Fuente: Centre for Food Safety. The Government of the Hong Kong Special Administrative Region. (2024). Clothing

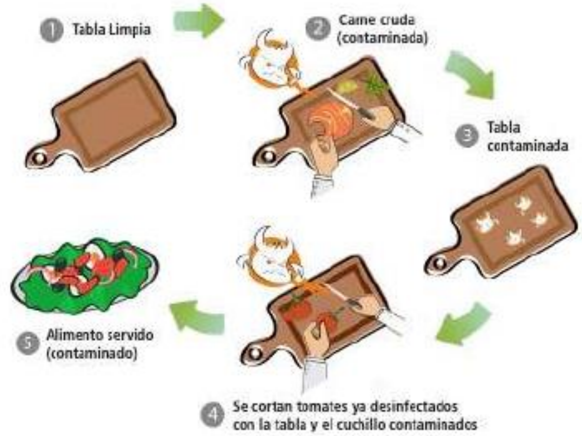
sahasrabudhe & associates inc.
FOOD INDUSTRY CONSULTANTS



Discusión

BUENAS PRÁCTICAS EN EL SITIO DE TRABAJO

a. Evitar la contaminación cruzada



Fuente: Food Organización Mundial de la Salud (OMS). (2017). Manual para manipuladores de alimentos.

b. Limpieza de equipo y utensilios

- Equipos de fácil limpieza
- Lisos y resistentes a la corrosión
- Todo material debe ser limpiado y desinfectado
- Equipos de refrigeración trabajando adecuadamente con termómetro visible
- Solicitar al proveedor información sobre la limpieza del equipo


1


2

Fuente: 1- Comedores industriales. (2022). Utensilios de cocina, llaves y perillas los más contaminados por bacterias
2-Food Business Solution. (2023). Recomendaciones de limpieza que puedes implementar en la cocina de tu restaurante

Pasos a seguir para lavar los equipos e instalaciones

1	2	3	4	5
Raspar residuos sólidos	Lavar con agua potable y detergente	Enjuagar con agua potable	Desinfectar	Secar

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos./*Food Organización Mundial de la Salud (OMS). (2017). Manual para manipuladores de alimentos.*

c. Almacenamiento de alimentos

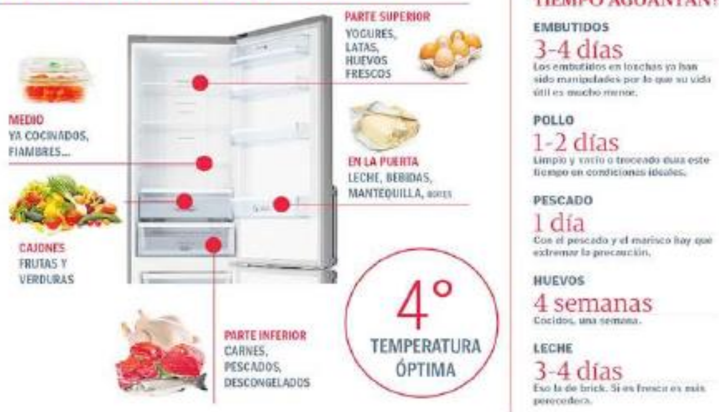
- El almacenamiento de alimentos depende del tipo de producto.
- El almacenamiento de productos que no requieran refrigeración o congelación debe ser:
  - fresco, seco, ventilado, limpio
  - separado de paredes, techo y suelo por un mínimo de 15 centímetros.
- Se deben utilizar estantes o tarimas para apoyar las materias primas.
- Medidas para ayudan a evitar la presencia de roedores e insectos.

11

12

Fuente: 1-Restauración colectiva. (2022). Buenas prácticas para mantener bajo control el almacenamiento en frío de los alimentos.
2-Printerest. (2022). Almacenamiento – Productos.

d. DISTRIBUCIÓN DE ALIMENTOS



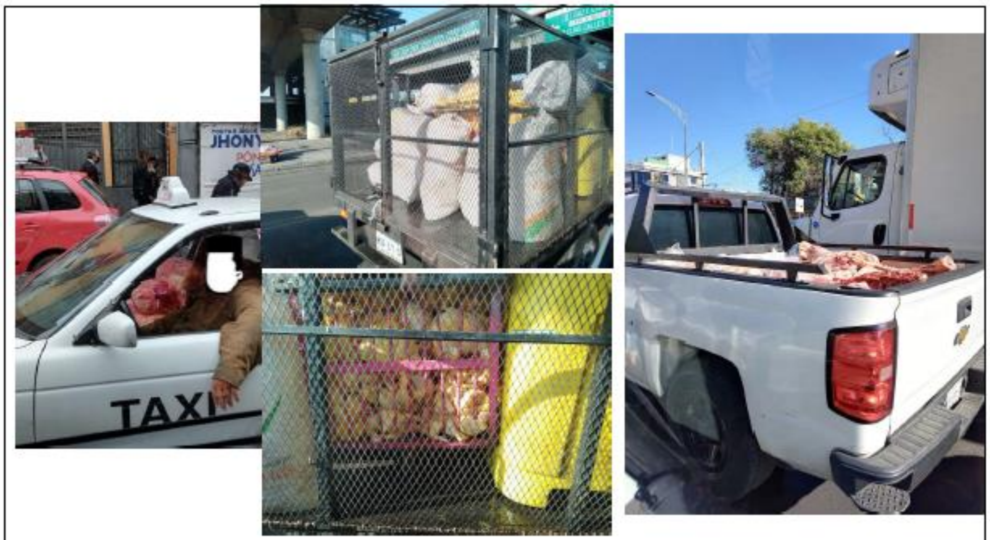
Fuente: La Voz de Galicia. (2024). Instrucciones para conservar los alimentos en la nevera y no intoxicarnos

e. ALMACENAMIENTO REFRIGERADO DE ALIMENTOS

Alimentos de alto riesgo deben mantenerse a temperatura por debajo de 5°C para evitar la multiplicación rápida de bacterias.

Buena circulación de aire / No almacenar alimentos calientes / Proteger alimentos con papel aluminio si no tienen tapa / Revisar y registrar T°C alimentos y equipo / Si hay 1 refrigerador dividirlo en sectores / Alimentos crudos abajo y cocidos arriba

Fuente: Dirección Nacional de Calidad e Inocuidad Agroalimentaria. (2023). Buenas prácticas para la manipulación de alimentos.



Discusión

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