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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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