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MEAT COLD CHAIN MANAGEMENT IN MEXICAN SUPERMARKETS

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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

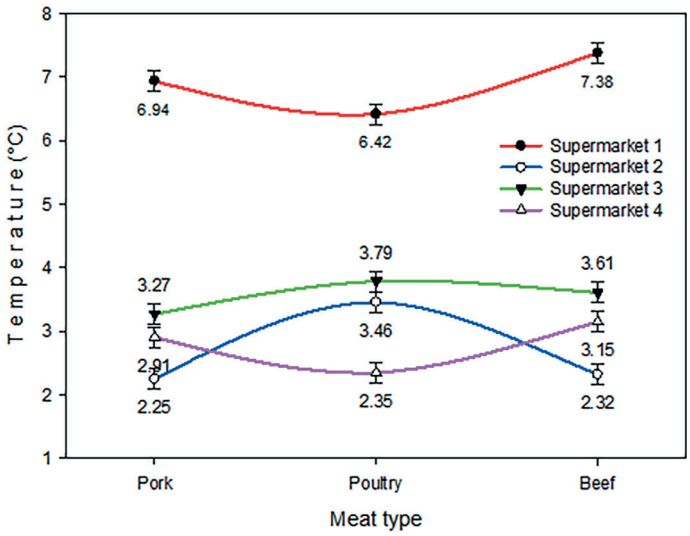

Figure 1. Temperature means of the three meat types in the supermarkets

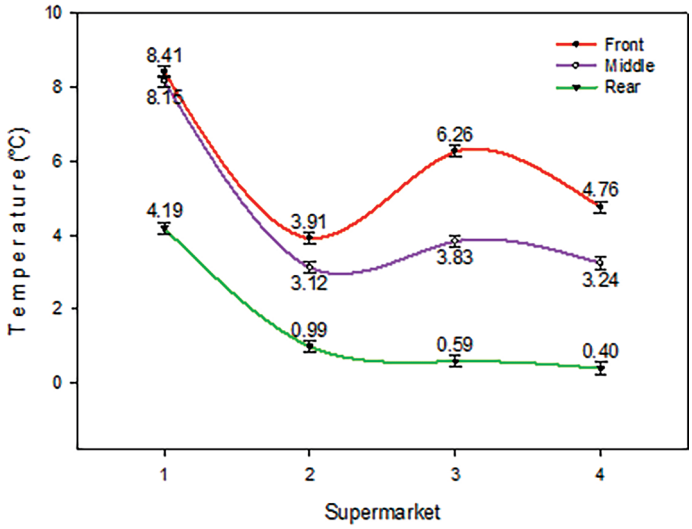

Figure 2. Temperature means of the three meat types in different positions in the refrigerator in the supermarkets

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.

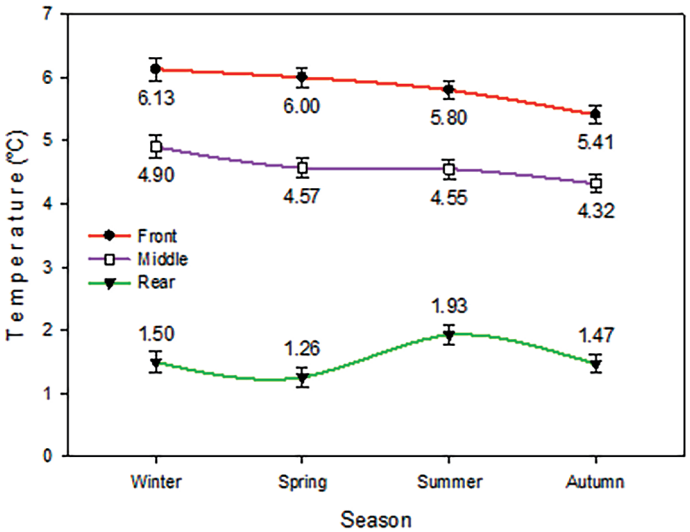

Figure 3. Temperature means of the three meat types in different positions in the refrigerator throughout the year

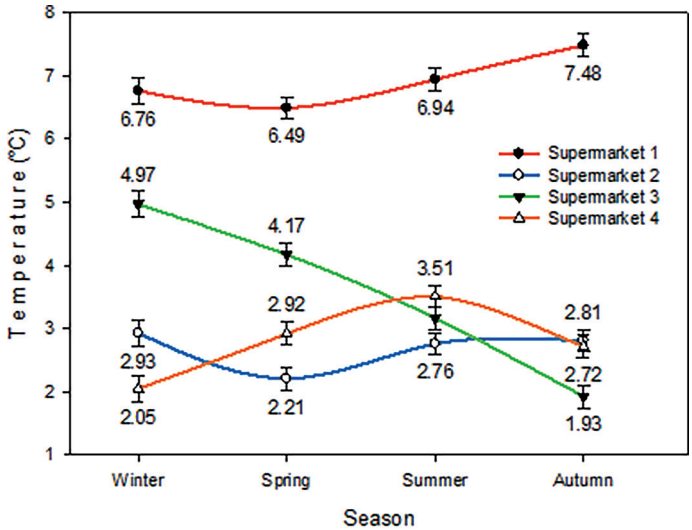

Figure 4. Temperature means of the three meat types in year seasons in the supermarkets

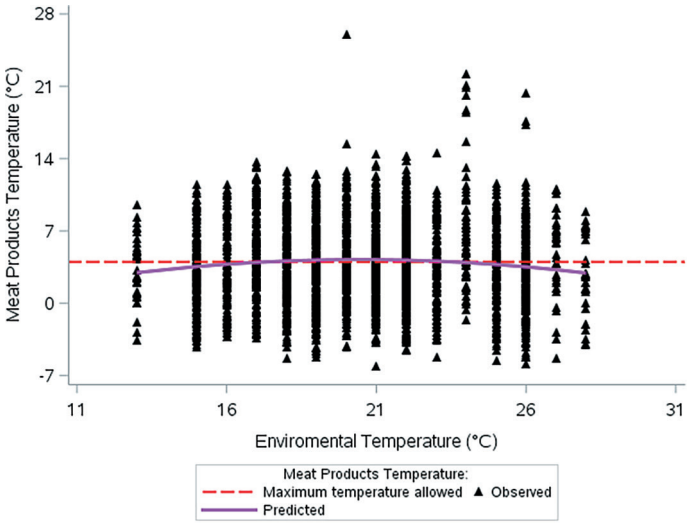

Figure 5. Effect of environmental temperature on meat products

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

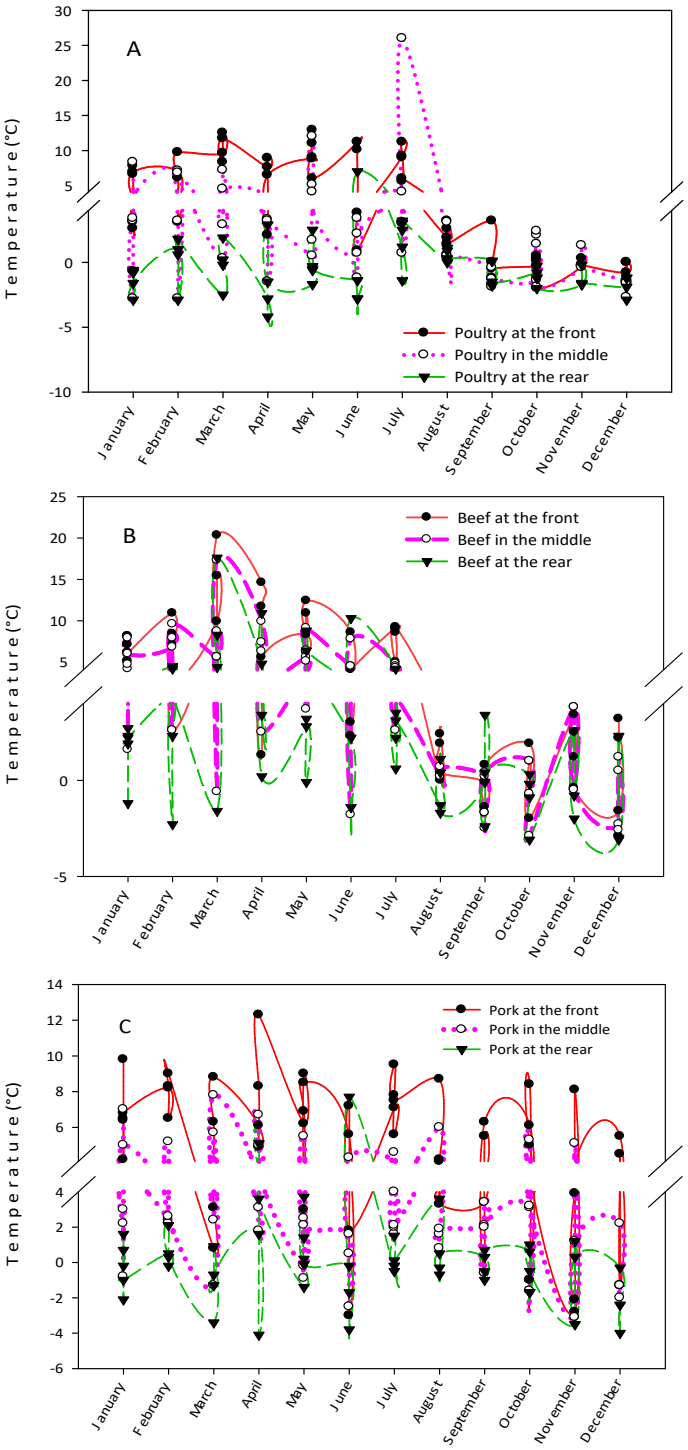

Figure 6. Effect of the change of refrigeration equipment in supermarket 3

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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