



Vacuum packaging system and the quality of fresh beef: a systematic review

Raimundo BERNADINO FILHO¹ , Fabiana Maria da SILVA¹ , Marilene da Silva LIMA¹ ,
Gerla Castello Branco CHINELATE¹ , Andréa Galindo Carneiro ROSAL¹ , Daniele Silva RIBEIRO¹ ,
Artur Xavier Mesquita de QUEIROGA² , Silvana Nazareth de OLIVEIRA¹ , Júlio César Bezerra Vilar da SILVA³ ,
Katcilanya Menezes de ALMEIDA⁴ , Sandra Regina Dantas BAÍA⁵ ,
Jessica Bezerra dos Santos RODRIGUES⁴ Neila Lidiany RIBEIRO^{4*}

Abstract

The quality and food safety of beef are fundamental in the food industry. In this study, a systematic review was carried out to assess the impact of the vacuum-packing technique added to some complementary beef preservation methodologies compared to the traditional method. The analysis made it possible to map the current state of the subject, identify gaps in knowledge, and suggest directions for future research. Using a robust methodology, which included a research protocol and critical analysis and evaluation of documents, with the aim of answering the guiding questions “What are the advantages, disadvantages and limitations of the vacuum packaging method compared to its adaptations used for packaging fresh beef?” and “How does the vacuum packaging system affect the nutritional and sensory quality of fresh beef?” Through the searches, 80 studies published between 2017 and 2023 were selected and analyzed in databases such as Web of Science, Science Direct, and Scopus, resulting in the choice of 7 for final analysis. The bibliometric analysis revealed a greater number of publications in 2017, with a predominant focus on beef production and preservation. The effectiveness of vacuum packaging in different methodologies to improve the preservation of fresh beef was highlighted, emphasizing the importance of complementary preservation methods such as refrigeration and freezing. It was concluded that combining vacuum packaging with other technologies offers an integrated approach to improving the preservation of meat products, extending their shelf life, and maintaining their sensory characteristics. This study makes a significant contribution to the understanding of packaging systems in the beef industry, providing valuable insights for academics and professionals in the sector.

Keywords: beef; vacuum packaging; preservation; systematic review.

Practical Application: The findings from this systematic review can guide meat processors and retailers in selecting optimal vacuum packaging methods to preserve beef quality.

1 INTRODUCTION

Over the years, the beef production and export landscape in Brazil has undergone significant transformations. Technological investments, efforts to improve production processes, concern for animal welfare, traceability, and other factors have been essential in establishing Brazil as one of the world's leading producers and exporters of beef, thus playing a valuable role in the country's economy (Costa et al., 2019; Mathias, 1997).

Beef is one of the main sources of animal protein consumed globally. Its nutritional and sensory characteristics make it an attractive food. Several factors can contribute to the deterioration of beef, rendering it unfit for consumption, such as temperature, sanitary conditions, packaging, and storage time. Among the various aspects of the food industry, packaging plays a crucial

role in preserving meat quality. The appropriate system can determine shelf life and safety, as well as influence the product's sensory attributes (Alexandrino et al., 2020; Borges & Souza, 2019; Melo et al., 2016).

The industry is constantly attentive to market innovations and seeks products that are flavorful, nutritious, and safe and meet consumer demands. To achieve this, it is essential that the product is packaged in a system that preserves its physico-chemical and sensory characteristics, protecting it from adverse conditions that could cause damage (Garzillo et al., 2022).

Currently, the most commonly used packaging systems in the meat processing industry include vacuum packaging and modified atmosphere packaging, as well as combinations of both techniques. The former involves removing all air from

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¹Universidade Federal do Agreste de Pernambuco, Garunhuns, Pernambuco, Brazil.

²Instituto Federal do Mato Grosso, Sorriso, Mato Grosso, Brazil.

³Instituto Federal da Paraíba, João Pessoa, Paraíba, Brazil.

⁴Universidade Federal da Paraíba, João Pessoa, Paraíba, Brazil.

⁵Unviersidade Federal de Campina Grande, Campina Grande, Paraíba, Brazil.

*Corresponding author: neilalr@hotmail.com

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the package before sealing it, creating an oxygen-free environment that inhibits the growth of aerobic microorganisms and extends shelf life. The latter involves altering the air composition inside the package, replacing oxygen with specific gases such as carbon dioxide and nitrogen, which help preserve the meat's color, texture, and flavor, while also inhibiting microbial growth (Smith et al., 2021).

Both techniques have their advantages and disadvantages. Vacuum packaging is effective in preventing bacterial growth and preserving the meat's sensory quality, while modified atmosphere packaging is highly efficient in reducing lipid oxidation and maintaining color. As drawbacks, vacuum packaging may lead to lipid oxidation and color loss, whereas modified atmosphere packaging may allow the growth of anaerobic bacteria (Costa et al., 2021; Mateus et al., 2018).

Vacuum packaging is widely preferred by Brazilian meat-packing plants due to its lower costs and ease of implementation compared to modified atmosphere packaging. This preference is attributed to the simplicity of the process, which requires fewer steps, thereby increasing efficiency and reducing production time (Kim et al., 2010).

Considering the aforementioned factors, this study aims to conduct a systematic literature review on vacuum packaging systems for fresh beef (chilled and/or frozen) in the meat processing industry. The objective is to provide an impartial analysis, examining how this technology impacts the nutritional and sensory quality of the product, as well as identifying its advantages, disadvantages, limitations, and innovations.

1.1 Relevance of the work

The use of vacuum packaging systems in preserving fresh beef is highly relevant to the food industry, especially in the context of food safety, waste reduction, and shelf-life extension. This technology minimizes oxygen exposure, slowing microbial growth and lipid oxidation—factors that compromise the sensory and nutritional quality of meat. Additionally, it meets consumer demands for fresher products with fewer preservatives. A systematic review on this topic helps consolidate scientific evidence and guide more efficient practices throughout the beef production chain.

2 MATERIAL AND METHODS

This study followed several stages: initially, a research protocol was developed, which included the research question, identification of databases, definition of inclusion and exclusion criteria, as well as search strategies and both preliminary and in-depth analyses. Subsequently, a critical analysis and evaluation of the retrieved documents was conducted, resulting in the creation of a critical summary that synthesizes the information from the selected sources.

2.1 Research protocol

In addition to reducing the risk of duplicating studies on an already-explored topic, the early disclosure of a scientific

research protocol also provides insights into how the subject is being addressed in the academic landscape. It allows for an assessment of whether the topic is well established or if there are gaps that could influence previous findings. Such investigations play a significant role in understanding the processes related to the object of study (Pacheco et al., 2018).

To develop the research protocol, a methodological approach based on the model from the International Prospective Register of Systematic Reviews (PROSPERO) was used, with adjustments made due to the model's focus on clinical issues in the health field. As a result, the following elements were incorporated into the protocol: research question, source selection criteria, search strategies, keywords, list of databases, types of documents, language, inclusion and exclusion criteria, quality criteria for primary studies, procedure for selecting primary studies, approach for data extraction, and analysis of results.

2.2 Research question

To construct the guiding question for the systematic review, the PICOS acronym was used (Table 1): P – population; I – intervention/exposure; C – comparison group; O – outcome; and S – study design. Modifications were made to adapt it to the study, where fresh beef represents the population, problem, or condition to be studied. This study compares interventions, which are the packaging systems used to store the product. The intended outcomes are the advantages, disadvantages, and limitations of each system and how they influence the physicochemical and sensory aspects of the product.

By objectively completing the framework, two guiding questions were formulated: “What are the advantages, disadvantages, and limitations of vacuum packaging compared to its adaptations used for storing fresh beef?” and “How does the vacuum packaging system affect the nutritional and sensory quality of fresh beef?”

2.3 Source selection criteria

To select the databases used in this study, a preliminary traditional search was conducted for systematic review documents to identify the most commonly used databases in this field. Among the analyzed documents, the most prominent databases for this type of research included: SciELO, SCOPUS, Web of Science, PubMed, Medline Ovid, Embase, and Google Scholar, among others (Pereira & Galvão, 2014).

Table 1. Components for formulating the research question.

Description	Question components
Population	Fresh beef
Intervention	Vacuum packaging system
Comparison	Innovations
Outcomes	Advantages, disadvantages, and limitations; influence on the physicochemical and sensory aspects of the product

Source: Author (2023).

For this study, the databases used were part of the CAPES Journal Portal (SCOPUS, Web of Science, and Science Direct), allowing documents to be easily accessed through a single account, enabling users to access them from anywhere using services provided by their educational institution, which must be integrated into the Federated Academic Community (CAFe).

2.4 Search strategy

For each database, a search method was applied to retrieve documents containing the keywords in the title, abstract, or keyword section. The defined keywords were: “fresh beef,” “vacuum pack*,” and “quality,” which were also determined through an initial search aimed at identifying the most relevant terms to include as many related documents as possible. The default language was English, as the selected databases host international articles. Boolean operators “AND” and “OR” were used according to each search engine, as described in Table 2.

2.5 Inclusion and exclusion criteria

Specific criteria were defined to guide this systematic review, aiming to include: (1) documents such as scientific articles published in journals, book chapters, and papers presented at conferences; (2) publications from 2017 to 2023; (3) documents available in open access or accessible through the CAFe; and (4) documents written in English or Portuguese.

Exclusion criteria included: (1) studies primarily focused on other packaging systems; (2) studies that do not explore the impact of vacuum packaging on the physicochemical and/or sensory properties of the product; (3) studies addressing vacuum packaging from different perspectives, such as sustainability; and (4) research focused on different meat products as the object of study.

2.6 Initial and advanced analyses

For the initial selection of articles retrieved from the databases, titles were first read, followed by abstracts. Then, Rayyan—a tool that simplifies the initial screening of abstracts and titles using a semi-automated process—was used, accessible at <http://rayyan.qcri.org>.

The articles resulting from this initial analysis were submitted to the State of the Art through Systematic Review (StArt) software, available at <http://lapes.dc.ufscar.br/tools/starttool>. Subsequently, the data were organized in an Excel spreadsheet containing the following fields: author, year of publication, origin, title, general objective of the study, and conclusion.

Table 2. Search mechanism used for the databases.

Databases	Search mechanism
SCOPUS	(“fresh beef” AND “vacuum pack*” AND “quality”)
Web of Science	(“quality” AND “vacuum pack*” AND “fresh beef”)
ScienceDirect	(“fresh beef” AND “vacuum pack” AND “quality”)

Source: Author (2023).

2.7 Critical analysis and evaluation of retrieved documents

To assess the reliability and relevance of the selected articles and their findings, methodological quality criteria followed the key assessment tool developed by the Joanna Briggs Institute (JBI) (Moola et al., 2015). The evaluation topics were modified to align with applicable studies, addressing the issues described in Figure 1 (Ribeiro, 2022).

Finally, a bibliometric analysis was conducted using the documents obtained through the previous steps. These were analyzed in relation to the topic to identify the current state of research, trends, and citations. This allowed for the identification of authors, countries, journals, and organizations interested in this area of study.

3 RESULTS

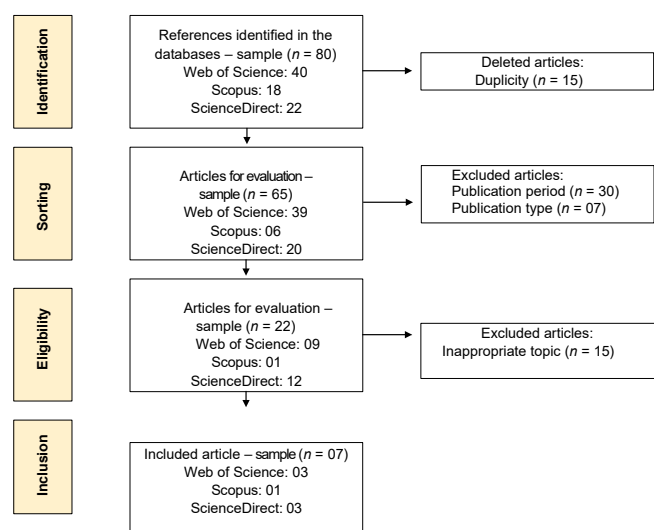
Following the search in the main databases, as detailed in the methodology, a total of 80 documents were identified. It was also observed that the database most prevalent in the sample was Web of Science, representing 50% of the total identified articles, followed by Science Direct with 27.5 and Scopus with 22.5%.

As shown in Figure 2, during the article search and identification phase, 40 articles were initially found in Web of Science,

Is the review question clearly and explicitly stated?
Were the inclusion criteria appropriate for the review question?
Was the search strategy appropriate?
Were the sources and resources used to search for studies adequate?
Were the criteria for evaluating the studies appropriate?
Was the critical appraisal conducted by two or more independent reviewers?
Were there methods to minimize errors in data extraction?
Were the methods used to combine the studies appropriate?
Were the recommendations for policies and/or practices supported by the reported data?
Were the specific guidelines for future research appropriate?

Source: Adapted from Moola et al. (2015).

Figure 1. Questions from the Joanna Briggs Institute checklist with adaptations.



Source: Author (2024).

Figure 2. Flowchart of study selection stages adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

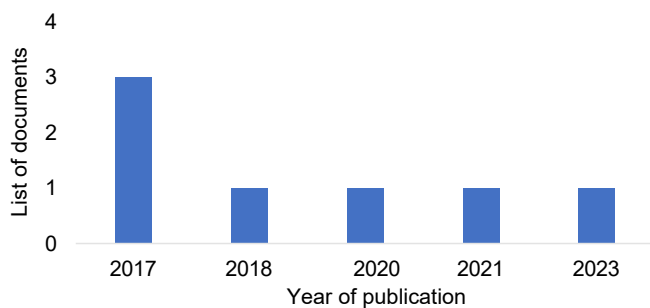
18 in Scopus, and 22 in Science Direct, totaling 80 articles. Of these, 15 were identified as duplicates. From the remaining 65 articles submitted for screening (39 from Web of Science, 6 from Scopus, and 20 from Science Direct), 37 were excluded. Among these, 30 were excluded due to being published outside the period specified in the methodology (2017 to 2023), and 7 were excluded for not being considered scholarly articles in the strict sense.

The eligibility analysis stage was divided into two phases: in the first, the studies were evaluated based on title and abstract, aiming to deepen the reading and understand the article's proposal. Out of 22 articles, 13 were excluded due to thematic inadequacy. The remaining articles were read in full, and 7 were found to be eligible regarding the relevance of the topic under study and the vacuum packaging technology. The results of the analyses conducted in this study are divided into two stages: bibliometric analysis and content analysis of the articles, considering the seven selected studies. These works present innovative approaches or the implementation of techniques in combination with vacuum packaging.

Table 3 presents the distribution of articles found in different journals related to meat packaging and preservation. Among the seven journals analyzed, three articles were published in *Meat Science*, followed by one article each in *Food Packaging and Shelf Life*, *Biocatalysis and Agricultural Biotechnology*, *Journal of Food Quality*, and *Foods*. These journals represent important sources of research and information on the topic, indicating academic relevance and interest in this specific area.

The literature review resulted in the identification of seven articles related to the subject, published in different journals. The distribution of articles by year of publication shows that most studies were conducted in 2017, with three articles. The years 2018, 2020, 2021, and 2023 had only one article each (Figure 3). These results indicate a varied distribution over the years, with a peak of interest in 2017, followed by lower production in subsequent years. This finding reinforces the relevance of the research and the need to continue investigating and improving the system in question.

The keywords reveal a variety of themes and research trends directly or indirectly related to the topic under study.



Source: Author (2024).

Figure 3. List of documents between the years 2017 and 2023.

By analyzing the keywords of the selected articles (Figure 4), three main points were identified. The keyword “beef” emerges as a central focus, indicating ongoing interest in production and preservation. It is associated with the term “storage,” which appears alongside other keywords such as “temperature,” “packaging,” “shelf life,” “vacuum packaging,” and “modified atmosphere,” suggesting concern with beef preservation and shelf-life extension through appropriate storage techniques. It also includes “color” and “temperature,” indicating parameters for product quality control.

Table 3 presents the basic information extracted from these documents to accurately and consistently answer the guiding question of this systematic review. Initially, the articles were organized by author name and publication date, title, objective, and conclusion.

The studies analyzed, as described in Table 3, highlight the widespread application of vacuum packaging in fresh meat products—a method traditionally adopted by the meat industry for preservation. This technique involves the removal of oxygen, which helps extend shelf life and inhibit microbial growth. The growth of spoilage aerobic microorganisms, such as *Pseudomonas spp.*, is inhibited. However, facultative anaerobic spoilage microorganisms (e.g., lactic acid bacteria [LAB] and yeasts) and strictly anaerobic bacteria (e.g., cold-tolerant *Clostridium spp.*) may continue to develop, resulting in meat spoilage.

4 DISCUSSION

The selected studies indicated that the addition of a pre-treatment step or a combined treatment can result in significant improvements in product preservation, including microbial load reduction, enhancement of sensory characteristics, and extension of shelf life. It is also important to emphasize the need for complementary preservation methods, such as refrigeration and freezing (Dorn-in et al., 2023; Nethra et al., 2023).

Article 01, titled “*The microbiology of beef steaks stored aerobically or anaerobically in vacuum packaging films with different oxygen barrier properties*,” analyzed the effects of different storage conditions and packaging types on the microbiology of beef steaks. High-barrier packaging and anaerobic storage were

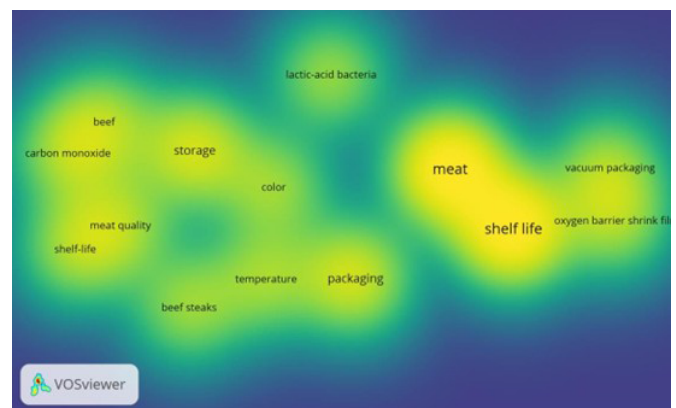


Figure 4. Main keywords related to the topic under study.

Table 3. Summary of studies eligible for research.

Article	Authors	Title	Objective	Conclusion
01	Mcsharry et al. (2020)	The microbiology of beef steaks stored aerobically or anaerobically in vacuum packaging films with different oxygen barrier properties	The study seeks to solve the problem of the proliferation of bacteria that cause spoilage of beef when stored in different atmospheric conditions, such as vacuum or modified atmosphere packaging.	The study highlights the importance of choosing the right packaging films with different oxygen barrier properties for beef preservation. High-barrier packaging and anaerobic storage proved more effective in maintaining red color and preventing discoloration, compared to low-barrier packaging or aerobic storage. These results highlight the importance of packaging in preserving the visual and sensory quality of meat.
02	Kirtonia et al. (2021)	Bacteriocin: A new strategic anti-biofilm agent in the food industry	The objective of this work is to minimize contamination of food products and increase food safety through the development and use of non-chemical products that, when added to food, reduce the chances of contamination.	The advantage of films containing enzymes, bacteriocins, and botanicals in meat products, compared to standard food preservation methodologies, lies primarily in their ability to provide an active and direct antimicrobial barrier against pathogens and spoilage microorganisms. Reducing the population of organisms that cause food spoilage is effective, and the process includes cooking meat products in packaging.
03	Bauer et al. (2017)	The effects of atmospheric pressure cold plasma treatment on the microbiological, physicochemical and sensory characteristics of vacuum-packed beef sirloin	The objective of this study is to analyze the effects of direct plasma treatment on meat samples prior to packaging, comparing them with two control groups: an “untreated control,” reflecting current commercial practices, and a “treated control,” which underwent direct plasma treatment. The study seeks to establish benchmarks for possible physicochemical or sensory changes resulting from plasma treatment	The study compared direct plasma treatment to the standard method and found that direct plasma exposure resulted in significant reductions in bacteria on food packaging films. Low-power plasma was more effective than high-power plasma due to the presence of reactive oxygen species, such as ozone. Ozone destroys bacterial cell membranes, making it effective against bacteria.
04	Lyu et al. (2018)	Using Carbon Monoxide Pretreatment Combined with Chlorine Dioxide and Lactic Acid to Maintain the Quality of Vacuum-Packed Fresh Beef	The study aimed to examine the effectiveness of pretreatment with carbon monoxide in combination with chlorine dioxide and lactic acid in preserving the quality of vacuum-packed beef. The research investigated how these treatments could contribute to meat decontamination and improve its quality, addressing aspects such as color, antimicrobial activity, and preservation of unsaturated fatty acids.	The study concluded that the combined pretreatment of carbon monoxide, chlorine dioxide, and lactic acid was effective in improving the antimicrobial activity and color stability of vacuum-packed beef. This combination resulted in the strongest antimicrobial activity, lowest microbial counts, lowest volatile basic nitrogen content, lowest pH, lowest thiobarbituric acid reactive substance, and lowest metmyoglobin during storage, while also maintaining a higher unsaturated fatty acid content. Therefore, this approach shows potential for maintaining the quality of vacuum-packed beef.
05	Rodrigues et al. (2017)	Assessment of the effectiveness of non-irradiated and chlorine-free packaging for the preservation of fresh beef	The study aimed to evaluate the potential of non-irradiated, chlorine-free, heat-shrinkable barrier films containing ethylene vinyl alcohol copolymer, polyamide, and ethylene ionomer in their structures for preserving vacuum-packed fresh beef, as an alternative to traditional gamma-irradiated polyvinylidene chloride bags. The research sought to compare the performance of EVOH films with PVDC bags regarding bacterial growth, weep loss, and sensory attributes of meat during storage at 0.5 °C.	The study concluded that the non-irradiated, chlorine-free 32 mol% EVOH film was as effective at preserving fresh beef during refrigerated storage as traditional irradiated PVDC shrink bags. The 32 mol% EVOH bags demonstrated better performance in terms of meat sensory attributes, such as fewer bubbles and better adhesion, compared to the PVDC control bags. Conversely, the 44 mol% EVOH bags exhibited the highest rate of color loss.
06	Mendes et al. (2023)	Chitosan coating functionalized with linseed oil and green tea extract as a biofuel-based solution for beef preservation	The objective of the study was to develop a coating using chitosan, green tea extract, and essential oils with the purpose of preserving the quality of beef by delaying lipid oxidation, reducing microbial growth, and maintaining the color and texture of vacuum-packed beef cuts during storage.	The study's conclusion highlights the effectiveness of the chitosan-based coating formulation in preserving beef quality by inhibiting microbial growth and lipid oxidation. The study showed that the coating treatment had a positive impact on maintaining the quality of meat cuts during refrigerated storage.
07	Van Rooyen et al. (2017)	The effect of exposure time to carbon monoxide pretreatment on color stability and quality attributes of vacuum-packed sirloin steaks	The objective of this study was to investigate the effect of exposure time to carbon monoxide pretreatment on the color stability and quality attributes of vacuum-packed beef steaks. The study sought to determine the optimal exposure time to carbon monoxide to achieve the desired red color.	Pretreatment with 5% carbon monoxide had no negative effects on microbiological safety, lipid oxidation, cooking loss, or shear force measurements at the end of storage. This study demonstrated that an exposure time of only 5 h was sufficient to achieve the desired results.

EVOH: ethylene vinyl alcohol copolymer; PA: polyamide; PVDC: polyvinylidene chloride.

more effective in reducing bacterial growth under refrigeration, while medium- and high-barrier packaging performed better under abusive temperature conditions (McSharry et al., 2020).

Article 02 discusses the incorporation of bacteriocins—antimicrobial proteins—into packaging films, which help eliminate microbial load. These can be applied directly to polymers or through coating or absorption onto the polymer surface. This technology ensures shelf-life extension and eliminates certain microorganisms, although it has limitations against Gram-negative bacteria. These films allow slow and controlled penetration of bacteriocins onto the food surface, which is more advantageous than methods like immersion or spraying, where antimicrobial activity may diminish more rapidly (Kirtonia et al., 2021).

Article 03 explores direct plasma treatment, which proved to be a promising alternative to standard methods, offering significant bacterial contamination reduction without the need for additional chemicals or thermal processes. This technology can improve food safety and quality while extending shelf life, representing an alternative to conventional thermal and chemical treatments (Bauer et al., 2017).

Article 04 examines a pre-treatment using carbon monoxide (CO) combined with chlorine dioxide and lactic acid, comparing this method to the standard approach. The study revealed that this treatment was more effective in inhibiting microbial growth, reducing chemical deterioration, preserving unsaturated fatty acids, and maintaining the color of vacuum-packaged beef. Chlorine dioxide (ClO₂) is an effective antimicrobial used to reduce microorganisms, while lactic acid is a commonly employed decontaminant to eliminate spoilage and pathogenic microorganisms in beef. This technology also helps maintain the characteristic red color of the meat without affecting other sensory attributes (Lyu et al., 2018).

Article 05 addresses shrink-barrier packaging containing ethylene vinyl alcohol copolymer (EVOH), polyamide (PA), and ethylene ionomer, which offer significant advantages in preserving meat quality, providing effective protection comparable to traditional packaging. Additionally, they offer sensory benefits such as fewer bubbles and better adhesion. These packages are also more environmentally friendly, as they are chlorine-free and non-irradiated, facilitating recycling and reducing the environmental impact associated with the disposal and treatment of harmful compounds. However, the oxygen permeability and water vapor transmission rates of EVOH packaging were comparable or slightly worse than the control packaging with PVDC. This may affect the ability to maintain meat quality over time, although the study found similar performance in terms of bacterial growth and liquid loss (Rodrigues et al., 2017).

Article 06 presents a chitosan coating functionalized with flaxseed oil and green tea extract as a promising solution for preserving the quality of fresh beef during refrigerated storage, especially when combined with vacuum packaging. This combination can significantly increase the product's shelf life. Chitosan is a functional biopolymer that inhibits the growth of bacteria, yeasts, and fungi. Green tea, rich in phenolic compounds, acts as a free radical scavenger, delaying lipid oxidation in foods and showing inhibitory effects against spoilage and pathogenic

microorganisms. Flaxseed oil, in turn, has antioxidant, anti-inflammatory, and anticancer properties, and does not have a strong odor (Mendes et al., 2023).

Article 07, by Van Rooyen et al. (2017), investigated the impact of exposure time to CO pre-treatment on color stability and quality attributes of vacuum-packaged beef steaks. The study concluded that CO pre-treatment could provide a reliable visual indication of freshness without compromising safety or quality attributes (Van Rooyen et al., 2017).

5 CONCLUSIONS

The study achieved its objectives by mapping the current state of the investigated topic, identifying knowledge gaps, and suggesting directions for future research. The findings of this work provide a solid foundation for understanding packaging systems and their implications, serving as a reference for academics and professionals in the field.

Vacuum packaging, when combined with other technologies, becomes more effective in extending shelf life, preserving color, and controlling microbial growth in fresh beef due to the synergy between different preservation methods. The removal of oxygen through vacuum packaging inhibits the growth of aerobic microorganisms such as *Pseudomonas spp.*, which are responsible for rapid meat spoilage. However, facultative anaerobic and strictly anaerobic microorganisms may continue to develop.

The addition of a pre-treatment step or a combined treatment can lead to significant improvements in product preservation. Furthermore, the use of modified atmosphere packaging can help maintain the color, texture, and flavor of the meat while also inhibiting microbial growth.

Therefore, combining vacuum packaging with other technologies—such as the application of bacteriocins and modified atmosphere systems—offers an integrated approach that enhances the preservation of meat products, extends shelf life, maintains sensory characteristics, and effectively controls microbial growth.

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