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INDICADORES DE LETALIDADE TÉRMICA EM PRODUTOS CÁRNEOS SOUS VIDE: UMA REVISÃO

INDICATORS OF THERMAL LETHALITY IN SOUS VIDE MEAT PRODUCTS: A REVIEW

INDICADORES DE LETALIDAD TÉRMICA EN PRODUCTOS CÁNICOS COCINADOS AL VACIO: UNA REVISIÓN

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RESUMO: Esse artigo buscou examinar dentre as publicações de cozimento de produtos cárneos 'sous vide', qual foi o critério estabelecido para eleger o indicador de letalidade térmica, avaliando o embasamento pautado na relevância atribuída à segurança do alimento processado. Para isso foi realizada uma busca bibliográfica nas bases de dados PubMed, Scopus, Web of Science, ScienceDirect e Google Scholar, abrangendo o período de 2000 a 2026. Foram identificados 340 registros, sendo 37 considerados estudos elegíveis e 12 foram incluídos no estudo. Observou-se que somente 2 trabalhos avaliados embasaram a escolha do tratamento e do indicador de letalidade térmica em alguma diretriz internacional. Alguns usaram evidências de doenças transmitidas por alimentos e outros nem sequer citaram argumentos do motivo da realização das análises microbiológicas realizadas ou até mesmo nem analisaram microrganismos patógenos, somente deterioradores, indicando que não houve preocupação com a segurança do alimento processado. Uma alternativa sugerida a ser adotada até que se crie uma regulamentação que ampare e estabeleça critérios para definição de indicadores de letalidade térmica e seus limites de detecção em cozimentos 'sous vide', é a exigência de inserção de recomendações e instruções sobre o cozimento prévio ao consumo nos rótulos dos produtos cárneos prontos para consumo.

Palavras-chave: Qualidade da carne. Segurança de alimentos. Método de cozimento.

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ABSTRACT: This article sought to examine, among publications on the cooking of 'sous vide' meat products, the criteria established to choose the thermal lethality indicator, evaluating the basis based on the relevance attributed to the safety of the processed food. To this end, a bibliographic search was carried out in the databases PubMed, Scopus, Web of Science, ScienceDirect and Google Scholar, covering the period from 2000 to 2026. 340 records were identified, 37 of which were considered eligible studies and 12 were included in the study. It was observed that only 2 studies evaluated based the choice of treatment and thermal lethality indicator on some international guideline. Some used evidence of foodborne illnesses and others did not even cite arguments as to why the microbiological analyzes were carried out or even did not analyze pathogenic microorganisms, only spoilage microorganisms, indicating that there was no concern about the safety of the processed food. A suggested alternative to be adopted until regulations are created that support and establish criteria for defining thermal lethality indicators and their detection limits in sous vide cooking, is the requirement to insert recommendations and instructions on cooking prior to consumption on the labels of ready-to-eat meat products.

Keywords: Meat quality. Food safety. Cooking method.

RESUMEN: Este artículo buscó examinar, entre publicaciones sobre la cocción de productos cárnicos 'sous vide', los criterios establecidos para elegir el indicador de letalidad térmica, evaluando la base en función de la relevancia atribuida a la seguridad del alimento procesado. Para ello, se realizó una búsqueda bibliográfica en las bases de datos PubMed, Scopus, Web of Science, ScienceDirect y Google Scholar, abarcando el período de 2000 a 2026. Se identificaron 340 registros, de los cuales 37 fueron considerados estudios elegibles y 12 fueron incluidos en el estudio. Se observó que sólo 2 estudios evaluados basaron la elección del tratamiento y el indicador de letalidad térmica en alguna directriz internacional. Algunos utilizaron evidencia de enfermedades transmitidas por alimentos y otros ni siquiera citaron argumentos de por qué se realizaron los análisis microbiológicos o incluso no analizaron microorganismos patógenos, solo microorganismos de descomposición, indicando que no había preocupación por la seguridad de los alimentos procesados. Una alternativa sugerida a adoptar hasta que se creen regulaciones que respalden y establezcan criterios para definir indicadores de letalidad térmica y sus límites de detección en la cocción sous vide, es la exigencia de insertar recomendaciones e instrucciones sobre la cocción previa al consumo en las etiquetas de los productos cárnicos listos para comer.

Palabras clave: Calidad de la carne. Seguridad alimentaria. Método de cocción.

INTRODUCTION

It is well established that meat is a significant component of the human diet. However, over time, significant changes in meat quality have occurred, such as those resulting from leaner animals due to the demand for healthier foods. Traditional thermal treatments used in meat processing, due to the high temperatures employed, lead to moisture loss which, combined with lower fat content, results in less succulent meats (Cropotova et al., 2019).

'Sous vide' (SV) technology is a cooking method where food is vacuum-sealed in impermeable packaging and cooked in circulating water at a controlled temperature for an extended period. The cooking temperature for meat is generally around 60 °C for varying times depending on the meat cut (Dominguez-Hernandez & Ertbjerg, 2021). Long-term heating at lower temperatures compared to those used for conventional foods results in meat tenderization and facilitates the production of particularly flavorful and nutritious products, even from cheaper cuts (Ayub & Ahmad, 2019).

Although 'sous vide' cooking can improve meat quality, such as tenderness with a significant reduction in cooking loss and color preservation, and prevents post-cooking recontamination, the handling of mild temperatures becomes a major concern regarding the safety aspect associated with microbial risk. Therefore, the selection of correct temperatures and times is crucial in 'sous vide' preparation, as it affects not only the physicochemical properties but also the microbiological properties of the meat (Baldwin, 2012).

Microbial safety assessment is an important benchmark for determining the efficiency of 'sous vide' cooking. SV cooked meat products are highly dependent on the pathogens present in the raw material and those that survive after cooking (Kathuria et al., 2022). However, it is observed in the literature that various thermal lethality indicators are used in meat processing, often without proper justification or basis for their selection. As there is no specific regulation for 'sous vide' cooking, this becomes a food safety issue leading to public health risks.

Therefore, the objective of the present study was to examine, among publications on 'sous vide' meat product cooking, the criteria established for electing the thermal lethality indicator, evaluating the foundation based on the relevance attributed to the safety of the processed food.

METHOD

This study is a literature review with a qualitative approach, aiming to gather and analyze scientific publications related to the use of 'sous vide' technology as a thermal treatment for meat products, with an emphasis on the thermal lethality indicator microorganisms adopted in these studies. The bibliographic search was conducted in the PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar databases, covering the period from 2000 to 2026.

The search terms used were “meat sous vide conditions”, “meat pasteurization”, “thermal lethality”, and “meat quality”, combined using the Boolean operators AND and OR.

RESULTS

A total of 340 articles were analyzed in the relevant databases; 37 were considered eligible studies and 12 were included in the study (Figure 1).

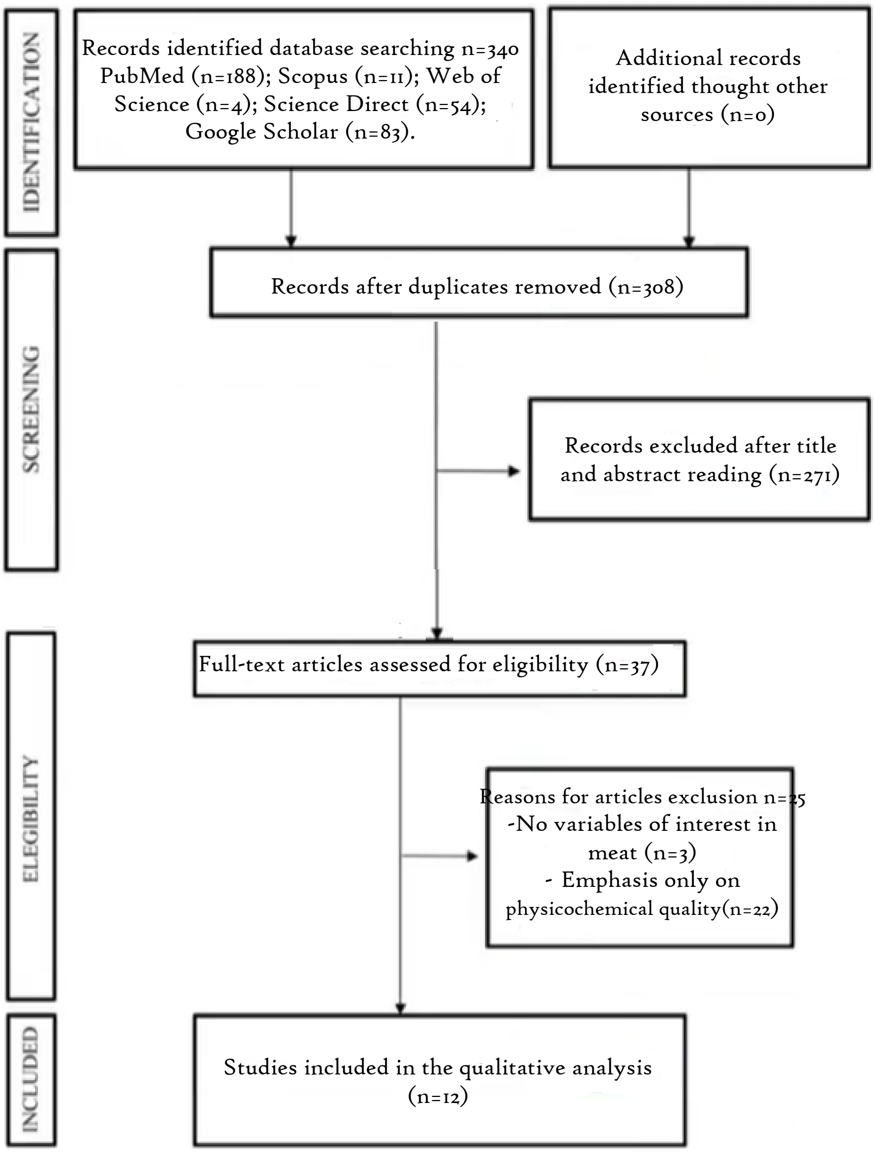

FIGURA 1: Diagram of records identified database searching.

Fonte: FERREIRA D.R et. al., 2026.

TABLE 1 - Thermal lethality indicators cited in 'sous vide' meat processing studies.

Product	'Sous vide' conditions	Reference microorganism	Key findings	Reference

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Marinated chicken breast	55, 57,5, 60°C in a period of one hour.	Salmonella e *L. monocytogenes*	D values for Salmonella: ranged from 47.65 min at 55°C to 7.48 min at 60°C. D values for L. monocytogenes: ranged from 54.81 min at 55°C to 10.39 min at 60°C.	Karyotis et al. (2017)
Chicken breasts.	two-step temperature treatment: 1*- 50º C / 40min and 60º C / 80min; 2*- 50º C / 80min and 60º C / 40min *total cooking time 1 and 2=120 min compared with the one-step temperature treatment (60º C for 120 min).	*Enterococcus faecalis*	The one-step sous vide treatment performed at 60ºC/120 minsuccessfully inactivated Enterococcus faecalis and 120min at two temperatures, 50ºC. The two-step sous vide treatment performed at 60ºC, achieved the target pasteurization performance criterion of a 3 log reduction in Enterococcus faecalis	Hasani et al. (2023)
Game meat: both loins (Musculus longissimus thoracis et lumborum) of roe deer and wild boar.	**50 °C:** 60 min, 120 min, 180 min, 240 min, 300 min, 360 min; **55 °C:** 20 min, 40 min, 60 min, 80 min, 100 min, 120 min; **60 °C:** 4 min, 8 min, 12 min, 16 min, 20 min	*L. monocytogenes*	Sous-vide cooking for several hours is able to destroy large amounts of vegetative pathogens. The results showed that the decimal reduction values (D values) were largely dependent on the surrounding matrix and the inactivation temperatures.	Abel et al. (2020)
Pork fillet	**55ºC:** 30, 60 and 90 min	*L. monocytogenes*	Treatments at 55 ◦C do not guarantee complete inactivation of L. monocytogenes	Vila-Brugalla et al. (2026)

Beef tournedos	56.1 °C/62 min; 58 °C/32 min; 62 °C/12 min; 72 °C/no dwell time	Salmonella	All treatments were effective in inactivating Salmonella.	Ferreira et al. (2026)
pork meat marinated in tomatillo beef marinated on a red chili sauce	55, 57.5, 60, and 62.58ºC for different periods of time	*L. monocytogenes*	The quantitative assessment of heat resistance *of L. monocytogenes*, as defined by D- and z values, should enable food processors to design thermal treatments with lower processing times and temperatures to inactivate this pathogen in sous-vide processed Mexican meat products.	Valenzuela-Melendres et al. (2016)
Beef Steaks	62.5 °C / 25min; 60.0 °C / 35 min; 57.5 °C / 29min; and 52.5 °C / 36min.	*S. enterica* and *L. monocytogenes.*	The time required for a 6.5 log10 cfu/g reduction of S. enterica: 13.90, 21.13, 28.47, and 86.74 min, while L. monocytogenes required significantly longer times of 24.12, 36.87, 74.54, and 347.45 min at 62.5 °C, 60.0 °C, 57.5 °C, and 52.5°C, respectively.	Manzoor et al. (2026)
Spiced turkey breast meat	65, 70, 75 °C x 20, 40, 60 min	Total mesophilic aerobic bacteria, total Enterobacteriacea, Escherichia coli, Listeria spp. and Salmonella spp.	The count of total mesophilic aerobic bacteria decreased approximately by 2 log CFU/g for the samples prepared in each cooking temperature/time combinations. Only in the samples cooked at 65 °C for 20 min, the presence of Listeria spp. was detected. Except the cooking at 65 °C for 20 min, all temperature-time combinations used for	Bıyıklı et al. (2020)

			cooking turkey cutlets provided inactivation for pathogenic microorganisms	
Pork hams	(61°C or 71°C), time (45 or 90 min)	total viable and coliform count	No microbial growth was detected for samples subjected to sous-vide cooking in any treatment groups.	Jeong et al. (2018)
Turkey breast	96ºC / 30 min	*L. monocytogenes*	The effectiveness of heat treatment for inactivating the pathogen was affected by product surface roughness. About 50 min of heating time was needed to achieve a thermal kill of 7 log10 CFU/cm2 on products with surface roughness up to 15 mm in depth.	Murphy et al. (2003)
Ready-to-eat meat products: turkey, ham, and roast beef.	90,6ºC, 93,8ºC or 96,1ºC / 2 to 10 min	*L. monocytogenes*	Minimal heating regimens of 2 min at 90,6 to 96,1ºC can readily provide 2-log reductions in most RTE deli meats we processed and suggest that this process may be an effective microbial intervention against L. monocytogenes on RTE deli-style meats.	Muriana et al. (2002)
Beef semitendinosus muscles	**50ºC**: 90min; 150min; 270min; 390min. **55ºC**: 390min **60ºC:** 90min; 150mon; 270min. **65ºC**: 90min	Total viable count (TVC), total viable psychrotroph (Ps), Enterobacteriaceae and Bochothrix thermosphacta counts. Lactobacillus spp.	The pasteurization values obtained were enough to inactivate vegetative cells but were insufficient to achieve a significant reduction of Clostridium botulinum spores. All the heat treatments reduced both counts below the detection limit of total viable count	Vaudagna et al. (2002)

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		(TVC), total viable psychrotroph, Lactobacillus and B. thermosphacta.

Source: FERREIRA DR, et al., 2026; data extracted from databases PubMed, Scopus, Web of Science, ScienceDirect e Google Scholar

DISCUSSION

The 'sous-vide' processing of meat (beef, pork, and poultry) has been studied by various researchers using a wide range of temperatures (50 – 96 °C) and times (4 - 360 min) (Table 1).

'Sous vide' cooking has become the focus of much research due to its versatility in manipulating cooking conditions, prioritizing low temperatures and long times. These are less severe thermal treatments that result in different degrees of meat tenderness, color, succulence, and palatability by avoiding moisture and flavor loss through evaporation during cooking, in addition to inhibiting cross-contamination after cooking. These factors are of utmost importance in determining the sensory, physical, and chemical quality of meat (Baldwin, 2012)

Many publications aim to study the parameters that impact the sensory quality of meat and disregard microbiological quality, whereas the primary concern in the 'sous-vide' cooking method is the safety aspect associated with microbial risk (Ismail et al., 2022).

There are also those dedicated to the study of microbiological risk control without concern for damage to sensory properties by using high cooking temperatures, such as the research conducted by Murphy et al. (2003) which verified the thermal inactivation of *Listeria monocytogenes* in ready-to-eat turkey breast meat products during 'sous vide' cooking. For this, a temperature of 96 °C for 50 minutes was used, which was the time the authors reported as necessary to achieve a thermal elimination of 7 log10 CFU/cm² in products with surface roughness up to 15 mm deep.

Muriana et al. (2002) also evaluated the reduction of *Listeria monocytogenes* in ready-to-eat 'sous vide' meats using temperatures of 90.8 °C, 93.38 °C, and 96.11 °C for times varying between 2 and 10 min. They suggest that processing for 2 min at 90.8 °C to 96.11 °C was effective in this study.

Higher temperatures (above 70 °C), such as those used by Murphy et al. (2003) and Muriana et al. (2002) lead to greater microbiological safety but may result in the generation of umami taste from nucleotides and also volatile flavors from the degradation of amino acids by the Strecker reaction, which suppresses the advantages of 'sous vide' cooking (Ismail et al., 2022).

These authors justify the use of *Listeria monocytogenes* as a thermal lethality indicator due to its potential as a contaminant in food processing environments because it is heat-resistant, has the ability to grow at refrigeration temperatures, and the capacity to form biofilms on all types of surfaces. Furthermore, they state that the potential contamination of *L. monocytogenes* in ready-to-eat meat products represents a threat to food safety.

However, Abel et al. (2020) state that although cooking duration depends on the type of meat product and the processing environment, temperatures of 60 °C are sufficient to inactivate *Listeria monocytogenes*. Yet, for food safety reasons, it is recommended to pan-fry after 'sous-vide' treatment or to cool rapidly. The authors further justify the use of the model microorganism for the heat inactivation experiment because it is a pathogen with high tolerance to pH and salt, in addition to having relatively high heat resistance. Additionally, listeriosis presents the highest mortality rate (16.2%) among all zoonoses monitored in Europe (Fernández-Martínez et al., 2022)

In another study, Vila-Brugalla et al. (2026) limited the study to a single temperature of 55 °C for 30, 60, and 90 min to propose a predictive model for survival and recovery of *Listeria monocytogenes*. The authors mention that *Listeria monocytogenes* is concerning due to its high hospitalization and mortality rates. Listeriosis outbreaks are predominantly associated with refrigerated ready-to-eat (RTE) foods, such as the one involving RTE pork and salmon in Spain in 2019 with 207 confirmed cases, resulting in 3 deaths and 141 hospitalizations (Fernández-Martínez et al., 2022). International regulatory approaches differ, with tolerance limits ranging from 100 CFU/g (which may occur throughout the declared shelf life) as in Canada, to a strict zero-tolerance policy for RTE meat products in the United States (Farber et al., 2021) and Brazil (BRASIL, 2022).

A study conducted by Valenzuela-Melendres et al. (2016) also used *Listeria monocytogenes* as a thermal lethality indicator when performing 'sous vide' cooking of pork marinated in tomatillo sauce and beef marinated in red chili sauce. They also used as justification for this choice the fact that the microorganism has high thermal resistance, in addition to the need to control this pathogen in 'sous vide' products.

Karyotis et al. (2017)) described the inactivation kinetics for *L. monocytogenes* and Salmonella in marinated chicken breast heated at temperatures of 55 °C, 57.5 °C, and 60 °C for

1 hour. These authors justify the use of these microorganisms as thermal lethality indicators based on the possibility that 'sous vide' processing may not be able to eliminate *Listeria monocytogenes* and non-viable populations of Salmonella spp. These pathogens can grow during refrigerated storage, especially if subjected to inadequate temperature conditions, commonly observed in retail and domestic environments.

Salmonella was used as a thermal lethality indicator by (Ferreira et al., 2026) when studying the impact of the 'sous vide' process on the quality of beef tournedos. The researchers based their work on Appendix A of the United States Food and Drug Administration Food Code (USDA & FSIS, 2021) which establishes time and temperature combinations for thermal treatments of 'sous vide' meat products targeting the inactivation of Salmonella. In all thermal treatments of the experiment, they successfully inactivated the microorganism. In addition to the cooking guideline, they also based the cooling on Appendix B of the same code (FSIS & USDA, 2021) with the objective of adding to the barrier of mild thermal treatment, refrigeration, and proper maintenance of the refrigerated product.

Similarly to Ferreira et al. (2026), Manzoor et al. (2026) used the justification that Salmonella is considered a lethality indicator by the Food Safety and Inspection Service of the United States Department of Agriculture (USDA & FSIS, 2021) to study its inactivation dynamics in 'sous vide' cooking of beef under the following conditions: 62.5 °C/25 min; 60.0 °C/35 min; 57.5 °C/29 min; and 52.5 °C/36 min. However, in addition to Salmonella, the authors also evaluated the inactivation of *Listeria monocytogenes* with the justification of it being a thermotolerant microorganism. As *L. monocytogenes* exhibited greater thermal resistance than *S. enterica* under the evaluated 'sous vide' cooking conditions, the researchers highlight the need for a comprehensive risk assessment to understand if *L. monocytogenes* should also be considered a lethality indicator organism during 'sous vide' processing by regulatory bodies.

In addition to Listeria spp. and Salmonella spp., Bıyıklı et al. (2020) analyzed total mesophilic aerobic bacteria, Enterobacteriaceae, and *Escherichia coli*. Although the study evaluated the effect of 'sous vide' cooking using the binomials 65, 70, 75 °C x 20, 40, 60 min in the cooking of seasoned turkey breast, the authors did not justify the choice of these microorganisms as thermal lethality indicators. They only described the results, emphasizing only those related to pathogenic microbiota, which does not support the purpose of performing microbiological analyses in this study.

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Other microorganisms were also evaluated by Vaudagna et al. (2002) as thermal lethality indicators with the justification that the treatment must be based on heat sensitivity and microbiological risk, without specifying the risks for each evaluated microorganism. In this experiment, beef was subjected to 'sous vide' cooking under the conditions of 50 °C (90 min; 150 min; 270 min; 390 min), 55 °C - 390 min; 60 °C (90 min; 150 min; 270 min), and 65 °C - 90 min, and total viable count (TVC), total viable psychrotrophs (Ps), Enterobacteriaceae, Lactobacillus spp., and *Bochothrix thermosphacta* counts were performed. The results indicate that the treatments were sufficient to inactivate vegetative cells but were insufficient to achieve a significant reduction of *Clostridium botulinum* spores. However, they justify this reduction inefficiency by the fact that the contamination level of *C. botulinum* spores is higher in fish than in beef, thus not being a potential hazard for products such as vacuum-packaged beef muscles. So why analyze this microorganism for 'sous vide' meat products? The authors only mention that counts of Lactobacillus and *B. thermosphacta* were performed because they are frequently isolated from meat; they do not base the choice of these as thermal lethality indicators.

Based on the 'sous vide' pasteurization performance criterion for poultry meat, *Enterococcus faecalis* was selected as the target microorganism in the work developed by Hasani et al. (2023) which compared the effect of one- and two-step 'sous vide' cooking on the microbiological and oxidative stability of chicken breast. For the pasteurization of food products, a 6-log reduction of pathogenic bacteria is defined as a pasteurization performance criterion (NACMCF, 2006), and the proposed treatments achieved this criterion.

When studying the effect of the 'sous-vide' method at different temperatures, times, and vacuum levels on the quality, structural, and microbiological properties of pork ham, Joung et al. (2018) used coliform counts as a thermal lethality indicator. The authors cite the study's objective to demonstrate cooking effectiveness through pathogen inactivation. However, no evidence was found that pathogenic microorganisms were evaluated in this work, which confirms the need for a regulation that establishes criteria for the use of thermal lethality indicators based on cooking conditions and food matrix, aiming at the safety of the processed food.

CONCLUSION

Understanding the public health implications of the survival of pathogenic microorganisms during cooking and the choice of an appropriate thermal lethality indicator are crucial for assessing the safety of 'sous vide' processing. However, it was observed in the evaluated works that the microbiological analysis after cooking was not based on a thermal lethality indicator that supported the safety of the food after SV cooking.

To ensure that treatments causing unacceptable thermal damage due to the use of high processing temperatures are not used, while simultaneously ensuring the microbiological safety of the product, there should be a labeling requirement to insert recommendations and instructions regarding cooking prior to consumption on the labels of ready-to-eat meat products. This is an interesting alternative to be adopted until a regulation is created that supports and establishes criteria for defining thermal lethality indicators and their detection limits, but it does not replace the latter. And the question arises: will the consumer have time to read? Simple and practical communication should be prioritized, highlighting explanatory images. It is not ideal, but until we have regulation for 'sous vide' cooking of meat products, we can minimize the impacts on food safety with this mitigation action.

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