

Review

# Unconventional Methods of Preserving Meat Products and Their Impact on Health and the Environment

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**Abstract:** A dual objective of food storage is to retain nutritional value and safe consumption over time. As supply chains have globalized, food protection and preservation methods have advanced. However, increasing demands to cater for larger volumes and for more effective food storage call for new technologies. This paper examines promising meat preservation methods, including high pressure process, ultrasounds, pulsating electric and magnetic field, pulsed light and cold plasma. These methods not only make it possible to obtain meat and meat products with a longer shelf life, safer for health and without preservatives, but also are more environment-friendly in comparison with traditional methods. With the use of alternative methods, it is possible to obtain meat products that are microbiologically safer, whilst also high quality and free from chemical additives. Moreover, these new technologies are also more ecological, do not require large quantities of energy or water, and generate less waste.

**Keywords:** unconventional preservation methods; meat; environment; health

## 1. Introduction

In recent years, food with a low degree of processing and without chemical additives has been increasingly sought-after [1]. The increase in the level of consumers' knowledge and awareness has contributed to the expectation of comfortable, safe food with health-promoting values and a long shelf life [2]. Food producers are subject to significant requirements and in order to meet them they have to seek new technological solutions. The need for continuous development of food processing and preservation methods is also the fact that there are continuous changes in the characteristics of pathogenic microorganisms, as well as in the natural environment [3–8]. The economic aspect is also crucial. In many sectors of the food industry, energy consumption is an important cost factor, while food preservation processes are high energy-consuming in processing. The systematic pursuit of a reduction in energy consumption is a very important issue, both in terms of environmental impact, e.g., the greenhouse effect, and in terms of savings. Alternative processing and preservation methods increase food production by reducing process time and, at the same time, contribute to environmental protection.

Minimizing the addition of chemical substances increases the attractiveness of food products on the market, which is extremely important for both food producers and consumers. The use of innovative technology also makes it possible to maintain higher nutritional and sensory values at the same time, especially if the increase in photothermal temperature is properly controlled [9]. Moreover, the demand for energy and water is much lower than in the case of traditional methods, and the

new methods do not require the use of solvents and do not lead to the production of hazardous substances [10].

Pathogenic microorganisms found in food pose a serious threat to human health and life. In order to ensure safe food production, various preservation methods, such as cooling, pasteurization, sterilization, or the addition of preservatives, are used. The desired result is the inactivation of microorganisms, and thus the protection of food products from deterioration. Traditional techniques, however, can bring about many undesirable changes, including partial loss of nutritional value and deterioration of the organoleptic quality of food [11–14]. In addition, conventional food processing methods have high energy requirements that lead to increased production costs and significant CO<sub>2</sub> emissions to the atmosphere.

Meat and meat products are a source of high-quality nutrients as they provide primarily vitamin B12, highly digestible protein and bioavailable iron [15]. However, rich nutrients are an ideal environment for the growth of destructive microorganisms and food-borne pathogens, which in turn may constitute a threat to public health and food waste [16,17]. The preservation of meat and meat products is a challenge for food producers not only due to the fact that the composition of meat makes it a perishable material, but also to the fact that meat has a very high sensitivity to loss of sensory properties during common sterilization processes [18]. In the thermal processing of meat, there occur frequent changes in the structure of food, loss of consistency, and in addition, lipid oxidation, which is the main cause of rancid smells during storage [19].

The constantly growing demand for fresh products is a challenge for the food industry, consisting in providing safe food with minimal processing. It is important that the food provided should be free of microbial contamination, the more so that some meat products are consumed raw, e.g., steak tartare [18]. In addition, in an era of rapid dissemination of information, consumers are increasingly concerned about the probable health problems and cancer-causing factors to which they may be exposed, including consuming thermally processed meat products [20]. It is therefore necessary to seek effective solutions, and safe for human health at that.

The method of packaging and the type of packaging material are also of great importance when it comes to food shelf life and minimizing negative impact on the environment. Promising methods of preserving meat products, among other things, include: high pressure technology, ultrasound, pulsating electric and magnetic fields, pulsating light flux and cold plasma. Scientists began their work on the application of high pressure in food preservation in the second half of the 19th century [21]. Currently, extensive literature is available on unconventional methods of food preservation, but there is still a need for research and careful analysis of the methods in terms of safety for human health and the environment.

This work is a review which was prepared on the basis of an analysis of published scientific papers in the discussed area. Its aim is to systematize knowledge and to summarize information on unconventional methods of preserving meat and meat products and to indicate their impact on human health and the environment.

## 2. Method of Study

Two major general scientific databases were used to identify the relevant research: Web of Science and Scopus. Scopus is considered to be a world-leading and dynamically developing bibliometric database [22]. It has an extensive coverage of over 25,100 titles, including over 23,452 peer-reviewed journals, 294 trade publications, over 852 book series from more than 5000 international publishers, and over 9.8 million conference papers from over 120,000 global events [23]. Web of Science (Clarivate Analytics) provides access to multiple databases, including over 21,294 journals, books, and conference proceedings [24]. We first conducted an exploratory search in Scopus, then conducted an exploratory search in Web of Science by focussing on two key concepts: “unconventional methods” and “meat”. The purpose of the exploratory literature search was to identify the most relevant keywords used to describe each of the concepts. Following this initial search, the final query was created (Table 1).

This query retrieved papers addressing all relevant concepts, where each concept was operationalized by search terms consisting of a combination of keywords. The year of publication was not limited. As a result of the sampling process in Scopus, 347 bibliometric records (i.e., publications) were retrieved, including articles (271), reviews (32), book chapters (26), books (3), conference papers (14) and a conference review (1). As a result of the sampling process in Web of Science, 289 bibliometric records (i.e., publications) were retrieved, including, articles (257), reviews (27) and book chapters (5).

**Table 1.** Search strings in Scopus and Web Science.

Concept	Search Strings
Meat	Meat and
And	high pressure process or sonication or pulsating electric field or pulsed
Unconventional methods	light or cold plasma or vacuum packing
And	Language: (English) and documents types: (article, review, book, book
Paper restriction	chapter, conferences paper, conference review)

Identification of the most prominent works within the field was used as the foundation for building up the corpus of publications used for the systematic literature review, supporting discussion, and interpretation of the research profiling findings. Then, using abstract analysis, the papers most relevant to the topic and aim of the study were selected. The Scopus database is biased towards English language publications, which results in the underrepresentation of literature in other languages in the sample. Therefore, the body of publications was supplemented with some other works not listed among core references in the research profiling sample.

### 3. A Review of Unconventional Meat Preservation Methods

#### 3.1. High Pressure Processing

The technology of high hydrostatic pressure is an unconventional method of food preservation, ensuring the preservation of high quality products with the desired sensory properties, nutritional value and extended shelf life. In the specialist literature, the term and abbreviation HHP (*High Pressure Processing*) are used for the method [25].

A characteristic feature of high pressure which is used in food processing is the destructive effect on large molecules (polymers), such as proteins and polysaccharides, while the low impact on low-molecular compounds: amino acids, vitamins and substances responsible for taste and smell [26]. Products subjected to high pressure in order to achieve the effect of pasteurization maintain the quality similar to raw material not subjected to this process.

The mechanism of destruction of microorganisms consists in the fact that under the influence of high pressure the ribosomes are destroyed and the reaction of cellular protein synthesis is inhibited. High pressure inactivates the body's intracellular enzymes, inhibits the process of replication, transcription and destroys cell DNA [27–29]. Proper selection of high-pressure process parameters enables inactivation of both vegetative cells and bacterial spores. On an industrial scale, pressure not exceeding 800 MPa is used [21]. In order to preserve meat and meat products, pressure in the range of 400–600 MPa is most commonly used, and the duration of action is from 3 to 7 min [10,28–30]. The highest sensitivity to high pressure is shown by vegetative cells of *Gram-negative bacteria* which die at pressures above 100 MPa, while in order to inactivate spore forms there is used a pressure of 600–800 MPa [31–33].

Meat preservation technology using high pressure is an alternative to the previously used thermal forms of inactivation of microorganisms [34]. The method makes possible obtaining microbiological safety of meat products without significantly raising the temperature. It can be used to eliminate pathogens such as *E. coli*, *Salmonella* and *Listeria*, which are frequent food contaminants and are a serious threat to the consumer's health. The non-thermal nature of the method gives wide application

possibilities, both in meat products and in the case of products normally consumed without heat treatment—an example of which is raw beef. Hać-Szymańczuk et al. [35] assessed the effect of high pressure on selected quality features and shelf life of Sopot sirloin and raw smoked sirloin. Samples were exposed to 600 MPa pressure for 30 min at room temperature. Based on the conducted research, it was found that the use of HHP extended the shelf life of the Sopot sirloin to 6 weeks in refrigerated conditions, and the taste, smell and texture did not deteriorate. It was observed that during storage of raw smoked sirloin exposed to high pressure, no psychrophilic, mesophilic and acidifying microorganisms developed [29]. Table 2 presents the results of research on the impact of high pressures on the microbiological quality of selected products.

**Table 2.** The impact of high pressure on the microbiological quality of selected products.

Product	Process Conditions	Storage Time (Weeks)	Number of Microorganisms [cfu/1g of Product]					Source		
			From the Cola Group	Enterococci	Mesophilic	Psychrophilic	Acidifying			
Raw smoked sirloin	Control sample	0	$3.3 \times 10^2$	$4.7 \times 10^2$	$5.3 \times 10^5$	$6.0 \times 10^4$	$4.7 \times 10^6$	[36]		
		6	$6.0 \times 10^1$	$2.2 \times 10^3$	$0.8 \times 10^8$	$4.0 \times 10^8$	$3.3 \times 10^8$			
		8	$2.0 \times 10^2$	$9.3 \times 10^2$	$2.3 \times 10^8$	$1.8 \times 10^8$	$3.0 \times 10^8$			
	500 MPa/10 min	0	-	$4.0 \times 10^2$	$1.8 \times 10^4$	<100	$1.0 \times 10^3$			
		6	-	<100	$2.0 \times 10^8$	$2.1 \times 10^8$	$3.6 \times 10^8$			
		8	-	<100	$1.0 \times 10^8$	$1.5 \times 10^8$	$2.1 \times 10^8$			
	500 MPa/30 min	0	-	$1.5 \times 10^2$	$3.8 \times 10^3$	<100	<100			
		6	-	<100	$1.0 \times 10^8$	$1.4 \times 10^8$	$9.5 \times 10^7$			
		8	-	<100	$8.9 \times 10^7$	$1.2 \times 10^7$	$1.4 \times 10^8$			
	Control sample	600MPa/30 min	0	<10	<100	$2.5 \times 10^4$	$2.5 \times 10^2$		$2.0 \times 10^2$	[35]
			6	$2.5 \times 10^1$	<100	$1.1 \times 10^7$	$1.2 \times 10^7$		$9.4 \times 10^6$	
			8	$1.5 \times 10^3$	<100	$1.1 \times 10^8$	$1.1 \times 10^8$		$6.0 \times 10^7$	
0		<10	<100	<10	<10	<10				
6		<10	<100	<10	<10	<10				
8		<10	<100	<10	<10	<10				
Haunch of beef	Control sample	0	-	-	$6.3 \times 10^8$	-	-	[29]		
	650 MPa/10 min	0	-	-	$1.4 \times 10^5$	-	-			
	650 MPa/20 min	0	-	-	$0.6 \times 10^2$	-	-			

HHP allows to extend the shelf life while maintaining organoleptic characteristics (i.e., taste, smell, colour, texture) and the natural nutritional values of the raw material [37]. The high quality of the products is maintained for a longer period without the need for chemical additives. Prolonged keeping of health-promoting features in the product is important for consumers seeking low-processed, preservative-free products. The preservation of meat and meat products with the use of high hydrostatic pressure also enables limiting the addition of salt to products. It is important due to the fact that meat products provide significant amounts of salt to the human diet, and excess sodium does not have a positive effect on health [38–40]. An important direction in the development of food preservation by high pressure processing is the use of the method to preserve packaged products. Additional HHP preservation of previously packaged raw materials enables significant extension of microbiological purity and safety [27,41].

The implementation of HHP technology in the meat industry is constantly progressing. Foods preserved by high-pressure technology do not pose a threat to human health. They are sterile, high quality and free from chemical preservatives. Under the influence of high pressure on the raw materials, there are not observed any changes leading to the formation of toxic compounds that could pose health risks. The high pressure method allows shortening of the technological process and reducing significantly energy consumption. No harmful by-products get into the environment and no volatile organic compounds are emitted [42].

### 3.2. Sonication

Sonication or ultrasound is an innovative technology that has recently been gaining popularity in the meat industry. The use of ultrasound during processing and treatment of meat has many benefits.

Sonication is an alternative technology for pasteurization and sterilization due to which it is possible to significantly increase the microbiological purity of the processed raw material, with a small impact on the nutritional value and product quality [43].

The term ultrasound refers to sound waves not heard by humans [44]. In food technology, first of all, high-power and low-frequency ultrasonic waves are used, located in the range of 20 kHz–100 kHz. The waves produce the effect of cavitation causing changes in the physicochemical and biological properties of the material and the disintegration of cellular structures [43,45,46]. As a result of cavitation, elements of biological cells are damaged, especially microbial cell membranes and tissue structures. The extent to which the bacterial microflora is inactivated depends mainly on the type of bacterial strain and the ultrasound parameters and duration of action. Table 3 presents the results of research on the impact of ultrasound and combined methods on the reduction in microorganisms in selected products. These data show that the best effects of microbial reduction were obtained on pig's skin using ultrasounds with 30–40 kHz parameters for 4 s.

**Table 3.** Reduction in microorganisms due to the use of ultrasound and combined methods.

Product	Type of Microorganism	Reduction (cfu)	Process Parameters	Source
Pork meat	<i>E. coli</i>	2.5/cm <sup>2</sup>	Ultrasound + water vapour 30–40 kHz, 130 °C, 2 s, 3.5–5 atm.	[47]
	<i>S. typhimurium</i>	2.0/cm <sup>2</sup>		
	<i>Y. enterocolitica</i>	2.1/cm <sup>2</sup>		
Chicken breast	<i>Psychrophilic bacteria</i>	0.2/g	Ultrasound 20 kHz, 5 min	[48]
Chicken wing	<i>Gram-negative bacteria</i> ( <i>S. anatum</i> , <i>E. coli</i> , <i>Proteus sp.</i> , <i>Pseudomonas fluorescens</i> )	1.0/cm <sup>2</sup>	Ultrasound + water 40 kHz 2.5 W/cm <sup>2</sup>	[49]
Pork skin	<i>S. typhimurium</i> , <i>S. derby</i> , <i>S. infantis</i> <i>Y. enterocolitica</i>	1.1/cm <sup>2</sup>	Ultrasound 30–40 kHz 1 s	[50]
	<i>S. typhimurium</i> , <i>S. derby</i> , <i>S. infantis</i> , <i>Y. enterocolitica</i>	3.3/cm <sup>2</sup>	Ultrasound 30–40 kHz 4 s	

Traditional thermal treatment causes the loss of many valuable nutrients which are sensitive to high temperatures. The use of ultrasound in the meat industry reduces microbial contamination, which notably improves food safety and extends the shelf life of meat without affecting the quality in a significant way [50]. Sonified foods retain their organoleptic properties and are rich in nutritional values. Meat processing with the use of ultrasound also makes it possible to limit the use of chemical additives and preservatives. It also creates the possibility of considerable reduction in the amount of salt used in food preservation, which is a significant advantage, taking into account the consumer's health [51].

Ultrasounds in meat processing technology have been used not only to inactivate microorganisms, but also by enabling significant modifications of physicochemical properties, to noticeably shape the characteristics of the final product. Prolonged exposure of meat to high intensity ultrasound may lead to, among others, improvement in the tenderness and juiciness of the product [52,53]. Another option is to combine ultrasonic technology with conventional cooking. Before consumption, meat and meat products often undergo a cooking process that has a direct effect on the texture and, together with the leakage of juice, causes the loss of many valuable vitamins and nutrients. The combined use of sonication with cooking not only allows you to improve the texture, maintaining high juiciness of the product, but also to significantly reduce the losses resulting from the cooking process. The use of ultrasound for thermal treatment of meat allows the reduction in the process time by half in comparison with the traditional method [50,54,55].

The introduction of the ultrasonic method in the meat industry enables the production of pro-health, minimally processed food, which is currently very popular among consumers. The food subjected to ultrasound is completely safe for human health, and the method itself does not pose a threat to the environment. The method does not use chemical additives that could get into the water along with the production sewage. The risk of contamination of the aquatic environment with harmful substances is

minimized. In addition, the technique enables the reduction in the duration of technological processes and energy consumption, and thus the reduction in costs [54].

### 3.3. Pulsating Electric Field and Oscillatory Magnetic Field

PEF (*Pulsating Electric Field*) technology is an alternative method of preserving food and protecting against the development of pathogenic organisms. In comparison with thermal treatment, it enables inactivation of microorganisms, while maintaining the original colour, taste and texture of unprocessed food. The PEF method enables effective and safe improvement of safety of meat and meat products [56].

The PEF method uses short pulses of high voltage electricity from 10 to 50 KV/cm. The pulsating electric field causes electrical potential to be created across bacterial, yeast or other microorganism cells. After reaching a critical potential point, usually 1 V, there is dielectric perforation, i.e., perforation of the cell membrane and irreversible damage [57–61]. The whole process of inactivation of microorganisms does not cause heating of the preserved product, because the process takes place relatively quickly, and the pulse duration is from micro to milliseconds. High temperatures, which are usually used in food preservation processes, are responsible for the loss of vitamins and bioactive ingredients, while the non-thermal nature of PEF ensures the preservation of high-quality meat and nutrients sensitive to high temperatures.

In addition to providing microbiologically safe, minimally processed food, PEF technology has the potential to economically and efficiently improve energy consumption. An additional advantage is also the possibility of obtaining safe products with a long shelf life, without the need to use preservatives [56]. Another way to use the pulsating electric field method is to combine the technique with traditional raw material processing. The use of PEF before freezing considerably shortens the freezing process, which makes possible obtaining a high-quality product in a more economical way.

In addition to the electric field in food preservation, there can also be used an oscillatory magnetic field, in short OMF (*Oscillatory Magnetic Field*). Pulsating magnetic field is another non-thermal method of food preservation, which has little influence on reducing the nutritional value, taste and aroma values or on functional properties. As a result of the use of magnetic field, a high-quality final food product can be obtained, although the effectiveness of the method is optimal in combination with other unconventional methods of food preservation [62].

The mechanism of the pulsed magnetic field is the transfer of energy through paramagnetic molecules to the DNA molecule and the destruction of chemical bonds, resulting in irreversible destruction of the cell. Studies confirm the inactivating effect of a strong magnetic field on vegetative forms of microorganisms. To reduce excessive heating of the product, the pulse duration is from 10  $\mu$ s to 1 ms, and the frequency is up to 500 MHz [62].

The described method is not yet fully understood; however, on the basis of on current research, it is estimated that changes in the sensory quality of products which are preserved by using the method of pulsating magnetic field are small. Therefore this technique may also serve as an additional treatment for previously pasteurized and packaged meat products, and thus considerably extend the shelf life. The advantage of the method is also low energy demand [63].

The use of electromagnetic field-based technology for food preservation has great potential in the meat industry. Thanks to the PEF and OMF methods, it is possible to obtain microbiologically safe food, more durable, more nutritious and with healthy properties. Furthermore, the research conducted so far has not shown that the discussed technologies are harmful and that the food preserved with the given methods constitutes a threat to human health. Under the influence of electrical impulses on food, there are formed none or in very limited quantities new substances. According to the current state of knowledge, PEF and OMF are safe methods, which are very promising and consistent with the idea of balanced development [53].

Non-thermal food preservation methods, such as pulsating electric fields and oscillatory magnetic fields, are gaining importance in the food industry and research laboratories. The methods offer a reasonable alternative to conventional thermal processes, where quality and cost aspects are becoming

an ever increasing problem. Despite the fact that the products preserved by the discussed methods are present on the global market, the cost of purchasing technology is still an important barrier in the implementation of PEF and OMF in the food industry on an industrial scale. That is why continuous research and popularization of new methods on global and European markets is so important.

### 3.4. Pulsed Light

Growing requirements for food make modern technologies constantly sought after. Traditional methods are insufficient to ensure microbiological purity and simultaneously maintain high quality of product. New technologies of non-thermal disinfection, including pulsed light, increasingly appear as an alternative to thermal and chemical methods of disinfection and preservation. Pulsed light PL (Pulsed Light) is an innovative technology that may replace traditional techniques and meet the current requirements of consumers. It demonstrates effectiveness in the inactivation of a wide range of microorganisms (vegetative bacteria, moulds, bacteria, fungal spores), and at the same time is safe for the consumer and the environment [56].

Pulsed light technology is based on the use of very short pulses of light in the range: from 1  $\mu$ s to 0, 1 s with a wide spectrum (from ultraviolet to near infrared 100–1100 nm). High-power light pulses that act for a short time are a powerful tool for inactivating microorganisms on food surfaces and packaging materials by combining both photochemical and photothermal mechanisms with no visible effect on product properties [64,65]. The PL method may also be used to reduce microbial contamination on food contact surfaces, equipment and media (e.g., water, air) associated with production [64,66]. It was found that pulsating light has bactericidal properties against a wide range of microorganisms, mainly due to the UV part of the visible light spectrum. Pulsed UV irradiation with different fluences (1.25–18.0 J/cm<sup>2</sup>) has been found to reduce pathogens and bacteria that naturally contaminate fresh chicken meat. The reduction range for selected bacteria was: 0.9–2.4 log for *Salmonella enteritidis*, 1.1–2.0 log for *Listeria monocytogenes*, 1.3–3.0 log for *Staphylococcus aureus*, 1.1–2.9 logs for *Escherichia coli* [9,67]. Ganan et al. [28], among others, conducted research on the effectiveness of pulsed light in reducing *Listeria monocytogenes* and *Salmonella typhimurium* on the surface of meat products (Table 4). The research material consisted of two cured dry ready-to-eat (RTE) meat products—salchichon (Spanish salami) and loin. In these products, microbial inactivation increased with fluence. Maximum logarithmic reduction between 1.5 and 1.8 cfu/cm<sup>2</sup> was obtained for both microorganisms using 11.9 J/cm<sup>2</sup> fluence. Ganan et al. [68], in their research, in addition to confirming the effectiveness of the method in reducing microorganisms on the surface of meat products, dried RTE, also showed that pulsed light does not significantly affect the change in sensory properties of preserved products [69].

**Table 4.** Reduction in microorganisms (log cfu/cm<sup>2</sup>) in selected products, using different PL levels.

Product	Pulse Energy J/cm <sup>2</sup>	Microbial Reduction log cfu/cm <sup>2</sup>		Source
		<i>Listeria Monocytogenes</i>	<i>Salmonella Typhimurium</i>	
Spanish salami	0.70	0.89	0.26	
Spanish salami	11.90	1.81	1.48	[65]
Dried loin slices	0.70	1.01	0.51	
Dried loin slices	11.90	1.61	1.73	
Beef carpaccio	11.90	0.90	1.00	[66]

In comparison with conventional thermal sterilization, pulsed light makes it possible to achieve the effective inactivation of microorganisms in a much shorter processing time and using less energy. Compared with other techniques that use chemical preservatives or ionizing radiation, the pulsed light stream does not include toxic chemicals or photolytic by-products. The technique may successfully be used for special-purpose items, such as baby food, as well as to reduce allergens in food [9]. The PL method generates little liquid and solid waste, does not require high water consumption and energy input, and does not release (or cause emissions of) organic compounds and volatile compounds.

An additional advantage is the use of mercury-free xenon lamps. Working with pulsating light is also safe because the process takes place in a chamber that has no direct contact with the environment. Less energy use reduces the extraction of fossil fuels, the extraction of which is not neutral for the environment [70].

The use of PL technology in the food industry is receiving increasing attention and has more potential applications. Conducting research in this area makes it possible to extend the pulsating light technique to various sectors of the food industry. The small construction size, easy implementation on production lines and the possibility of integration with other innovative solutions mean that the pulsating light beam technique can be considered as a simple and economical alternative increasing food safety [68]. The integration of process techniques allows maximizing food production and minimizing emissions into the environment at the same time.

### 3.5. Cold Plasma

Meat and meat products are a source of high-quality nutrients as they provide primarily vitamin B<sub>12</sub>, highly digestible protein and bioavailable iron [15]. However, rich nutrients are an ideal environment for the growth of destructive microorganisms and food-borne pathogens, which in turn can lead to a threat to public health and food waste [16,17]. The preservation of meat and meat products is a challenge for food producers not only due to the fact that the composition of meat makes it a perishable material, but also that it has a very high sensitivity to loss of sensory properties during common sterilization processes [18]. As a result, there is a great deal of interest in novel ways of preserving food and destroying microorganisms without affecting quality. Among the promising, non-thermal techniques of food preservation, there is also distinguished the “cold” plasma method.

Plasma is defined as the fourth state of matter. It is a mixture of inert and electrically charged particles [71]. By supplying a sufficiently large amount of energy, each substance can be converted into a plasma. Depending on the pressure and temperature ranges it occurs in, we distinguish high and low temperature (cold) plasma that can be obtained in earthly conditions [72,73]. The inactivating agent for cold plasma technology is ionized gas such as air, oxygen, nitrogen or argon. The operation of cold plasma is based on its high reactivity, and, what is important, it is a non-thermal process that does not cause thermal changes in the preserved raw material.

Cold plasma has the potential in the food production sector to inactivate pathogens, thus improving food safety. It demonstrates the ability to effectively inactivate a wide range of microorganisms, including spores, biofilms and even some viruses. The advantage of the process is also the fact that plasma components involved in the destruction of microorganisms are unstable, and therefore there is no risk that they will be present in the finished product [72–74]. The action of cold plasma also does not cause significant changes in the nutritional and sensory properties of raw materials [75].

### 3.6. Vacuum Packing with Shrinking

The lifestyle of a society that has been changing in recent years, as well as the intensive development of technology in the food industry, contributes to the development of new methods of packaging meat and meat products and to the modification of traditional food packaging systems. Manufacturers are required not only to ensure a high standard of food quality, but also to provide packaging aesthetics and functionality. It is also important to search for new materials that would solve ecological problems [76,77].

Packaging is an inseparable element of food products, including meat and meat products. With the development of new packaging materials, packaging can perform a number of new functions. New generations of packaging are emerging that maintain and even improve the physical characteristics of the packaged product, which may have particular use in the meat industry. In addition to the fact that properly selected packaging prolongs the shelf life of meat and meat products, it also constitutes a barrier against microbes and mechanical deformations of packaged products during transport and



storage [78]. Table 5 shows an example storage time for meat and meat products in refrigeration conditions, packed traditionally and vacuum packed.

**Table 5.** Stability of traditionally and vacuum packed meat and meat products, stored in the temperature range from 3 °C to 5 °C.

Products	Product Shelf Life in Traditional Packaging	Product Shelf Life in Vacuum Packaging	Source
Beef	3 days	8 days	
Pork	2 days	6 days	
Poultry meat	1–2 days	7 days	
Cooked Beef	5 days	12 days	[35]
Cooked pork	5 days	12 days	
Smoked meat	2–4 weeks	6–12 weeks	
Sliced ham	3–4 days	3 weeks	
Frankfurters	1–2 days	2 weeks	
Minced meat	2–3 days	45–60 days	[79]

In the meat industry, a modified atmosphere packaging system is used, including vacuum packaging and, increasingly, vacuum packaging combined with shrinking [80]. The essence of vacuum packaging is to reduce the atmospheric pressure in the packaging by removing 98–99% of air. Due to the almost complete elimination of oxygen from the packaging and tight sealing, the growth of aerobic bacteria, moulds and fungi, which pose a threat to the health of the consumer, is prevented. The vacuum-packed product stays fresh longer, does not lose the desired sensory characteristics and retains its aroma [81].

The combination of vacuum packaging technology and shrinking gives many new benefits and opportunities in the meat industry. The product packed in a vacuum technique with shrinking has a considerably extended shelf life in comparison with traditional packaging. The shrink film has barrier properties, high mechanical strength, and excellent weldability and transparency. Thanks to its properties, the film enables the air-tight closing of meat and meat products without generating unnecessary losses during packaging, and protects the product against mechanical damage during transport. The use of heat-shrinkable film in vacuum packaging allows increasing the availability of products, protection against contamination, as well as reducing weight loss due to water evaporation. The high barrier properties of the film for water vapour ensure a constant weight of the meat product throughout the storage period [82].

The continuous development of technology makes it possible that heat-shrinkable films currently available on the market are biodegradable or 100% recyclable. Moreover, the small thickness of the film contributes to the reduction in the amount of produced plastic packaging waste. Available films are also characterized by a reduced welding and shrinking temperature, which significantly reduces energy costs [76].

#### 4. Discussion

Pulsed light (PL) is a non-thermal innovative technique used for food preservation among other relevant novel technologies such as high-pressure processing, pulsed electric fields and high electrical voltage discharges [83]. There are data in the literature showing that PL is effective to inactivate *Listeria* spp. and *Salmonella* spp. on the surface of simple media, such as agar [84–86]. In these studies, different fluences have been assayed but, in general, reductions from 3 to 7 log cfu/cm<sup>2</sup> have been reported. This level of inactivation is higher than that obtained in complex matrices since the properties of the surface (roughness, porosity, etc.) can protect microorganisms from light.

Ganan et al. [68], analyzing using pulsed light to increase the safety of ready-to-eat cured meat products, show that salchichón and dry cured loin microbial inactivation increased as fluence did, with reductions from 1.5 to 1.8 log cfu/cm<sup>2</sup> when 11.9 J/cm<sup>2</sup> were applied. In general, *S. Typhimurium* showed a slightly higher resistance to PL than *L. monocytogenes*, although these differences tended to disappear at the highest fluences assayed. Moreover, Kramer et al. [87] show that PL treatment

allows for reductions in *L. innocua* by about 1 log on the surface of sliced boiled ham and chicken cold cuts while 3–4 log can be achieved on frankfurter sausages. Similarly, count reductions in selected pathogens by approximately 1 log were previously found by Hierro et al. [69] in the case of PL-treated tuna and beef carpaccio, but distinctively higher fluences of up to 8.4 and 11.9 J/cm<sup>2</sup> were applied. The same research group reported maximum log reductions for *L. monocytogenes* on packaged sliced cooked ham and bologna by 1.11 cfu/cm<sup>2</sup> and 1.78 cfu/cm<sup>2</sup> after treatments at 8.4 J/cm<sup>2</sup>, respectively [88]. The inactivation achieved in the present work with a fluence of 8.4 J/cm<sup>2</sup> in both cooked ham and bologna is higher than the outcome reported by Uesugi and Moraru [89], who obtained a reduction of 1.37 log cfu per sausage for *Listeria innocua* on the surface of unpackaged Vienna sausages, when treated with 9.4 J/cm<sup>2</sup>. Furthermore, Ganan et al. [68] found reductions in *L. monocytogenes* and *S. Typhimurium* on the surface of ready-to-eat dry cured meat products (salchichón and loin) by 1.5–1.8 log cfu/cm<sup>2</sup> at a fluence of 11.9 J/cm<sup>2</sup>. On the other hand, Keklik et al. [90] assayed different PL treatment conditions (time and distance from the lamp) for the inactivation of *L. monocytogenes* Scott A on chicken frankfurters. These authors established optimum parameters as 60 s at 8 cm distance, yielding 1.5 and 1.6 log cfu/cm<sup>2</sup> reductions in unpackaged and vacuum-packaged frankfurters, respectively. When calculating the fluence, these treatments are equivalent to 55.9 and 48.4 J/cm<sup>2</sup>, respectively, which exceed, by far, the FDA regulations. According to this administration, the total cumulative PL treatment for foods must not exceed 12 J/cm<sup>2</sup> [91]. However, PL promoted some changes in the sensory characteristics of these products. The study carried out by Koch et al. [92] on pork skin and loin indicated that the lowest levels of PL fluence (0.52 log CFU/cm<sup>2</sup>) were the only sensory accepted samples in comparison to more intense treatments (4.96 and 12.81 log CFU/cm<sup>2</sup>). Moreover, both pork skin and loin treated with 0.52 log CFU/cm<sup>2</sup> received the same scores of untreated samples for rancid odor. Interestingly, the authors did not associate this effect with lipid peroxidation due to low oxidation level induced by PL treatments on pork skin (<0.12 µg/g). Moreover, Hierro et al. [69] assessed the feasibility of PL treatments (0.7, 2.1, 4.2, 8.4 and 11.9 J/cm<sup>2</sup>) to enhance the safety of beef and tuna carpaccio. The results indicated a significant reduction in the initial microbial count (≈1 log CFU/cm<sup>2</sup>) of the samples inoculated with *Vibrio parahaemolyticus*, *E. coli*, *L. monocytogenes* and *S. typhimurium* after applying PL treatments (8.4 and 11.9 J/cm<sup>2</sup>), and obtained a significant improvement in the food safety of these products. However, PL treatments at high doses (8.4 and 11.9 J/cm<sup>2</sup>) resulted in color variation (lower redness and yellowness than untreated sample) and a negative impact on sensorial quality (lower score for color and odor in comparison to untreated samples). Regarding the impact on sensory properties, the study carried out by Koch et al. [92] indicated an association between the most intense PL treatments (4.96 and 12.81 J/cm<sup>2</sup>) with unpleasant, ozoneous, pungent, ammoniacal, and off-odor perception in pork skin and loin. Conversely, the samples subjected to 0.52 J/cm<sup>2</sup> were perceived as “less porky” and “slightly chemical”, which support the indication that excessive PL treatment reduced the quality of food. Additionally, significant changes on color caused by PL treatment were also indicated particularly for redness. Pulsed Light (PL) represents a promising technology to reduce microorganisms, including pathogens, on meat products.

Technically, ultrasound can act in two ways in the meat tissue: by breaking the integrity of the muscle cells and by promoting enzymatic reactions [93]. While some authors [94] assert that prolonged exposure to high-intensity ultrasonic waves causes a significant tenderising of the meat, others have failed to confirm this effect [95,96]. One study showed that sonication of beef muscle with an intensity of 2 W cm<sup>-2</sup> for 2 h at a frequency of 40 kHz damages the perimysium resulting in improved texture [97]. To observe changes in maturation, Pohlman et al. [98] applied ultrasound (20 kHz, 22 W cm<sup>-2</sup>) for 0.5 or 10 min to shear pectoral muscles that had been vacuum-packed and ripened for 1, 6 or 10 days. The sonicated muscles showed reduced hardness with no effect of sonication time or storage of packed meat on weight loss, hardness or sensory characteristics. Non-packaged pectoral muscles that were treated ultrasonically had less weight loss than muscles processed by other methods. Another study showing that ultrasound can improve tenderness and the technological properties of meat was conducted by Jayasooriya et al. [99]. These authors sonicated (24 kHz, 12 W cm<sup>-2</sup>) bovine muscles for

a maximum of 4 min and subsequently stored them. Sonication resulted in increases in tenderness and pH without significant interaction between ultrasound and maturation time. Ultrasound treatment did not affect the colour or drip loss, but cooking losses and total losses decreased. Recent literature has shown that ultrasound treatment alone reduced about 1 log CFU/cm<sup>2</sup> of *Gram-negative bacteria* including *Salmonella* spp., *E. coli* and *Pseudomonas fluorescens* on the surface of chicken wings, while ultrasound with lactic acid inactivated more than 1.5 log CFU/cm<sup>2</sup> [49]. Morild et al. [47] analyzing inactivation of pathogens on pork by steam-ultrasound treatment show that on skin and meat surfaces of pork jowl samples, counts of total viable bacteria were reduced by 1.1 log CFU/cm<sup>2</sup> after treatment for 1 s and by 3.3 log CFU/cm<sup>2</sup> after treatment for 4 s. The mean reduction of 1.7 to 3.3 log CFU/cm<sup>2</sup> on the skin surface was significantly higher than the reduction of 1.1 to 2.5 log CFU/cm<sup>2</sup> on the meat surface. These studies suggest that ultrasound could be combined with antimicrobials such as chemical sanitizers and organic acids to enhance the bactericidal effect.

Pulsed electric field (PEF) involve the application of microsecond pulses of a high-strength electric field through a material located between two electrodes and is often classed as a “non-thermal” treatment though some elevation in product temperature can occur. The effect of an electric field on cells has been explained by the dielectric breakdown theory, where the external electric field induces an electric potential over the membrane causing the reversible or irreversible permeabilization of membranes of both eukaryote and prokaryote cells [100]. Although the technology is used commercially in the food industry in some countries [101], there is limited understanding of the impact of PEF processing on solid food matrices [102], particularly high-fat and high-protein foods such as meat [101]. Bolton et al. [103] reported that PEF was ineffective at controlling *E. coli* O157:H7 on beef trimmings or in beef burgers, possibly due to low conductivity and high protein and fat contents. On the other hand, a PEF treatment at 7 kV/cm was effective at reducing *E. coli* K12 (2-log reduction) in a meat injection solution, showing the potential of PEF in meat processing [104]. Arroyo et al. [105] who analyzed effect of pulsed electric field treatment at various stages during conditioning on quality attributes of beef *longissimus thoracis et lumborum* muscle, showed that the length of meat ageing before and after PEF application exerted no influence on weight loss, colour and cook loss. Results demonstrated that PEF treatments applied at different times post-mortem (2, 10, 18 and 26 days) showed a tendency towards reducing the toughness of beef samples, but that the application of PEF did not affect the tenderization process provided by ageing itself.

High pressure processing (HPP) is another emerging and promising technology for meat safety, including boloness meat products, cred meat products, and RTE meat [106]. It is technology used to damage pathogens in meat products while enhancing tenderness [107]. The use of HPP to reduce microbial loads has shown great potential in the meat, poultry and seafood industry [108]. HPP is generally applied at the post-packaging stage so that it will avoid further contamination during later food processing. At ambient temperatures, vegetative microorganisms and enzymes can be inactivated by applying a pressure of 400 to 600 MPa [109]. Similarly, HPP at 400 to 600 MPa was effective in controlling most major foodborne pathogens (*E. coli* O157:H7, *L. monocytogenes*, *Salmonella* spp. *S. aureus*, and so on) present in various meat products such as vacuum-packaged ground beef, cooked ham, and dry cured ham [110,111]. It has been reported that in RTE meat treated with 600 MPa at 20 °C for 180 s, no significant deterioration in sensory quality was perceived [112].

Cold plasma (CP) is an emerging non-thermal treatment and decontaminates meat products effectively in the experiments. The antimicrobial efficacy of CP treatment have been established by a significant number of studies [113–116]. Rød et al. [117] reported that a 20 s CP treatment of a ready-to-eat meat product bresaola resulted in reduced *Listeria innocua* concentrations by 0.8–1.6 log cfu/g. Fröhling et al. [118] found that after a CP treatment, total aerobic plate counts from fresh pork meat remained between 10<sup>2</sup> and 10<sup>3</sup> cfu/g during a 20-d storage period at 5 °C. Noriega et al. [119] used CP to treat chicken meat and chicken skin contaminated with *L. innocua* and found that under optimal conditions an 8-min treatment resulted in a 1 log *L. innocua* reduction on skin, while a 4-min treatment produced a >3 log reduction on muscle. With bacon slice, Kim et al. [120]

found that the decrease in pathogen bacteria was 1–2 logs after helium CP treatment, while it was 2–3 logs after helium/oxygen CP treatment. With a DBD-based probe, Dirks et al. [121] demonstrated that CP treatment could reduce bacterial population, including both pathogens and background microflora, on either fresh poultry muscle or skins. These experiments suggested that the in-package DBD-based CP treatment might be used to reduce the meat background micro-flora and extend fresh poultry meat shelf life.

This emerging technique negatively affected the fatty acids of pork, beef, and chicken. Applying atmospheric pressure cold plasma for one minute at the power of 62 W to Bresaola (dried and aged salted beef) inside a modified atmosphere package (30% O<sub>2</sub> and 70% Ar) adversely affected the beef lipids and increased the TBARS value from 0.15 to about 0.35 mg/kg [117]. Similar values of TBARS was reported by Jayasena et al. [122] for a 10-min plasma-treated beef loin. According to the reported data by Rød et al. [117], lipid oxidation correlates with increasing the input power (from 15.5 to 31 W), plasma exposure time (from two seconds to one minute) and storage time (1–14 days). Similarly, Sarangapani et al. [123] reported that plasma-treated beef was free from oxidation products when the exposure time was limited to less than 30 min. However, long exposure time to plasma oxidized the beef lipids. The effect of a 60 min atmospheric plasma treatment on the physiochemical properties of a pork-based batter was investigated by Jung et al. [124], and no sign of lipid oxidation was observed in the plasma-treated batter according to the malondialdehyde concentrations of the samples. The study concluded that different plasma treatment systems might affect food lipids differently and; therefore, selecting suitable equipment and defining appropriate process conditions can protect the food lipid from oxidation during plasma treatment. Similarly, exposure to a 600 W cold plasma did not increase the malondialdehyde content of canned ground hams [125]. Likewise, Cui et al. [126] investigated the effects of cold nitrogen plasma on the pork lipid and reported that plasma treatment significantly increased the TBARS value of the plasma-treated meat.

On the basis of previous observations, in Table 6 there is a comparison of the discussed techniques of preservation of meat products in terms of nuisance for service as well as costs and possibilities of their application on the technological line.

**Table 6.** Comparison of the discussed techniques of preservation of meat products in terms of nuisance for service as well as costs and possibilities of their application on the technological line.

Specification	Nuisance to the Service	Application Costs on the Technological Line	Possibilities of Application on the Technological Line
PL	The need to work in safety glasses at the workplace - point action but with reflections	Low	For use in a belt conveyor system
OMF	Harmless	Midium	For use in a belt conveyor system
Sonication	Very harmful - the need for acoustic shields	High	Special, separate room for use on material
Low temperature plasma	Work in an insulated system under a glass bowl, in an atmosphere of gases and under vacuum	High	Special, separate room for use on material
HHP	Harmless	Very high	Special, separate room for use on material
Vacuum packing with shrinking	Harmless	Medium	For use in a belt conveyor system

## 5. Conclusions

Unconventional food processing is a new concept required to meet the challenges of the 21st century. It may have the potential to protect both the natural environment and consumers, and at the same time makes it possible to increase competition from industry so that it should be more ecological, economical and innovative. Unconventional methods may solve the problem of new emerging pathogens, and at the same time provide food with high nutritional value and with a longer shelf life. The development of methods that shorten the duration of food preservation processes contributes both to the reduction in food production costs and to the protection of the natural environment, as well as to the production of high-quality products without chemical additives. New technologies reduce

energy and water consumption, and lower water consumption reduces the amount of waste water to be disposed. Still, the use of new technologies on a global scale is a challenge for food technologists and researchers. It is therefore necessary to provide clear and objective information on the available possible solutions as well as on the existing potential of the development of given technologies.

Common features of unconventional food preservation methods include the inactivation of microorganisms, and thus the prolongation of the shelf life of meat products without deterioration, and sometimes even with the improvement of their nutritional, sensory and in most cases organoleptic properties. Most often, vegetative forms of bacteria are inactivated, while the effect on the spore forms of microorganisms and the extension of the storage period depends on the type of method and the parameters used. Moreover, the use of these methods of meat products preservation does not seem to cause changes leading to the formation of toxic compounds that might pose health risks. On the other hand, the diversification of the use of the described methods is associated with costs and possibilities of their application on the technological line.

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