DOI: https://doi.org/10.70749/ijbr.v3i8.2170

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://ijbr.com.pk
ISSN: 2960-2793/ 2960-2807

Sustaining Meat Quality and Shelf-life: Comparative Review of Packaging Techniques and Their Nutritional Implications

Hafiza Aiman Shehzadi[1], Muhammad Akhtar[1], Fatima Afzal Khan[1], Maheen Riaz[1], Aneeza Imran[1], Maria Haris[1], Hifza Arshad[2], Abdurrehman Abbas[2], Saliha Khursheed[1], Almas Asghar[1], Sheikh Ammar Saeed[1], Ayesha Fazal[1]

[1]Department of Food and Nutritional Sciences, Faculty of Science and Technology, University of Central Punjab, Lahore, Punjab, Pakistan.
[2]National Institute of Food Science and Technology, Faculty of Food Nutrition and Home Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan.

ARTICLE INFO

Keywords: Vacuum Packaging, Active and Smart Packaging, MAP, Biodegradable Packaging, Meat Safety, Sustainability.

Correspondence to: Muhammad Akhtar, Department of Food and Nutritional Sciences, Faculty of Science and Technology, University of Central Punjab, Lahore, Punjab, Pakistan.
Email: muhammadakhtar@ucp.edu.pk

Declaration
Authors' Contribution
All authors equally contributed to the study and approved the final manuscript

Conflict of Interest: No conflict of interest.

Funding: No funding received by the authors.

Article History
Received: 14-06-2025 Revised: 17-08-2025
Accepted: 24-08-2025 Published: 30-08-2025

ABSTRACT

Packaging plays a significant role in maintaining the safety, quality, and nutrition of meat and meat products. The effects of packaging technologies on shelf life, spoilage, and sensory qualities are covered in this review. Nowadays, several techniques are in practice such as vacuum sealing, active and smart packaging, MAP, and biopolymer films. With an emphasis on microbial life, nutrition, and acceptability, it also addresses the relationship between the meat quality and the packing materials utilized. Moreover, the preservation techniques employed, the economic and environmental effects of meat waste, and how these aspects affect the competitiveness of international trade are also covered. The effects of meat waste on the economy, the environment, and the competitiveness of international commerce are also covered. Product safety, sustainability, and the use of eco-friendly, bioactive, and intelligent materials should be the main areas of future study. Conclusively, innovations in the product's package design and materials will undoubtedly affect waste management, product safety, and industry and customer expectations.

INTRODUCTION

Maintaining human health requires eating whole, nutrient-dense, and fresh foods. The term "balanced diet" has gained popularity worldwide, ensuring the body consumes all essential nutrients for everyday functions. Understanding the nutritional composition of food is crucial for a well-balanced meal. Nutrients, including macronutrients like proteins, lipids, and carbohydrates, are essential for growth and life maintenance. Foods like meat, cereal grains, milk, fruits, and vegetables provide these nutrients, with meat being the most important. Glycogen, a carbohydrate in meat, affects its color, texture, and tenderness. Research focuses on improving fatty acid composition in meat, especially in single-stomach poultry and pigs. Meat contributes up to 20% of long-chain omega-3 fatty acid intake, reducing cardiovascular illnesses, obesity, and diabetes. (Ahmad *et al.,* 2018).

Meat is a crucial nutrient-dense, energy-dense natural dietary product, rich in proteins, lipids, vitamins, and amino acids. It comes from domestic animals, poultry, and wild animals. Breeds, feed types, climate, and cuts affect its nutritional content. Research is ongoing to understand variations Packaging plays a crucial role in the production, storage, and transportation of meat and meat products, ensuring their quality and upholding standards for sale. It shields meat from mechanical, chemical, and biological risks, such as parasites, germs, dirt, and harmful chemicals. Although packaging alone cannot prevent contamination, it acts as a barrier against subsequent contamination. The "hurdles technology" approach suggests that packaging should be used in conjunction with other treatments to reduce beef deterioration. There are three types of packaging: main, secondary, and tertiary. Main packaging preserves sensory and chemical qualities, secondary packaging offers mechanical protection, and tertiary packaging simplifies palletizing, shipping, and transportation (Robertson *et al.,* 2012).

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

Nutritional Profile of Meat

Meat is a crucial nutrient-dense and energy-dense natural dietary product, rich in proteins, lipids, vitamins, and amino acids. It comes from domestic animals, poultry, and both wild and domesticated animals. Meat's nutritional content varies across breeds, feed types, climate, and cuts. Red meat is popular due to its high biological value protein, micronutrients, and omega-3 polyunsaturated fats. It contains essential vitamins, minerals, and bioactive substances, including vitamin B12, riboflavin, niacin, vitamin B6, pantothenic acid, vitamin A, and folate. Meat's moisture content affects its color, texture, and flavor. Glycogen, a carbohydrate stored in the liver, affects meat color, texture, tenderness, and water-holding ability. Research focuses on improving fatty acid composition in meat, especially in single-stomach poultry and pigs. Plant-based diets should include high-quality protein, riboflavin, vitamin B12, vitamin D, iron, zinc, and selenium if animal consumption decreases (Karwowska *et al.,* 2021).

Health Benefits

Meat is a crucial nutrient-dense and energy-dense natural dietary product, rich in proteins, lipids, vitamins, and amino acids. It comes from domestic animals, poultry, and both wild and domesticated animals. Meat's nutritional content varies depending on breeds, feed types, climate, and cuts. Red meat is popular due to its high biological value protein, micronutrients, and omega-3 polyunsaturated fats. It contains essential vitamins, minerals, and bioactive substances, including iron, zinc, selenium, and bioactive substances. Meat's moisture content affects its color, texture, and flavor, and its fatty acid composition, especially in single-stomach poultry and pigs, can contribute up to 20% of long-chain omega-3 polyunsaturated fatty acid intake. Plant-based diets should include high-quality protein, riboflavin, vitamin B12, vitamin D, iron, zinc, and selenium if animal consumption decreases. Meat has been a staple of human diets since prehistoric times due to its health-promoting properties (Nath *et al.,* 2024). Consumption in moderation and as part of a balanced diet offers health advantages, including preserving muscle mass and reducing chronic illnesses. However, substantial consumption of red meat and meat can cause chronic diseases due to the lipid profile of animal fat and substances added during processing. Meat and animal products are a major source of iron and vitamin D, with meat and liver containing 25(OH) D3, a high biological activity vitamin D3 metabolite. Moderate meat consumption is generally advised despite ongoing discussions about its potential health effects (Carlotta *et al.,* 2022).

Protein

Meat protein offers numerous health benefits due to its high-quality amino acid profile and bioactive peptides. It is essential for muscle maintenance, immune function, and preventing chronic diseases. Beef bioactive peptides have potential health benefits, including anti-inflammatory, antihypertensive, and antioxidant properties. Dietary protein is essential for overall health and growth, and higher-protein diets offer potential benefits like strength, preservation, and muscle protein synthetic response. However, excessive meat consumption can lead to negative health outcomes (Carbone *et al.,* 2019).

Minerals and Vitamins

Meat is a rich source of minerals, vitamins, and proteins, with an average daily consumption of 189g among British adults contributing to 19-52% of iron, zinc, selenium, and phosphorus. Red meat is the greatest dietary source of iron, with heme-iron, a complexed form, having the highest bioavailability. Meat and meat products account for 30% of the total vitamin B12 consumption in the UK. Switching to a vegan diet can significantly impact vitamin and mineral status, essential for healthy neurological function, immune system function, and energy metabolism (Lujuan et., al 2020). Minerals are necessary micronutrients for cellular development, function, and neuromodulation as well as for preserving health. Chronic illnesses, organ damage, metabolic problems, and even death can result from a deficiency in certain minerals. Mineral shortages affect more than 2 billion individuals globally, the majority of whom live in third-world nations. Pregnant women and infants are more susceptible to these deficits. Severe anemia, weakened immunity to infections, and pregnancy difficulties can all result from iron deficiency. In order to increase the intake of critical minerals—at least twenty are required for human biochemical processes—dietary variety is required. Minerals like iron and zinc, which are exclusively found in muscle foods, are absent from plant-based diets. The body's iron content and bioavailable iron may be raised by consuming around 50g of meat, poultry, or fish per day (Falowo *et al.,* 2021).

Amino Acids

Meat, similar to human skeletal muscle, provides amino acids essential for muscle growth and maintenance. Consuming animal protein can help prevent sarcopenia; the loss of muscle mass due to aging. Studies show an inverse relationship between frailty incidence and animal protein consumption. Meat also contains essential amino acids and bioactive metabolites, which can influence the gut environment. A Mediterranean diet with dietary fiber reduces toxic amino acid metabolites (Nina *et al.,* 2021).

Dietary EAAs (Essential amino acids) have been found to improve meat quality in pigs. Lysine, a limiting amino acid, is essential for growth performance and muscle growth. Flavor amino acids (FAAs) are also important for meat quality. Supplementation of FAAs, such as aspartic acid, glutamic acid, and arginine, can accumulate in meat. EAAs, such as lysine, methionine, threonine, tryptophan, and BCAAs, may also affect meat quality in other ways (Liao *et al.,* 2024).

Fatty Acids

Red meat, a major source of saturated fat, has been linked to increased risk of cardiovascular disease and diabetes. To reduce saturated fat, feeding practices have been developed to alter the fatty acid composition of beef and pork. Ruminant meat contains conjugated linoleic acid and unique rumen-derived fatty acids, which have been linked to positive health effects. However, increasing unsaturated fat content can lead to meat products that consumers find unacceptable due to oxidation and less firm structure (Nina *et al.,* 2021).

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

Meat, a significant fat source, has gained attention for its health benefits. It contains high saturated fatty acids, while ruminant meats are low in polyunsaturated fatty acids. This balance can predispose people to diseases like cardiovascular disease. However, meat fatty acid composition can be influenced by factors like animal diet, age, weight, sex, and breed (Ingrid *et al.,* 2023).

Production Losses

The meat industry faces significant production losses and consumer product waste, with up to 23% of production lost or discarded. Consumption accounts for 64% of food waste, with manufacturing second at 20%. Meat production has the highest emissions per kilogram, necessitating rational management throughout the entire chain. New prospects for the meat business include turning waste into useful goods like biologics, expensive additives, and culinary treats. Efficient solutions must exist along the whole meat supply chain to decrease food lost and wasted (Ruigang *et al.,* 2023). Meat production losses in Pakistan are influenced by climate change, disease outbreaks, and inadequate feed resources. Rising temperatures negatively impact livestock growth and production rates, while over 30% deficiency in crude protein and total digestible nutrients exacerbates productivity losses. Advancements in livestock management and disease control could potentially mitigate these losses and enhance Pakistan's overall productivity and food security.

In 2019, 18 billion animal lives were lost due to meat loss and waste, emphasizing the need to address production losses and food waste for improved animal welfare. Producer welfare losses vary by type, with poultry experiencing the lowest losses due to fewer processing plants and smaller own-price elasticity. China's normalized total meat loss rate was 6.4%, or about 4.9 million tons, representing significant protein and energy losses in the supply chain. Future dietary structural changes and environmental issues necessitate specific attention and mitigation actions to address this growing loss (Ruigang *et al.,* 2023).

Global Import and Export Status

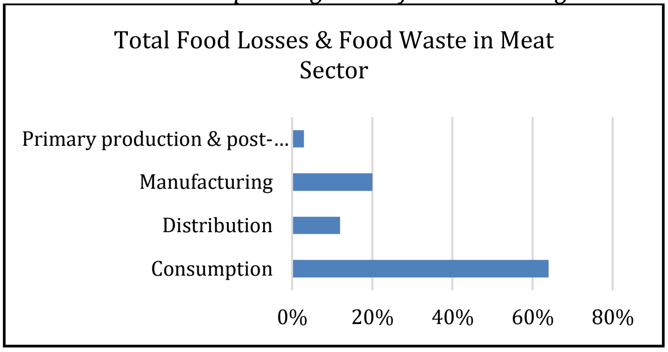
The global meat trade is crucial for meeting the growing population demands and is influenced by factors such as changing consumer tastes and market access restrictions. In 2020, 337.2 million tons of meat were produced globally, with 36.6 million tons intended for export. The growing middle class in developing nations contributes to the increased demand for meat products. Brazil, the United States, and China are the largest producers of chicken meat, accounting for over half of exports and 46% of global production. However, imports are still essential to satisfy consumer demand, with China and Brazil growing production capacities. The global meat and dairy trade is interconnected, with the anticipated doubling of milk exports from wealthy nations. Despite its expansion, the global beef trade faces challenges such as trade disputes, market access obstacles, and geopolitical conflicts. China's increasing global meat suppliers impact import demand and the competitiveness of U.S. meat exporters. Addressing these issues requires creative solutions and international collaboration (Enahoro *et al.,* 2021).

Impact of Meat Wastage on Global Import & Export Status

Meat wastage is defined as the decrease in the amount of edible food mass that happens throughout the meat supply chain from the processing & production stages to the consumption stage. It brings attention to the need of innovative methods to cut waste while improving the value of meat products (Mohan & Long, 2021). Meat wastage is a crucial issue within the global food system. The Food and Agriculture Organization estimates that every year, over 20% of the world's meat production is wasted. This waste occurs throughout the entire supply chain, from the production phase through the consumption phase (Attila *et al.,* 2019).

Figure 1

Food losses & food waste in the meat market in the European Union in 2011 corresponding to the food chain stages



Meat waste reduces marketable volumes, lowers export competitiveness, and increases import dependence, in addition to its environmental & ethical impacts. While 64% of all food loss occurs at the consumer level, about 23% of the meat industry's output is wasted or lost (Karwowska *et al.,* 2021). It is necessary to comprehend the complex relationship between waste and trade in order to develop sustainable solutions in the global meat market. About 1.7 million tons of meat are wasted annually in the European retail industry, with 20% of the meat that could be consumed going to waste. Thirty-three percent of all meat waste in Europe comes from the processing and retail stage (Pinto *et al.,* 2022)

Economic Implications of Meat Wastage on Trade

Countries with high meat waste rates have lower exportable surpluses. This makes them less competitive on the world market. For example, Brazil which is a major meat exporter predicted yearly economic losses from meat waste of more than $2 billion in 2020. Wasted meat makes domestic markets scarcer, which forces imports to keep up with demand. India and other developing nations frequently depend on imports to fill the gaps left by post-harvest losses and supply chain inefficiencies (Meat Market Report, 2021). Due to reduced shelf life and quality, meat spoiling impacts trade and imposes major financial losses globally. These losses get severe by poor preservation techniques, which have an effect on the meat and meat product trade and economy.

Meat Processing Methods

Meat processing is a critical component of the food industry, ensuring the transformation of raw animal products into a diverse array of consumable goods. In

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

order to improve the safety and preservation of meat as well as its flavour, texture, and nutritional value, a variety of methods are used. It encompasses various techniques each with its unique advantages and challenges (Zhou *et al.,* 2012)

Traditional Meat Processing Methods

Cutting and Grinding

Two fundamental yet crucial meat processing techniques are cutting and grinding. Cutting is the process of dividing meat into smaller, easier-to-handle chunks, which is necessary for packaging, portion control, and additional processing. The process of grinding, on the other hand, reduces the size of meat particles and is frequently utilized for goods like minced beef, burgers, and sausages. Although it might affect texture and moisture retention, grinding improves seasoning absorption by increasing surface area. However, a mushy texture which is undesirable in some beef products, might result from excessive grinding. A multi-stage method is used by contemporary meat grinders, including the ones outlined. This involves cutting and then grinding the flesh. The total effectiveness and calibre of the minced product are enhanced by this technique (Travis *et al.,* 2024).

Curing

Applying salt, nitrates, nitrites, and sugar to meat is known as curing. It is an ancient method of preserving meat. This method aids in meat preservation, flavour enhancement & colour development. The curing agents extend the shelf life by preventing oxidation & microbiological growth. Although curing works, there are health risks linked to it, especially when nitrite is consumed. For this reason, natural curing agents have been developed as alternatives (Harris, 2009). Cured meats, like ham and bacon, get their distinctive taste from chemical reactions occurring during the curing process. However, consuming excessive amounts of them has been associated with an increased risk of developing cancer since cooking produces chemicals which lead to cancer (Bingham *et al.,* 2002).

Smoking

Smoking is commonly combined with curing and drying to extend the meat's shelf life. Smoking provides the meat unique flavours and colours while also having antibacterial properties. Phenolic compounds present in wood smoke aid in preventing the growth of decaying microbes. However, factors such as the type of wood, smoking temperature, and exposure time affect the amount of smoke absorption and the chemical composition of the smoke (Lorenzo *et al.,* 2015). The concentration of organic acids and total phenols rises as a result of higher temperatures during smoking (Rekanović, 2024).

Fermentation

One of humanity's earliest methods of food preservation is microbial fermentation. When a strain of microbial flora develops successfully, it overpowers and displaces other unwanted microbes. This results in fermented meat whose metabolites help give it the right sensory qualities. Fermented meats come in a wide range of variations, depending on the country, area, climate, heritage, and culture. As a result, fermentation is carried out using varying quantities of raw ingredients, spices, condiments, and processing times (Toldrá, 2001).

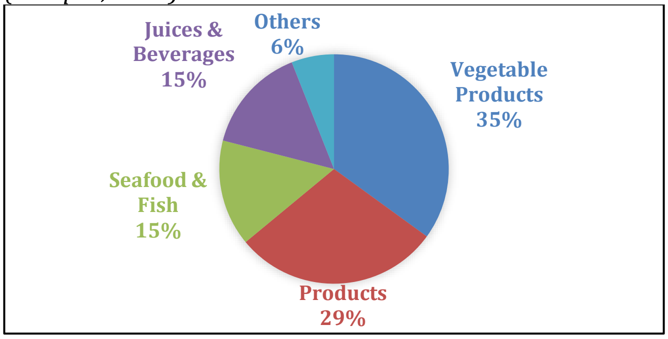
Modern Meat Processing Technologies

High-Pressure Processing (HPP)

High-Pressure Processing (HPP) is a non-thermal method for preserving meat by inactivating harmful microbes without altering flavor, color, or nutritional content. It has gained popularity in the meat, poultry, and seafood industries for preserving freshness and meeting regulatory requirements, particularly in stabilizing cured and ready-to-eat meats (Patterson *et al.,* 2012).

Figure 2

Industrial HPP machines in different food industries (Campus, 2012)



Thermal Processing

Thermal processing methods, such as pasteurization, sterilizing, and frying, use heat to get rid of harmful microbes from meat. These methods are commonly used for ready-to-eat meats, canned meats, and sausages. Although thermal treatments are useful for guaranteeing food safety, they can also result in unfavourable alterations to the nutritional value, flavor, and texture of food. Water-soluble vitamins such as vitamin C and B vitamins, can be lost due to overheating, which can also denaturize proteins HPP is being evaluated for its impact on muscle proteomes, with ideal processing factors determined for meat items and sauces. Gram-negative bacteria are more susceptible, making HPP a suitable final processing step for safer food items. It can extend refrigerated shelf life and remove food-borne pathogens without affecting color, flavor, texture, or moisture. HPP and thermal processing are being combined for individual sterilization in food items (Buckow *et al.,* 2014)

Pulsed Electric Field (PEF)

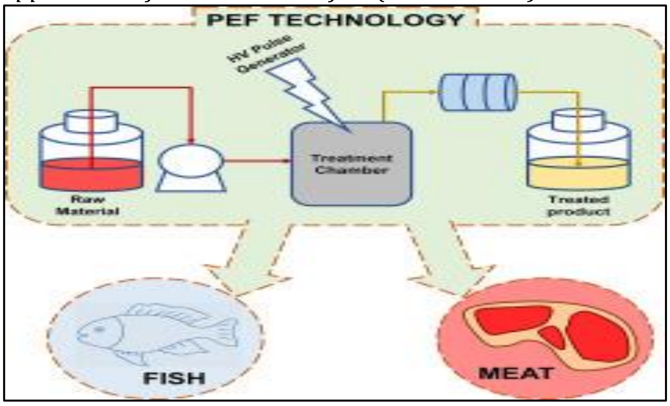
A developing technique called pulsed electric field (PEF) uses electrical currents applied between two electrodes to create electroporation which enables a non-invasive alteration of the structure of tissues. Preservation, tenderization, and aging are just a few of the processes that PEF treatment can enhance. The pulsed electric field (PEF) is regarded as a very promising non-thermal method for food preservation and quality enhancement. The technique applies electric field pulses with an intensity of 0.1–80 kV/cm and a brief duration (a few nanoseconds to a few milliseconds) to food that is enclosed between or passed through two electrodes. (Buckow *et al.,* 2013). PEF has also been reported to improve drying, speed up curing, and lower the quantity of pathogens and spoilage

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

organisms in meat, however this requires rigorous processing conditions. (Bhat *et al.,* 2018)

Figure 3

Application of PEF on meat & fish (Gómez, 2019)



Sous-Vide Processing

Sous-vide (SV) is a cooking technique that involves cooking vacuum-packed ingredients under regulated temperature and time conditions. It was initially used to prolong food items' shelf life. SV incorporates techniques such as prolonged process time, low temperature, and vacuum conditions to restrict adverse changes. It requires longer heating times and temperatures ranging from 50 to 85°C. Heat treatment conditions depend on factors like meat type, cut size, intramuscular connective tissue, and myofibrillar protein components (Ismail *et al.,* 2019).

Combining SV with non-thermal techniques like electron beams, gamma irradiation, hydrostatic pressure processing, and ultrasound can enhance meat's juiciness and tenderness without overcooking. Histological investigations show that sous-vide processing at different temperatures improves overall texture and preserves vital elements like vitamins and minerals. By regulating the cooking process, sous-vide preserves meat's nutritional value while improving its flavor (Alam *et al.,* 2024).

Meat Preservation Methods

Meat preservation aims to improve quality, eliminate bacteria, and extend shelf life. Traditional techniques are divided into temperature, moisture, and inhibitory processes. Antimicrobial principles can be used in each technique, with each control procedure acting as a "hurdle" to prevent microorganism growth. Combinations of these techniques can be developed to achieve specific goals for both microbiological and organoleptic quality (Rahman *et al.,* 2023).

Traditional Meat Preservation Methods

Salting and Drying

Salting meat lowers its water activity and stops microbes from growing, making it one of the oldest methods of meat preservation. Salt also acts as a preservative by drawing moisture out of the meat. This reduces the possibility of bacterial growth and rotting. This method is commonly combined with drying, either by air-drying or smoking. However, the high sodium content in salted and dried meats can have detrimental effects on health, including hypertension and cardiovascular issues, even if they are beneficial for long-term preservation (Toldrá, 2006).

Freezing

A popular preservation technique is freezing, which lowers the meat's temperature below freezing to inhibit enzymatic and microbiological reactions. This procedure helps maintain the nutrition, texture, and quality of meat, especially when it comes to beef, pork, and chicken. But there are some disadvantages to freezing as well. During freezing, ice crystals form inside the flesh cells. When these crystals thaw, they can tear the muscle fiber, causing moisture loss and changes in texture called freezer burn which can degrade meat quality (Leygonie *et al.,* 2012).

Modern Meat Preservation Methods

Tray and Overwrap

A common method applied for retail meat is to wrap it in plastic film that helps allowing some gaseous exchange. It keeps the products visible while preventing it from contamination of impurities. As usually, overwrapping needs plastic films, which play and act as a barrier against the moisture and oxygen and are mandatory for obtaining the desired quality of meat. This technique, which is most frequently applied to poultry, entails placing the meat on a tray and wrapping it with the use of plastic wrap. Although, it is easy to applied and reasonably costly, it provides protective defense against spoiling (Maheswarappa *et al.,* 2015).

Vacuum Packaging

Vacuum packing is the process of assembling a product in a high-barrier container with air removed to stop the growth of aerobic spoilage organisms, shrinkage, oxidation, and color deterioration. By eliminating air from the package, this technique prolongs shelf life by lowering oxygen levels that may encourage spoiling. According to studies, vacuum-packed meat frequently has higher juiciness and tenderness ratings than MAP, which could influence consumer preference (Ząbek *et al.,* 2021). Vacuum Packaging has a preservative effect because it creates an oxygen-deficient environment that severely or completely inhibits potential spoiling organisms. Large boneless joints are packed in flexible plastic bags using the vacuum packaging technique to keep moisture out and keep oxygen out of the meat samples. For vacuum packaging, the plastic films must be tough enough to support hefty meat joints and have low gas and moisture penetration (Seideman & Durland 2007).

Aseptic Packaging

To get rid of pathogens, the meat is cooked at temperatures between 140 and 150°C. To prevent from reinfection, the meat is packed in airtight containers after sterilization. To ensure that the sterilized meat is sealed into sterile containers without contacting with impurities, a variety of aseptic fillers are utilized. Depending on the product requirements, aseptic packaging can make better use of materials including flexible pouches, paperboard cartons, and metal cans. Packaging materials that has to be employed must have barriers to light, oxygen, and moisture to maintain product quality. Convenience and safety are the desired features for the tremendous demand for shelf-stable meat items, especially in the Asia-Pacific area. Sustainable packaging materials are attaining more

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

focus, yet recycling problems still persist in various areas (Hwang *et al.,* 2015).

Chilled Vacuum Packaging

Recent studies show, better hygienic practices and packaging techniques have enhanced the shelf life of chilled vacuum-packed beef from 14 weeks to almost 28 weeks. Lactic acid bacteria are the most commonly found bacteria in vacuum-packed beef, as they rise in low-oxygen conditions and aid in preserving the meat. (Sumner *et al.,* 2021). It has been shown that thermoforming vacuum packaging can lower down the lipid oxidation and preserve ground beef pigments while it is kept for storage. The meat color metrics are impacted by the composition of storage time and packaging type, suggesting that appropriate packing aids in preventing quality degradation (Bernardez-Morales *et al.,* 2024).

Retort Pouch Packaging and Caning

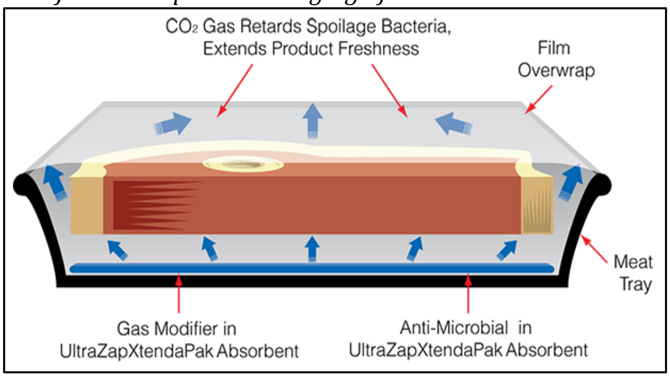
Thermally processed canned meat items are hermetically packaged into sealed containers, often tin coated steel cans, to prevent air exchange. Sterilized products have shelf stability and require heating at a minimum of 101°C. They remove or place all living microorganisms. Retort cookers process canned items at pressures between 12 and 15 psi. Retort pouches, flexible, laminated multi-layer pouches, have been replaced by metal cans for moisture and gas barriers. Foil-laminated retort pouches are lighter, less costly, and more efficient for distribution and marketing.

Modified Atmosphere Packaging (MAP)

Modified atmosphere packaging (MAP) is a method that removes or replaces the atmosphere surrounding a product before sealing in vapor-barrier materials. It uses three primary gases: oxygen, carbon dioxide, and nitrogen to prevent anaerobic growth, inhibit microorganisms, yeast, and molds, and prevent package collapse. MAP offers numerous benefits for maintaining market quality and safety of meat products, slowing down life processes. Success depends on factors like initial product quality, hygiene, packaging material selection, gas mix, reliable equipment, and controlled temperatures and humidity levels (Singh *et al.,* 2011).

Figure 4

Modified Atmosphere Packaging of Meat



Irradiation

Irradiation technology is a highly effective method for food preservation, removing harmful bacteria without compromising the food's nutritional value or organoleptic properties. It efficiently lowers microbial contamination and increases the meat's shelf life by destroying DNA and cell membranes. Irradiation can be applied continuously, regardless of temperature, humidity, or pressure during the food sterilization process. When microbial spoiling is a limiting issue, irradiation can extend the shelf life of food. Irradiation can speed up the oxidation of lipids and proteins, particularly sulfur-containing amino acids and unsaturated fatty acids, while decreasing the quantity of microorganisms and prolonging the shelf life of meat. It impacts both sarcoplasmic and myofibrillar proteins. However, its impacts on meat quality must be carefully considered. Strategies to maintain the general quality and customer acceptance of irradiated meat products include maximizing irradiation doses, using appropriate packaging techniques, and monitoring lipid oxidation. Overall, irradiation technology offers benefits for food safety and shelf life, but its impact on meat quality must be carefully considered (Kim *et al.,* 2024).

Interaction of Meat-Packaging Materials and its Effect on Meat Quality

Canning and Retort Pouch Packaging

Packaging for meat and its products is influenced by various factors, including polymer shrinkage, strength, thickness, oxygen and moisture transmission, and shelf life. Successful packaging depends on how the product inside and packaging materials interact with other display, production, and distribution factors. Factors such as pigment globin state, harvest duration, storage temperature, muscle placement, headspace, and exposure to heat or light can affect the quality of the product. Packing materials can cause flavor scalping, which can lead to loss of desired flavor and transfer of unwanted chemicals. Polyethylene materials are the most common cause of flavor scalping, which degrades food integrity and undermines customer trust in packaged foods. Packaging components with absorption and barrier controls can help address these issues. Elevated oxygen levels in food packaging can significantly reduce meat shelf life due to color changes, microbial development, lipid oxidation, and nutrition loss. Low oxygen MAP can improve flavor intensity and tenderness while preventing off-flavors. Carbon dioxide, which prevents microorganism growth, is used in packaging to prevent microbial growth and enhance shelf life. Nitrogen filling is used to preserve pack shape or lower gas concentration. The gaseous environment surrounding meat and meat products can vary due to muscle respiration or microbe metabolism (Maheswarappa *et al.,* 2015).

Active Packaging

Active packaging uses natural extracts like citrus and essential oils for antimicrobial and antioxidant properties. Biodegradable films with Andız shell extract can lower microbial growth in fresh meat during storage. Nanotechnology can improve oxidation and microbiological growth in muscle meats by adding nanoscale active ingredients to polymeric matrices. Customized active packaging solutions are in high demand in cultural contexts like China and New Zealand, using multifunctional active chemicals and sustainable polymers to meet consumer and environmental requirements (Li *et al.,* 2022).

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

Smart Packaging

Both quantitative and qualitative sensors are employed in intelligent or smart packaging to track the integrity of the meat. For instance, pH sensors made from natural sources, such as red spinach extract, might signal freshness by observable color alterations (Supardianningsih *et al.,* 2023).

It has been demonstrated that active ingredients, such as garlic extract, can successfully maintain meat integrity by preventing microbial growth; the best ratios for this purpose have been found. Bromo Phenol Blue and other color-changing indications give consumers visual clues about the freshness of meat, enabling them to rapidly evaluate quality (Dirpan & Hidayat, 2023). By communicating information about product conditions, smart packaging technologies can have enhanced consumer confidence and traceability (Fazliddinovich, 2022).

Overview of Meat Packaging and its Significance in Food Preservation

Meat packaging is more than just for the purpose of retaining food, as the packaging used plays a critical role in the way that food is preserved which directly affects shelf life and nutrient availability. Packaging materials that are superior will reduce the oxygen and moisture exposure needed for spoilage and deterioration in meat quality. Vacuum packaging for example dramatically reduces aerobic bacterial growth, leading to greater freshness and safety of storage. In addition, gas flushing technologies that employ modified atmospheres are also beneficial in the preservation of color and texture and will also help prevent loss of key nutrients. Advanced Packaging Methods Just like sous vide cooking (use of low temperature will increase the safety and shelf life) raises the bar for not only taste but also acceptance among consumers, similar techniques of application. Therefore, inter-doother among meat packaging techniques and preservation process is fundamental for the satisfaction of current food safety requirements on the one side as well consumer need (Misu *et al.,* 2024).

Comparison of Traditional Vs. Modern Packaging Materials

Packaging development has had a profound effect on meat preservation the evolution of packages, from ancient ways versus current innovation packaging at least traditional ones (plastic wrap or butcher paper) offer the minimum barrier against physical contaminants but no microbial protection beyond that. Conversely, contemporary packaging trends considered (MAP and under vacuum packaging in a plastic bag) utilize advanced techniques that advanced the efficiency in preserving meats. For example, that can both cook a package of vacuum-sealed meats to precision, centered on keeping the utmost nutritional values and sensory qualities therefore creating this latest extension on shelf-life for meat. Analysis of Research also suggests that the modern bio packaging materials based on biopolymers can increase the quality of meat under appropriate storage conditions and improve industry sustainability That comparative analysis of course shows how modern meat packaging does not just work to save the meat, but also fit into consumer demand for healthier and safer food (Thathsarani *et al.,* 2022).

Impact of Packaging on Shelf-life Stability

While many environmental factors are responsible for the shelf stability of meat products packaging, which includes control on oxygen; moisture level and microbial contamination respectively. Effective packaging not only acts as a barrier from outside, but helps to the hygiene of products as well and preserve the nutrition. For instance, advanced package technologies such as vacuum, modified atmosphere packaging have been identified to significantly decrease the count of spoilage microorganisms and enzymatic reactions that spoil meat quality 8. In addition, natural packaging preservation has been investigated as a new technology to translate consumer need for healthier options with extended shelf life. It is also aimed at extending the sensory properties and nutritional value of meat products without compromising with freshness by incorporating natural antimicrobials or antioxidants in the packaging.

Packaging Materials for Meat Products Based on polymers and Shungite

The creation of antibacterial polymer composite materials to enhanced meat items shelf life. For the reason of packaging meat products, polymer compositions and packaging materials with different shungite contents were developed. The ideal quantity of shungite in the polymer composition to enhanced the shelf life of meat products was established based on the testing findings. The results of the studies showed that, in comparison to the package made of pure polypropylene, the package made of a composite material containing polypropylene and 20% shungite inhibit the growth of microorganisms on the surface of chilled beef and chicken. Additionally, using the created materials provides the actual three-day improvement in shelf life. (Kirsh *et al.,* 2024).

Impact of Agricultural By-products-based Packaging Material Impact on Meat Shelf-life

The study developed an environmentally friendly bionanocomposite film for meat packaging using inedible agricultural waste and cellulose nanoparticles (CNPs). The film was tested using X-ray crystallography, FTIR, SEM, and agar disc diffusion tests. The results showed that the CNPs were evenly distributed throughout the film, enhancing tensile strength and Young's modulus. The nanocomposites also had antimicrobial activity, limiting spoilage microbes. The CNP-CS films were found to be a main alternative for traditional food package materials, with lower bacteria growth compared to nylon materials after 8 days of storage (Mirhosseini *et al.,* 2024).

Antioxidant and Antimicrobial Coatings and Edible Films in the Chicken Meat Shelf-life Improvement

Meat degradation during manufacturing, distribution, and display can compromise product integrity and safety, affecting industry and consumer health. To address this, research has explored decontamination protocols and packaging techniques. Edible coatings and films made from biopolymers or natural resources, combined with active ingredients, have been studied for their impact on chicken flesh's shelf-life, physicochemical, microbiological, and sensory properties. The primary results include enhanced sensory quality, shelf-life (from 4 to 12 days), lipid oxidation breakage, and reduced microbial growth and pathogen survival (Moura-Alves *et al.,* 2023).

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

Role of Different Packaging in Meat Shelf-life Stability and Nutritional Retention

Packaging of meat products is a crucial in maintaining both shelf stability as well preserving crucial nutritional integrity. As the worldwide meat consumption grows more, appropriate packing solutions are of high importance in meeting consumer needs for safety, freshness and quality. Numerous packaging strategies including vacuum packing, modified atmosphere packaging and immersed wrapped packaging have a major effect on the biochemical processes that can result in spoilage or nutrient degradation. And, the packaging itself (whether it be plastic, biodegradable materials or a natural paper) will have the meat on its direct exposure to oxygen, moisture and microbial contamination. It is for this reason that the interaction between packaging techniques and meat preservation benefits both in terms of prolonging shelf life of products and lessen waste relating to food wastage. The examination of different packaging types discusses a cornerstone research topic to improve meat quality and sustainability challenge for the food industry (Konuk *et al.,* 2024).

Analysis of how different packaging methods affect microbial growth and spoilage

The microbial growth and spoilage in meat products is strongly moderated by packaging, hence affects its quality & shelf-life as well as nutrient retention. Conventional packaging approaches are powerless to reduce microbial load in food items, thus providing an environment for pathogens to thrive and increased risk of food borne illness. On the other hand, vacuum/packaging and MAP technologies are examples of advanced packaging strategies that have been shown capable of slowing microbial growth by modulating oxygen content and organism's spoiling metabolic activity. Bio preservation and natural antimicrobials have been considered as complementary to these packaging methods, supporting an additional barrier against microbial growth while maintaining sensory characteristics of the meat. According to review on preserve strategies, simultaneously approved these packaging tricks and also edible films/coatings save the ability to usher the antimicrobials with surface of meat directly, this increases freshness and also throughput (Konuk *et al.,* 2024).

Nutritional Retention in Packaged Meat

As the demand for fresh and healthy meat stays high, the importance of packaging on nutritional retention is big. Different packaging techniques such as vacuum packing and freeze-drying had profound effects on preventing chemical degradation in the meat essential nutrients. To be more exact, according to research as a function of storage treatments revealed that vacuum packaging resulted in a pronounced decrease in certain saturated, monounsaturated and polyunsaturated fatty acids. which are not included in Table 1 in total five fatty acids. This finding emphasizes, not just how meat is wrapped but also the long-term impression on nutrition quality when done so. Put another way, the packaging material selection helps to suppress oxidation which is quite important for nutritional quality of meats. For this reasons, superior packaging technologies must be used for nutritional value and quality of packaged meat which, since it has to please health consumers, extend the shelf life (Dalle *et al.,* 2022)

Influence of Packaging on The Retention of Essential Nutrients in Meat Products

Packaging plays a crucial role in retaining vital nutrients in meat products, as they are perishable. Active packaging systems using natural chemicals like essential oils have shown potential in improving meat nutritional stability. Biodegradable substances like antioxidants help prolong shelf life and reduce waste, benefiting the food industry. Subsequent advancements, such as sous-vide cooking techniques, have been recognized for preserving meat's natural flavors and nutrients, surpassing traditional methods that typically result in nutrient loss (Fonseca *et al.,* 2015).

Future Perspective of Different Packaging Materials Significant Challenges for Meat Products

Meat products are a rich source of protein, essential nutrients, vitamins, minerals, and water, which are beneficial for human health. However, their high water activity promotes the growth of harmful microorganisms, making them perishable. Meat quality and shelf life are influenced by factors like color, flavor, odor, texture, and storage conditions. Meat color plays a significant role in customers' purchase decisions, and preservation can be achieved through vacuum packaging, modified atmosphere packaging, and additives like salt and nitrite. Meat's red color comes from myoglobin, a complex muscle protein, which undergoes oxidation-reduction processes to give it its color (Wongphan *et al.,* 2024).

Natural Polymers in Food Packaging

Biopolymer-based biodegradable films have emerged as a viable alternative to traditional polymers due to environmental concerns. In 2020, 0.99 million tons of bio-based plastics were used in food packaging, accounting for 47% of total production. Biopolymers are profitable due to abundant raw materials and agricultural waste utilization. Proteins, carbohydrates, and their derivatives are researched nanocomposite biomaterials for food packaging. Starch and cellulose-based nanocomposites offer eco-friendly alternatives and sustainability goals. Edible films and coatings with cellulose derivatives like galactomannans, alginate, chitosan, and gelatin are natural antioxidants for fatty foods (Gil *et al.,* 2023).

Biodegradable Packaging

The production of biodegradable packaging is challenging due to the environmental benefits of conventional plastics. Biodegradable packaging, such as cellulose, is more environmentally friendly than traditional plastics but often contains harmful chemical additives.

Polylactic acid (PLA) and polyhydroxyalkanoates, renewable polymers, have recently entered the market but are not widely used in meat products. PLA, approved by the European Commission and GRAS Generally Recognized as Safe by the American Food and Drug Administration, is a promising option for compostable packaging materials. These substances can preserve food quality, prolong shelf life, and slow down the deterioration of perishable food items. Meat is one of the most perishable items sold in stores, and storage can change its safety and organoleptic qualities. To protect chilled meat

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

from contamination, it is usually wrapped in a polyvinyl chloride (PVC) plastic film and placed on amorphous polyethylene terephthalate. This study investigated edible chitosan-acid solutions containing sodium lactate, lauric arginate ester, and sorbic acid on PLA packaging sheets. LAE-treated PLA films significantly decreased the development of Salmonella and Listeria compared to controls. However, PLA films coated with chitosan, NaL, and SA were less effective against Salmonella (Panseri *et al.,* 2018).

Cellulose Being the most prevalent biopolymer on the planet, cellulose is a perfect starting point for sustainable packaging supplies. Packaging films can be made from cellulose ethers like methylcellulose, carboxymethylcellulose, and hydroxy propyl methyl cellulose. Natural sources of cellulose include cotton, wood, and food waste, fruit skins, cereal bran, and agricultural waste. Because of its diverse origins, biodegradability, affordability, and environmental friendliness, cellulose is frequently chosen as a material for packaging. Cellulose has advantageous organoleptic qualities and sensory in addition to being biodegradable and edible; as a result, it can be utilized to encapsulate bioactive ingredients to improve the nutritional value of food items (Gil *et al.,* 2023).

Starch due to its abundance, affordability, biodegradability, and renewability, Starch is among the most significant biodegradable polymers. As starch-based films offer exceptional film-forming capabilities, distinct gelatinization qualities, and are colorless, tasteless, and odorless, they have been utilized in food packaging and preservation methods. Because starch-based films have strong organoleptic and gas barrier qualities, they have been widely employed in the packaging of various food products up to this point, including meat, fruit, oil and cheese. However, the hydrophile and brittleness of starch-based materials restrict their usage and processing. To enhance its qualities, starch is combined with a variety of natural and synthetic polymers, which strengthens the materials' processing capabilities (Gil *et al.,* 2023).

Chitosan a biopolymer derived from chitin, has strong antioxidant and antibacterial properties for food packaging. Its structure influences its antibacterial action against gram-negative and gram-positive bacteria. Chitosan films contain a strong gas barrier, making them suitable for use with plasticizers like fatty acids or polyols. Gelatin, a water-soluble natural polymer, is used in various industries due to its biocompatibility, biodegradability, and commercial availability. This study aimed to create bio nanocomposites using chitosan and ZnO nanoparticles, using fresh poultry flesh as the food matrix. The bio-based biodegradable films showed good antibacterial activity, with chitosan's antimicrobial capabilities being enhanced by the addition of ZnO nanoparticles (Souza *et al.,* 2020).

Functional packaging of meat

Antioxidant packaging

Antioxidant packaging is a growing trend in the food industry, incorporating natural antioxidants like vitamins, minerals, and fiber from plants and plant materials to preserve and enhance meat. These antioxidants can prevent or postpone oxidation, reducing quality degradation in taste, odour, color, and texture. However, the use of synthetic compounds, nanoparticles, and natural extracts is also being researched. Studies have shown that adding cinnamon oil and rambutan peel extract to whey protein and cassava plant isolate films can maintain meat quality (Horbańczuk *et al.,* 2019).

Additionally, red extract of cabbage and sweet whey contain phenolic compounds and anthocyanin, which can slow down oxidation and prevent loss of meat quality. The interaction between natural extraction antioxidants and polyphenols is primarily caused by polyphenols, which can slow down oxidation and prevent loss of meat quality (Wongphan *et al.,* 2024).

Antimicrobial packaging

Microorganism development impacts food safety, shelf life, and quality. Antimicrobial chemicals are added to preserve food quality and prolong shelf life by preventing the growth of microorganisms. These substances penetrate bacterial walls, leading to denaturation of proteins, disintegration of cell membranes, and cell lysis. Factors such as solubility, concentration gradient, and release ability of antimicrobial agents are crucial for their effectiveness (Dongo *et al.,* 2020).

Bioplastic polymers can be coated, extruded, or cast with antimicrobial agents to prevent the growth of Gram-negative, Gram-positive, and fungal bacteria. New functional packaging technologies can also improve meat quality and shelf life. Absorbent materials like oxygen absorbers, ethylene absorbers, moisture absorbers, and anti-mold and anti-bacteria films are used to prevent bacteria growth and work well with moist foods. Antibacterial compounds like chitosan, tea tree oil, ethanol, cinnamon, thyme oils, and alginates are also used in active packaging (Laorenza *et al.,* 2021).

CONCLUSION

Meat packaging maintains quality while preserving freshness and nutrients. Simple preservation techniques provided way to more advanced ones like vacuum sealing, smart packaging, modified environment packaging, and even biodegradable films. These methods not only extend the shelf life of products while maintaining their nutrition, flavor, and texture, but they also tackle important problems including sustainability, production losses, and food waste. Selecting appropriate packaging materials and methods aids in satisfying customer demands and preserving competitiveness in global marketplaces. Another problem is meeting expectations while preserving the environment. Advanced potential for containing meat while simultaneously taking care of the environment is offered by bioactive, intelligent, and biodegradable packaging. The secret to success is to properly preserve the safety and nutritional value of beef, meet customer demands while reducing waste, and deliver it in the best possible condition.

REFERENCES

Ahmad, R. S., Imran, A., & Hussain, M. B. (2018). Nutritional composition of meat. *Meat Science and Nutrition*. https://doi.org/10.5772/intechopen.77045

Alam, A., Mia, N., Monti, J., Hashem, M., & Ali, M. (2024). Enhancing the qualitative attributes of meat through processing and preservation techniques- A review. *Meat Research*, *4*(3).

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

https://doi.org/10.55002/mr.4.3.92

Arvanitoyannis, I. S., & Stratakos, A. C. (2012). Application of modified atmosphere packaging and active/Smart technologies to red meat and poultry: A review. *Food and Bioprocess Technology*, *5*(5), 1423-1446. https://doi.org/10.1007/s11947-012-0803-z

Baldwin, D. E. (2012). Sous vide cooking: A review. *International Journal of Gastronomy and Food Science*, *1*(1), 15-30. https://doi.org/10.1016/j.ijgfs.2011.11.002

Barba, F. J., Ahrné, L., Xanthakis, E., Landerslev, M. G., & Orlien, V. (2018). Innovative technologies for food preservation. *Innovative Technologies for Food Preservation*, 25-51. https://doi.org/10.1016/b978-0-12-811031-7.00002-9

Bashir, O., Rashid, S., Jan, N., Umam, A., Amin, T., Jabeen, A., Wani, S. M., Afiya, S., & Sidiq, H. (2022). Aseptic packaged food. *Shelf Life and Food Safety*, 307-320. https://doi.org/10.1201/9781003091677-16

Belova, A. V., Smutka, L., & Rosochatecká, E. (2013). World chicken meat market - its development and current status. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *60*(4), 15-30. https://doi.org/10.11118/actaun201260040015

Benyathiar, P., Mishra, D. K., Szemplenski, T. E., & David, J. R. (2022). Aseptic filling and packaging for retail products and food service. *Handbook of Aseptic Processing and Packaging*, 171-210. https://doi.org/10.1201/9781003158653-10

Bernardez-Morales, G. M., Douglas, S. L., Nichols, B. W., Barrazueta-Cordero, R. J., Belk, A. D., Brandebourg, T. D., Reyes, T. M., & Sawyer, J. T. (2024). Vacuum packaging can protect ground beef color and oxidation during cold storage. *Foods*, *13*(17), 2841. https://doi.org/10.3390/foods13172841

Bhat, Z. F., Morton, J. D., Mason, S. L., & Bekhit, A. E. (2018). Current and future prospects for the use of pulsed electric field in the meat industry. *Critical Reviews in Food Science and Nutrition*, *59*(10), 1660-1674. https://doi.org/10.1080/10408398.2018.1425825

Bongiorno, T., Tulli, F., Comi, G., Sensidoni, A., Andyanto, D., & Iacumin, L. (2018). Sous vide cook-CHILL mussel (Mytilus galloprovincialis): Evaluation of chemical, microbiological and sensory quality during chilled storage (3 °C). *LWT*, *91*, 117-124. https://doi.org/10.1016/j.lwt.2017.12.005

Buckow, R., Chandry, P. S., Ng, S. Y., McAuley, C. M., & Swanson, B. G. (2014). Opportunities and challenges in pulsed electric field processing of dairy products. *International Dairy Journal*, *34*(2), 199-212. https://doi.org/10.1016/j.idairyj.2013.09.002

Buckow, R., Ng, S., & Toepfl, S. (2013). Pulsed electric Field processing of orange juice: A review on microbial, enzymatic, nutritional, and sensory quality and stability. *Comprehensive Reviews in Food Science and Food Safety*, *12*(5), 455-467. https://doi.org/10.1111/1541-4337.12026

Campagnol, P. C., Lorenzo, J. M., Teixeira, A., Santos, E. M., Andrés, S. C., Dos Santos, B. A., Pinton, M. B., Vaz Leães, Y. S., & Cichoski, A. J. (2023). The nutritional characteristics and health-oriented advances of meat and meat products. *Meat and Meat Replacements*, 111-144. https://doi.org/10.1016/b978-0-323-85838-0.00002-x

Campus, M. (2010). High pressure processing of meat, meat products and seafood. *Food Engineering Reviews*, *2*(4), 256-273. https://doi.org/10.1007/s12393-010-9028-y

Carbone, J. W., & Pasiakos, S. M. (2019). Dietary protein and muscle mass: Translating science to application and health benefit. *Nutrients*, *11*(5), 1136. https://doi.org/10.3390/nu11051136

Carpena, M., Nuñez-Estevez, B., Soria-Lopez, A., Garcia-Oliveira, P., & Prieto, M. A. (2021). Essential oils and their application on active packaging systems: A review. *Resources*, *10*(1), 7. https://doi.org/10.3390/resources10010007

Cenci-Goga, B., Iulietto, M., Sechi, P., Borgogni, E., Karama, M., & Grispoldi, L. (2020). New trends in meat packaging. *Microbiology Research*, *11*(2), 56-67. https://doi.org/10.3390/microbiolres11020010

Chollakup, R., Pongburoos, S., Boonsong, W., Khanoonkon, N., Kongsin, K., Sothornvit, R., Sukyai, P., Sukatta, U., & Harnkarnsujarit, N. (2020). Antioxidant and antibacterial activities of cassava starch and whey protein blend films containing rambutan peel extract and Cinnamon oil for active packaging. *LWT*, *130*, 109573. https://doi.org/10.1016/j.lwt.2020.109573

Dalle Zotte, A., Pranzo, G., Tenti, S., Szendrő, Z., & Szabó, A. (2022). Sample preparation and storage effects on fatty acid profile of rabbit Longissimus thoracis et lumborum muscle. *World Rabbit Science*, *30*(3), 187-193. https://doi.org/10.4995/wrs.2022.17160

Danilčenko, H., Jarienė, E., Lasinskas, M., Vaitkevičienė, N., Danilčenko, H., Danilčenko, H., ... & Vaitkevičienė, N. (2022). Processing Technologies. In *Jerusalem Artichoke Food Science and Technology: Helianthus Tuberosus* (pp. 139-195). Singapore: Springer Nature Singapore.

Dirpan, A., & Hidayat, S. H. (2023). Quality and shelf-life evaluation of fresh beef stored in smart packaging. *Foods*, *12*(2), 396. https://doi.org/10.3390/foods12020396

Falowo, A. B. (2021). A comprehensive review of nutritional benefits of minerals in meat and meat products. *Sci Lett, 9(2)*, 55-64. https://doi.org/10.47262/sl/9.2.132021010

Fiore, A., Park, S., Volpe, S., Torrieri, E., & Masi, P. (2021). Active packaging based on PLA and chitosan-caseinate enriched Rosemary essential oil coating for fresh minced chicken breast application. *Food Packaging and Shelf Life*, *29*, 100708. https://doi.org/10.1016/j.fpsl.2021.100708

Fox, R. (2022). Aseptic packaging materials and sterilants. *Handbook of Aseptic Processing and Packaging*, 211-222. https://doi.org/10.1201/9781003158653-11

Geiker, N. R., Bertram, H. C., Mejborn, H., Dragsted, L. O., Kristensen, L., Carrascal, J. R., Bügel, S., & Astrup, A. (2021). Meat and human health—Current knowledge and research gaps. *Foods*, *10*(7), 1556. https://doi.org/10.3390/foods10071556

Gil, M., & Rudy, M. (2023). Innovations in the packaging of meat and meat products—A review. *Coatings*, *13*(2), 333. https://doi.org/10.3390/coatings13020333

Giromini, C., & Givens, D. I. (2022). Benefits and risks associated with meat consumption during key life processes and in relation to the risk of chronic diseases. *Foods*, *11*(14), 2063. https://doi.org/10.3390/foods11142063

Gómez, B., Munekata, P. E., Gavahian, M., Barba, F. J., Martí-Quijal, F. J., Bolumar, T., Campagnol, P. C., Tomasevic, I., & Lorenzo, J. M. (2019). Application of pulsed electric fields in meat and fish processing industries: An overview. *Food Research International*, *123*, 95-105. https://doi.org/10.1016/j.foodres.2019.04.047

Guo, P., Fu, Y., Liu, X., Li, D., & Xu, W. (2018, January). Research and application progress on food active MAP packaging. In *Applied Sciences in Graphic Communication and Packaging: Proceedings of 2017 49th Conference of the International Circle of Educational Institutes for Graphic Arts Technology and Management & 8th China Academic*

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

Conference on Printing and Packaging. Singapore: Springer Singapore. pp. 495-501

Hassoun, A., Carpena, M., Prieto, M. A., Simal-Gandara, J., Özogul, F., Özogul, Y., Çoban, Ö. E., Guðjónsdóttir, M., Barba, F. J., Marti-Quijal, F. J., Jambrak, A. R., Maltar-Strmečki, N., Kljusurić, J. G., & Regenstein, J. M. (2020). Use of spectroscopic techniques to monitor changes in food quality during application of natural preservatives: A review. *Antioxidants*, *9*(9), 882. https://doi.org/10.3390/antiox9090882

Hejazi, M., Marchant, M. A., Zhu, J., & Ning, X. (2018). The decline of U.S. export competitiveness in the Chinese meat import market. *Agribusiness*, *35*(1), 114-126. https://doi.org/10.1002/agr.21588

Horbańczuk, O. K., Kurek, M. A., Atanasov, A. G., Brnčić, M., & Rimac Brnčić, S. (2019). The effect of natural antioxidants on quality and shelf life of beef and beef products. *Food technology and biotechnology*, *57*(4), 439-447. https://doi.org/10.17113/ftb.57.04.19.6267

Hussain, A., Abubakar, M., Shah, H., Arshed, M. J., Batool, S., & Afzal, M. (2019). Impact assessment of ring vaccination to control economic losses of foot and mouth disease in Pakistan. *Pakistan Journal of Agricultural Sciences*, *56(4)*, 929-935. https://pakjas.com.pk/papers/3046.pdf

Hwang, K., Ham, Y., Song, D., Kim, H., Lee, M., Jeong, J., & Choi, Y. (2021). Effect of gamma-ray, electron-beam, and X-ray irradiation on antioxidant activity of mugwort extracts. *Radiation Physics and Chemistry*, *186*, 109476. https://doi.org/10.1016/j.radphyschem.2021.109476

Hwang, K., Kim, H., Song, D., Kim, Y., Ham, Y., Lee, J., Choi, Y., & Kim, C. (2015). Effects of antioxidant combinations on shelf stability of irradiated chicken sausage during storage. *Radiation Physics and Chemistry*, *106*, 315-319. https://doi.org/10.1016/j.radphyschem.2014.08.014

Iqbal, M. (2023). Active packaging from natural ingredients applied to meat: A review. *IOP Conference Series: Earth and Environmental Science*, *1230*(1), 012184. https://doi.org/10.1088/1755-1315/1230/1/012184

Ismail, I., Hwang, Y., & Joo, S. (2019). Interventions of two-stage thermal sous-vide cooking on the toughness of beef semitendinosus. *Meat Science*, *157*, 107882. https://doi.org/10.1016/j.meatsci.2019.107882

Jacinto-Valderrama, R. A., Andrade, C. T., Pateiro, M., Lorenzo, J. M., & Conte-Junior, C. A. (2023). Recent trends in active packaging using nanotechnology to inhibit oxidation and Microbiological growth in muscle foods. *Foods*, *12*(19), 3662. https://doi.org/10.3390/foods12193662

Kandeepan, G., & Tahseen, A. (2022). Modified atmosphere packaging (MAP) of meat and meat products: A review. *Journal of Packaging Technology and Research*, *6*(3), 137-148. https://doi.org/10.1007/s41783-022-00139-2

Karwowska, M., Łaba, S., & Szczepański, K. (2021). Food loss and waste in meat sector—Why the consumption stage generates the most losses? *Sustainability*, *13*(11), 6227. https://doi.org/10.3390/su13116227

Katekhong, W., Wongphan, P., Klinmalai, P., & Harnkarnsujarit, N. (2022). Thermoplastic starch blown films functionalized by plasticized nitrite blended with PBAT for superior oxygen barrier and active biodegradable meat packaging. *Food Chemistry*, *374*, 131709. https://doi.org/10.1016/j.foodchem.2021.131709

Kim, Y., Cha, J. Y., Kim, T., Lee, J. H., Jung, S., & Choi, Y. (2024). The effect of irradiation on meat products. *Food Science of Animal Resources*, *44*(4), 779-789. https://doi.org/10.5851/kosfa.2024.e35

Klaura, J., Breeman, G., & Scherer, L. (2023). Animal lives embodied in food loss and waste. *Sustainable Production and Consumption*, *43*, 308-318. https://doi.org/10.1016/j.spc.2023.11.004

Konuk Takma, D., Çin, S., & Şahin Nadeem, H. (2024). Active biopackaging films enriched with andiz (Juniperus drupacea L.) shell extract for fresh meat packaging. *Packaging Technology and Science*, *37*(10), 989-1002. https://doi.org/10.1002/pts.2836

Koubaa, M., Roselló-Soto, E., Šic Žlabur, J., Režek Jambrak, A., Brnčić, M., Grimi, N., Boussetta, N., & Barba, F. J. (2015). Current and new insights in the sustainable and green recovery of nutritionally valuable compounds from *Stevia rebaudiana* Bertoni. *Journal of Agricultural and Food Chemistry*, *63*(31), 6835-6846. https://doi.org/10.1021/acs.jafc.5b01994

Laorenza, Y., & Harnkarnsujarit, N. (2021). Carvacrol, citral and α-terpineol essential oil incorporated biodegradable films for functional active packaging of Pacific white shrimp. *Food Chemistry*, *363*, 130252. https://doi.org/10.1016/j.foodchem.2021.130252

Latoch, A., Głuchowski, A., & Czarniecka-Skubina, E. (2023). Sous-vide as an alternative method of cooking to improve the quality of meat: A review. *Foods*, *12*(16), 3110. https://doi.org/10.3390/foods12163110

Leygonie, C., Britz, T. J., & Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat: Review. *Meat Science*, *91*(2), 93-98. https://doi.org/10.1016/j.meatsci.2012.01.013

Li, X., Zhang, R., Hassan, M. M., Cheng, Z., Mills, J., Hou, C., Realini, C. E., Chen, L., Day, L., Zheng, X., Zhang, D., & Hicks, T. M. (2022). Active packaging for the extended shelf-life of meat: Perspectives from consumption habits, market requirements and packaging practices in China and New Zealand. *Foods*, *11*(18), 2903. https://doi.org/10.3390/foods11182903

Liao, J., Zhang, P., Yin, J., & Zhang, X. (2025). New insights into the effects of dietary amino acid composition on meat quality in pigs: A review. *Meat Science*, *221*, 109721. https://doi.org/10.1016/j.meatsci.2024.109721

Lund, M. N., Heinonen, M., Baron, C. P., & Estévez, M. (2010). Protein oxidation in muscle foods: A review. *Molecular Nutrition & Food Research*, *55*(1), 83-95. https://doi.org/10.1002/mnfr.201000453

Mangalassary, S. (2019). Advances in packaging of poultry meat products. *Food Safety in Poultry Meat Production*, 139-159. https://doi.org/10.1007/978-3-030-05011-5_7

Marchetti, L., Andrés, S. C., & Califano, A. N. (2016). Physicochemical, Microbiological and oxidative changes during refrigerated storage of N-3 PUFA enriched cooked meat sausages with partial NaCl substitution. *Journal of Food Processing and Preservation*, *41*(3), e12920. https://doi.org/10.1111/jfpp.12920

Mekouar, M. A. (2020). 15. Food and agriculture organization of the United Nations (FAO). *Yearbook of International Environmental Law*, *31*(1), 326-340. https://doi.org/10.1093/yiel/yvab061

Mia, N., Rahman, M., & Hahem, M. (2023). Effect of heat stress on meat quality: A review. *Meat Research*, *3*(6). https://doi.org/10.55002/mr.3.6.73

Mirhosseini, M., Afra, A., Banadkooki, F. B., & Banifatemeh, F. (2024). The study of increasing shelf-life of meat by using nanocellulose-chitosan composite film obtained from agricultural by-products. *Journal of Nutrition and Food Security*. https://doi.org/10.18502/jnfs.v9i1.14837

Misra, N., & Jo, C. (2017). Applications of cold plasma technology for microbiological safety in meat industry. *Trends in Food Science & Technology*, *64*, 74-86.

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

https://doi.org/10.1016/j.tifs.2017.04.005

Misu, G. A., Canja, C. M., Lupu, M., & Matei, F. (2024). Advances and drawbacks of sous-vide technique—A critical review. *Foods*, *13*(14), 2217. https://doi.org/10.3390/foods13142217

Mohan, A., & Long, J. M. (2021). Valorization of wastes and by-products from the meat industry. *Valorization of Agri-Food Wastes and By-Products*, 457-474. https://doi.org/10.1016/b978-0-12-824044-1.00010-6

Moura-Alves, M., Esteves, A., Ciríaco, M., Silva, J. A., & Saraiva, C. (2023). Antimicrobial and antioxidant edible films and coatings in the shelf-life improvement of chicken meat. *Foods*, *12*(12), 2308. https://doi.org/10.3390/foods12122308

NARROD, C., TIONGCO, M., & SCOTT, R. (2011). Current and predicted trends in the production, consumption and trade of live animals and their production. *Revue Scientifique et Technique de l'OIE*, *30*(1), 31-49. https://doi.org/10.20506/rst.30.1.2014

Nath, S., Majumder, S., Samanta, S., Nanda, P. K., Pal, A., Das, A., & Das, A. K. (2024). Meat and meat byproducts derived bio-active peptides and their importance on human health. *INDIAN JOURNAL OF ANIMAL HEALTH*, *Online*. https://doi.org/10.36062/ijah.2024.04223

Nina, A., Biagi, P. F., Mitrović, S. T., Pulinets, S., Nico, G., Radovanović, M., & Popović, L. Č. (2021). Reduction of the VLF signal phase noise before earthquakes. *Atmosphere*, *12*(4), 444. https://doi.org/10.3390/atmos12040444

Nikulina, E. O., Ivanova, G. V., Kolman, O. I., Ivanova, A. N., & Perestoronin, D. Y. (2021). Research of the influence of vacuum packaging on the quality and safety of meat semi-finished products. *IOP Conference Series: Earth and Environmental Science*, *677*(3), 032066. https://doi.org/10.1088/1755-1315/677/3/032066

Orlien, V., & Bolumar, T. (2019). Biochemical and nutritional changes during food processing and storage. *Foods*, *8*(10), 494. https://doi.org/10.3390/foods8100494

Panseri, S., Martino, P., Cagnardi, P., Celano, G., Tedesco, D., Castrica, M., Balzaretti, C., & Chiesa, L. (2018). Feasibility of biodegradable based packaging used for red meat storage during shelf-life: A pilot study. *Food Chemistry*, *249*, 22-29. https://doi.org/10.1016/j.foodchem.2017.12.067

Patterson, M. F., & Kilpatrick, D. J. (2012). High-pressure processing of meat. *Meat Science*, 92*(4)*, 419-424.

Pereira, P. M., & Vicente, A. F. (2013). Meat nutritional composition and nutritive role in the human diet. *Meat Science*, *93*(3), 586-592. https://doi.org/10.1016/j.meatsci.2012.09.018

Pinto, J., Boavida-Dias, R., Matos, H. A., & Azevedo, J. (2022). Analysis of the food loss and waste valorisation of animal by-products from the retail sector. *Sustainability*, *14*(5), 2830. https://doi.org/10.3390/su14052830

Puértolas, E., & Barba, F. J. (2016). Electrotechnologies applied to valorization of by-products from food industry: Main findings, energy and economic cost of their industrialization. *Food and Bioproducts Processing*, *100*, 172-184. https://doi.org/10.1016/j.fbp.2016.06.020

Ranaei, V., Pilevar, Z., Esfandiari, C., Khaneghah, A. M., Dhakal, R., Vargas-Bello-Pérez, E., & Hosseini, H. (2021). Meat value chain losses in Iran. *Food Science of Animal Resources*, *41*(1), 16-33. https://doi.org/10.5851/kosfa.2020.e52

Rekanović, S. (2024). Dynamics of smoke ingredients penetration into the interior of chicken meat products during boiling/Smoking and drying. *Technologica acta*, *17*(1), 11-18. https://doi.org/10.51558/2232-7568.2023.17.1.11

Rodriguez, N. R. (2021). Role of meat in healthy eating patterns: Considerations for protein quantity and protein quality. *Meat and Muscle Biology*, *4*(2). https://doi.org/10.22175/mmb.11687

SALTER, A. (2018). The effects of meat consumption on global health. *Revue Scientifique et Technique de l'OIE*, *37*(1), 47-55. https://doi.org/10.20506/rst.37.1.2739

Ribeiro Sanches, M. A., Camelo-Silva, C., Da Silva Carvalho, C., Rafael de Mello, J., Barroso, N. G., Lopes da Silva Barros, E., Silva, P. P., & Pertuzatti, P. B. (2021). Active packaging with starch, red cabbage extract and sweet whey: Characterization and application in meat. *LWT*, *135*, 110275. https://doi.org/10.1016/j.lwt.2020.110275

Shaltout, F. A. (2024). Impacts of meat spoilage on economy and public health. *Nutrition and Food Processing*, *7*(6), 01-06. https://doi.org/10.31579/2637-8914/217

Siddiqui, S. A., Sundarsingh, A., Bahmid, N. A., Nirmal, N., Denayer, J. F., & Karimi, K. (2023). A critical review on biodegradable food packaging for meat: Materials, sustainability, regulations, and perspectives in the EU. *Comprehensive Reviews in Food Science and Food Safety*, *22*(5), 4147-4185. https://doi.org/10.1111/1541-4337.13202

Singh, P., Wani, A. A., Saengerlaub, S., & Langowski, H. (2011). Understanding critical factors for the quality and shelf-life of MAP fresh meat: A review. *Critical Reviews in Food Science and Nutrition*, *51*(2), 146-177. https://doi.org/10.1080/10408390903531384

Smith, A. M. (2015). *Optimization of pulsed-vacuum osmotic dehydration of blueberries* (Master's thesis). West Virginia University.

Souza, V., Rodrigues, C., Valente, S., Pimenta, C., Pires, J., Alves, M., Santos, C., Coelhoso, I., & Fernando, A. (2020). Eco-friendly ZnO/Chitosan Bionanocomposites films for packaging of fresh poultry meat. *Coatings*, *10*(2), 110. https://doi.org/10.3390/coatings10020110

Sumner, J., Vanderlinde, P., Kaur, M., & Jenson, I. (2021). The changing shelf life of chilled, vacuum-packed red meat. *Food Safety and Quality-Based Shelf Life of Perishable Foods*, 145-156. https://doi.org/10.1007/978-3-030-54375-4_8

Tavares, J., Martins, A., Fidalgo, L. G., Lima, V., Amaral, R. A., Pinto, C. A., Silva, A. M., & Saraiva, J. A. (2021). Fresh fish degradation and advances in preservation using physical emerging technologies. *Foods*, *10*(4), 780. https://doi.org/10.3390/foods10040780

Thathsarani, A., Alahakoon, A. U., & Liyanage, R. (2022). Current status and future trends of sous vide processing in meat industry; A review. *Trends in Food Science & Technology*, *129*, 353-363. https://doi.org/10.1016/j.tifs.2022.10.009

Wang, R., Liu, G., Zhou, L., Yang, Z., Tang, Z., Lu, S., Zhao, M., Sun, H., Ma, C., & Cheng, G. (2023). Quantifying food loss along the animal products supply chain in China with large-scale field-survey based primary data. *Resources, Conservation and Recycling*, *188*, 106685. https://doi.org/10.1016/j.resconrec.2022.106685

Wongphan, P., Promhuad, K., Srisa, A., Laorenza, Y., Oushapjalaunchai, C., & Harnkarnsujarit, N. (2024). Unveiling the future of meat packaging: Functional biodegradable packaging preserving meat quality and safety. *Polymers*, *16*(9), 1232. https://doi.org/10.3390/polym16091232

Wyness, L. (2015). The role of red meat in the diet: Nutrition and health benefits. *Proceedings of the Nutrition Society*, *75*(3), 227-232.

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.

https://doi.org/10.1017/s0029665115004267

Xing, L., Liu, R., Cao, S., Zhang, W., & Guanghong, Z. (2019). Meat protein based bioactive peptides and their potential functional activity: A review. *International Journal of Food Science & Technology*, *54*(6), 1956-1966. https://doi.org/10.1111/ijfs.14132

Younas, M., Ishaq, K., & Ali, I. (2012). Effect of climate change on livestock production in Pakistan. *Proc. 2 nd Internat. Sem. Anim. Indus., Jakarta*, 5-6.

Ząbek, K., Miciński, J., Milewski, S., & Sobczak, A. (2021). Effect of modified atmosphere packaging and vacuum packaging on quality characteristics of lamb meat. *Archives Animal Breeding*, *64*(2), 437-445. https://doi.org/10.5194/aab-64-437-2021

Zavadlav, S., Blažić, M., Van de Velde, F., Vignatti, C., Fenoglio, C., Piagentini, A. M., Pirovani, M. E., Perotti, C. M., Bursać Kovačević, D., & Putnik, P. (2020). Sous-vide as a technique for preparing healthy and high-quality vegetable and seafood products. *Foods*, *9*(11), 1537. https://doi.org/10.3390/foods9111537

Zhao, Y., Chen, L., Bruce, H. L., Wang, Z., Roy, B. C., Li, X., Zhang, D., Yang, W., & Hou, C. (2022). The influence of vacuum packaging of hot-boned lamb at early postmortem time on meat quality during postmortem chilled storage. *Food Science of Animal Resources*, *42*(5), 816-832. https://doi.org/10.5851/kosfa.2022.e34

Zhou, G., Zhang, W., & Xu, X. (2012). China's meat industry revolution: Challenges and opportunities for the future. *Meat Science*, *92*(3), 188-196. https://doi.org/10.1016/j.meatsci.2012.04.016

Copyright © 2025. IJBR Published by Indus Publishers
This work is licensed under a Creative Commons Attribution 4.0 International License.