European Journal of Nutrition & Food Safety

Volume 16, Issue 10, Page 186-202, 2024; Article no.EJNFS.123826
ISSN: 2347-5641

High Pressure Processing: Pros and Cons

Pinki S Sharma [a++], D.V. Swami [b#*], M. Ramya [c†], Arshad Khayum [d‡] and Manish Kapoor [e]

[a] Office of Directorate of Extension Education, Junagadh Agricultural University, India.
[b] Post-Harvest Management, Dr. YSR Horticultural University, A.P, India.
[c] Department of Fish Processing Technology, College of Fishery Science, Andhra Pradesh Fisheries University (APFU), India.
[d] Department of Postharvest Management, College of Horticulture, Mudigere-577132, University: KSNUAHS, Shivamogga-577412, India.
[e] Punjabi University, Patiala, 147002, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ejnfs/2024/v16i101568

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/123826

Review Article

Received: 19/08/2024
Accepted: 21/10/2024
Published: 26/10/2024

ABSTRACT

The food industry now uses high pressure processing to increase the shelf life of foods and maintain their nutritional value. This non-thermal preservation technique can successfully inactivate rotting and spoilage-causing bacteria and enzymes without the need for high temperatures during the preservation process. Food is exposed to high pressure, usually in the range of 100 to 600

[++] Assistant Extension Educationist;
[#] Principal Scientist;
[†] Assistant Professor(C);
[‡] Assistant Professor;
**Corresponding author: Email: swamihorti@gmail.com;*

Cite as: *Sharma, Pinki S, D.V. Swami, M. Ramya, Arshad Khayum, and Manish Kapoor. 2024. "High Pressure Processing: Pros and Cons". European Journal of Nutrition & Food Safety 16 (10):186-202. https://doi.org/10.9734/ejnfs/2024/v16i101568.*

MPa. High-performance processing keeps food at or slightly above room temperature to prevent heat-sensitive flavors and nutrients from being thermally destroyed during food preparation. This contributes to the preservation of the natural sensory and nutritional properties of the product. Because this process is able to eliminate bacteria and organisms responsible for spoilage, it is a very efficient way to increase the time available to eat foods. Unlike traditional heat-based methods, HPP inactivates harmful microorganisms and enzymes through the application of extreme pressure (100–600 MPa) at low temperatures, thereby reducing thermal degradation. HPP also helps retain bioactive compounds, making it an ideal choice for consumers looking for minimally processed, high-quality foods. This article explores the principles, applications, and benefits of HPP, as well as the challenges and future prospects of its integration into food processing systems.

Keywords: Spoilage; traditional; HPC; consumption; quality; preservation.

1. INTRODUCTION

One of the most essential procedures in modern food systems is food preservation, which is carried out with the objectives of extending the shelf life of products, ensuring that they are safe to consume and preserving the amount of nutrients that they contain. Traditional methods of food preservation, which include heat processing, chemical preservation and refrigeration, have been the cornerstones of food preservation for a very long time [1]. These methods comprise the traditional techniques of food preservation. Every one of these approaches comes with its own individual set of benefits and difficulties. It is possible that thermal processing, which includes pasteurization and sterilization, would result in the loss of nutrients as well as changes in the texture and flavour of the product [2]. This is in addition to the fact that thermal processing will increase the shelf life of a product and eliminate germs in an effective manner [3,4,5,6].

1.1 Overview of Food Preservation Techniques

Food preservation is essential for extending the shelf life of food products, ensuring safety and maintaining nutritional quality. Traditional methods of food preservation have been developed and refined over centuries to meet these needs [7,8,9]. Here's an overview of some key traditional preservation techniques:

1.2 Thermal Processing

Thermal processing, often referred to as heat treatment, is one of the most commonly used methods for preserving food. This technique involves applying heat to destroy microorganisms and enzymes that cause spoilage [10]. The main types of thermal processing include:

- **Pasteurization**: Named after Louis Pasteur, this process involves heating food to a specific temperature for a set period to kill pathogenic microorganisms without significantly affecting the food's quality. Pasteurization is widely used for dairy products, juices and canned foods [11].
- **Sterilization**: This method involves heating food to a higher temperature than pasteurization, often under pressure (as in autoclaving), to kill all microorganisms, including bacterial spores. Sterilization is commonly used in the canning industry to ensure the long-term safety and shelf life of canned foods [12].
- **Blanching**: Blanching involves briefly immersing fruits or vegetables in boiling water, followed by rapid cooling. This process inactivates enzymes that can lead to spoilage, improves texture and helps preserve colour. Blanching is often used before freezing vegetables [13].

While thermal processing effectively kills harmful microorganisms, it can also lead to nutrient loss and changes in the texture and flavour of food [14]. For instance, vitamins such as Vitamin C and B vitamins are heat-sensitive and may degrade during processing.

2. CHEMICAL PRESERVATION

Chemical preservation involves adding substances to food that inhibit microbial growth and spoilage. This method includes:

- Salt is used to draw moisture out of food, creating an environment that inhibits microbial growth. Salting is traditionally used for preserving meats, fish and some vegetables [15].

- Similar to salting, the addition of sugar helps to preserve fruits by drawing out moisture and creating a high osmotic pressure environment that inhibits microbial growth. Sugaring is commonly used in making jams, jellies and preserves [16].
- Adding acids, such as vinegar or citric acid, lowers the pH of the food, creating an acidic environment that inhibits the growth of many microorganisms. Acidification is used in pickling and preserving sauces [17].
- Various chemical preservatives, such as sodium benzoate, potassium sorbate and sulphur dioxide, are used to extend shelf life and prevent spoilage. These additives work by inhibiting microbial growth or enzymatic activity. While chemical preservatives are effective, they can sometimes raise concerns among consumers who prefer natural or minimally processed foods. Additionally, some individuals may have sensitivities or allergies to specific chemical additives [18].

3. COLD PRESERVATION

Refrigeration involves storing food at low temperatures to slow down the growth of microorganisms and enzymatic activity that cause spoilage. Key aspects include:

- **Refrigeration**: Food is kept at temperatures just above freezing (usually 0-4°C or 32-39°F). This method is effective for short-term preservation and is commonly used for dairy products, meats, fruits and vegetables. While refrigeration slows down spoilage, it does not stop it entirely and food must be consumed within a reasonable time frame [19,20].
- **Freezing**: Freezing involves lowering the temperature of food to below -18°C (0°F), which halts microbial growth and enzymatic activity. This method is widely used for long-term preservation of a variety of foods, including meats, fruits, vegetables and prepared meals. Freezing helps maintain the nutritional quality of food better than thermal processing, but it can affect texture and flavour [21,22,23].

Refrigeration and freezing are effective methods for preserving food without significant changes to taste or texture. However, they require energy and infrastructure to maintain appropriate temperatures and power outages or equipment failures can lead to spoilage [24].

3.1 Introduction to High Pressure Processing (HPP)

High Pressure Processing (HPP) is a modern food preservation technique that uses high hydrostatic pressure to extend shelf life and maintain the nutritional and sensory qualities of food products. This non-thermal method is gaining popularity due to its ability to inactivate harmful microorganisms and enzymes without significant heat, which helps preserve the original flavour, texture and nutritional value of foods [25,26].

3.2 The Science behind High Pressure Processing

High Pressure Processing (HPP) is a sophisticated food preservation technology that utilizes high hydrostatic pressure to ensure food safety and extend shelf life while preserving the nutritional and sensory qualities of food products [27]. The science behind HPP involves several key principles related to pressure effects on microorganisms and enzymes, as well as the technical aspects of the process.

3.3 Principles of HPP

1. Hydrostatic Pressure Application

- **Uniform Pressure Transmission**: HPP involves subjecting food products to high pressures, typically ranging from 300-700 megapascals (MPa), within a sealed chamber filled with water [28]. The pressure is transmitted uniformly through the water, ensuring that all surfaces of the food product are exposed to the same level of pressure. This uniform application is critical for effective microbial inactivation and enzyme inhibition [29].
- **Pressure Effect on Microorganisms**: High pressure disrupts the cellular structure of microorganisms, including bacteria, yeasts, moulds and viruses. The pressure affects the cell membrane and internal cellular components, leading to cell death or inactivation. The extent of microbial inactivation depends on the type of microorganism, the pressure level and the processing time [30].
- **Enzyme Inhibition**: Enzymes responsible for spoilage and degradation, such as

those involved in browning and flavour changes, are sensitive to high pressure. HPP inactivates these enzymes, preventing undesirable changes in food quality [34].

- **Retention of Nutrients**: Unlike thermal processing, which can lead to significant nutrient loss, HPP is generally less damaging to heat-sensitive nutrients, such as vitamins and antioxidants. This is because the process occurs at ambient or slightly elevated temperatures, minimizing thermal degradation [35].

2. Mechanisms of Microbial Inactivation

- **Cell Membrane Disruption**: The high pressure causes structural changes to the cell membrane, leading to leakage of intracellular contents and loss of cell integrity. This disruption impairs the microorganism's ability to survive and reproduce [31].
- **Protein Denaturation**: Pressure also affects proteins and enzymes within the microorganisms. The denaturation of essential proteins and enzymes disrupts metabolic processes, further contributing to microbial inactivation [32].
- **Alteration of Nucleic Acids**: High pressure can cause changes in the DNA and RNA of microorganisms, affecting their ability to replicate and function [33].

3. Physical and Chemical Changes

- **Pressure-Induced Structural Changes**: High pressure can cause reversible and irreversible structural changes in food products. These changes can affect texture, colour and flavour, although HPP typically maintains the original qualities of the food better than traditional thermal methods [36].
- **Non-Thermal Nature of HPP**: The non-thermal nature of HPP means that food is not subjected to high temperatures, reducing the risk of thermal degradation and preserving the sensory attributes of the food [37].

4. Technical Aspects of HPP

- **Equipment and Process Design**: HPP requires specialized equipment, including high-pressure vessels that can withstand extreme pressures. The design of these vessels and the process parameters (pressure levels, processing time) are crucial for achieving effective preservation while maintaining food quality [38].
- **Batch vs. Continuous Processing**: HPP can be performed in batch or continuous systems. Batch systems process food in discrete quantities, while continuous systems allow for the continuous flow of food through the high-pressure chamber. The choice between batch and continuous processing depends on the type of food and production requirements [39].

5. Applications and Efficiency

- **Food Types**: HPP is suitable for a wide range of food products, including juices, ready-to-eat meals, dairy products, seafood and fresh-cut fruits and vegetables. The technology's versatility makes it a valuable tool in modern food processing [40,41].
- **Efficiency Considerations**: The efficiency of HPP in achieving microbial inactivation and preserving food quality depends on factors such as pressure levels, processing time and the nature of the food product. Optimization of these factors is essential for maximizing the benefits of HPP [42].

3.4 Nutrient Preservation through HPP

High-Pressure Processing (HPP) is a rapidly growing food preservation technology that offers a unique advantage over traditional thermal processing methods, primarily due to its ability to retain the nutritional and sensory qualities of food [43]. This non-thermal technique uses extremely high levels of hydrostatic pressure (ranging from 100 to 600 MPa) to inactivate microorganisms and enzymes responsible for food spoilage, without the need for heat. The result is a longer shelf life, improved food safety and most importantly, better preservation of key nutrients that are often lost in conventional food processing methods [44]. In this essay, we will explore how HPP helps to maintain nutrients, the types of foods it is most commonly used for and the implications this technology has for the future of food preservation [45].

1. The Science of High-Pressure Processing

HPP operates based on Pascal's principle, which states that pressure applied to a liquid is transmitted uniformly in all directions. In practical

terms, this means that food products are submerged in a liquid (usually water) and subjected to intense pressure, which disrupts the cellular structure of microorganisms and inactivates spoilage enzymes. Unlike thermal processing methods such as pasteurization or sterilization, which rely on high temperatures to kill bacteria, HPP achieves microbial inactivation without altering the temperature of the food significantly [46].

One of the most important aspects of HPP is that it works at ambient or low temperatures. This minimizes the thermal degradation of sensitive nutrients, such as vitamins, antioxidants and enzymes, which would otherwise be lost during heat treatment. HPP can be performed at temperatures ranging from near freezing to room temperature, making it particularly effective for preserving the fresh characteristics of food [47].

2. Nutrient Retention in HPP

Nutrient degradation is a major concern in traditional food processing methods. Heat, light and oxygen exposure during processing can lead to significant loss of vitamins, minerals and other bioactive compounds. In contrast, HPP preserves the nutritional profile of food products much more effectively due to its minimal reliance on temperature changes [48]. Let's break down how HPP preserves different categories of nutrients:

Table 1. Description of high pressure processing

Aspect	Description	Examples
Definition	A food preservation technique that uses high pressure (100-600 MPa) to inactivate microorganisms and enzymes.	- Juices: Freshly squeezed orange juice. - Ready-to-Eat Meals: Pre-packaged stews.
Process	Food products are subjected to high pressure in a sealed chamber, which uniformly transmits pressure through the food.	- Dairy Products: HPP-treated milk and cheese. - Meat: HPP-treated chicken breasts.
Temperature	Processing is done at ambient or slightly elevated temperatures, preserving heat-sensitive nutrients and flavours.	- Seafood: HPP-treated shrimp. - Fruits and Vegetables: HPP-treated strawberries.
Microbial Inactivation	High pressure effectively inactivates bacteria, yeasts, moulds and viruses without the use of heat.	- Juices: HPP-treated apple juice. - Sauces: HPP-treated tomato sauce.
Nutrient Preservation	Better retention of vitamins, antioxidants and other nutrients compared to traditional heat-based methods.	- Vegetables: HPP-treated carrots. - Smoothies: HPP-treated fruit smoothies.
Applications	Used in various food categories to enhance safety and extend shelf life while maintaining quality.	- Beverages: Fresh fruit juices, smoothies. - Packaged Foods: Ready-to-eat meals, soups.
Advantages	- Retains nutritional value. - Maintains original taste and texture. - Extends shelf life without preservatives.	- Juices: Maintains fresh taste and nutritional content. - Meats: Retains tenderness and flavour.
Limitations	- High capital and operational costs. - Not suitable for all food products. - Requires specialized equipment.	- Bread: Not suitable due to texture changes. - Certain Vegetables: May not retain texture well.

3. Vitamins and Antioxidants

Vitamins, especially water-soluble ones like vitamin C and B-complex vitamins, are highly susceptible to heat and oxygen. In conventional heat treatments, vitamin C is among the first nutrients to degrade, as it is highly sensitive to thermal exposure. HPP, however, preserves a high percentage of vitamin C due to the low processing temperatures, making it an ideal method for processing fruits, vegetables and juices rich in this essential nutrient [49].

In addition to vitamins, HPP also helps retain antioxidants such as polyphenols and flavonoids. These compounds, found in many plant-based foods, play a crucial role in neutralizing free radicals in the body and preventing oxidative stress [50]. Heat processing can significantly reduce the antioxidant capacity of foods, but HPP has been shown to preserve these compounds effectively. Studies indicate that fruit juices treated with HPP maintain higher levels of polyphenols compared to those processed with heat [51].

4. Minerals and Trace Elements

Minerals are generally more stable than vitamins during food processing since they are not as susceptible to heat or pressure. Nonetheless, one of the key advantages of HPP is that it does not involve any chemical treatments that could potentially bind to or inactivate minerals. Minerals such as potassium, magnesium, calcium and iron remain bioavailable in foods processed with HPP, ensuring that consumers receive the full nutritional benefits of these essential elements [52].

5. Proteins and Lipids

Proteins can be denatured by heat, leading to changes in their structure and function. This is particularly relevant in foods such as dairy products, where protein structure affects texture and digestibility. HPP preserves the structural integrity of proteins more effectively than thermal methods, ensuring that their nutritional value remains intact. Moreover, HPP maintains the functional properties of proteins, which is especially important in food applications where texture and consistency are key quality attributes [53].

Similarly, HPP prevents the oxidation of lipids, a process that can lead to rancidity and loss of essential fatty acids, particularly omega-3 and omega-6. The oxidation of fats is a common problem in heat-treated foods, especially in meat and dairy products. Since HPP operates without high temperatures, it helps maintain the freshness and quality of fats, ensuring that they retain their nutritional benefits and do not become harmful due to oxidative degradation [54].

6. Sensory Quality and Consumer Acceptance

Another important benefit of HPP is its ability to retain the sensory characteristics of food, including taste, texture and colour. In many cases, consumers associate fresh and minimally processed foods with better flavour and higher nutritional value. Heat treatments often alter the natural flavours of food, sometimes resulting in off-flavours, particularly in delicate products like fruit juices or dairy [55]. HPP, on the other hand, preserves the fresh taste of food by preventing the Maillard reaction (which occurs during heating and causes browning and flavour changes). This means that HPP-treated foods can be marketed as fresh or minimally processed, appealing to health-conscious consumers [56].

Texture is another important aspect of consumer acceptance and HPP excels at preserving the natural texture of food products. For example, fruits and vegetables subjected to thermal processing can become mushy due to the breakdown of cell walls. HPP maintains the structural integrity of plant cells, keeping the crisp texture of fresh produce. This is particularly valuable for ready-to-eat salads, fresh-cut fruits and other minimally processed foods [57].

Colour retention is also a significant advantage of HPP. Heat processing often causes the loss of vibrant colours in fruits and vegetables due to the degradation of pigments such as chlorophyll and carotenoids. HPP, being a non-thermal process, helps maintain the natural colour of food, enhancing its visual appeal [58].

3.5 Applications of HPP in Nutrient-Rich Foods

High-Pressure Processing (HPP) is widely used across various sectors of the food industry, particularly in products where maintaining nutritional quality is a priority. By using HPP, food producers can extend the shelf life of products while ensuring they retain essential vitamins,

minerals, proteins and bioactive compounds [59]. Below are some of the most common applications of HPP in nutrient-rich foods:

1. Fresh Juices and Smoothies

Fresh fruit and vegetable juices are naturally rich in vitamins (especially vitamin C), minerals and antioxidants, which are highly sensitive to heat. HPP is especially suited for cold-pressed juices, as it preserves these nutrients without the degradation that occurs during thermal pasteurization [60].

- **Nutrient Preservation**: HPP helps retain the vitamin C and polyphenols in fruit juices, which are prone to oxidation and degradation under heat [61].
- **Shelf Life**: It extends the shelf life of fresh juices without the need for added preservatives, maintaining a “freshly made” taste and appearance [62].
- **Consumer Benefits**: HPP-treated juices are marketed as healthy, fresh and minimally processed, appealing to consumers looking for natural beverages rich in nutrients [63].

2. Dairy Products

Dairy products, such as milk, yogurt and cheese, are nutrient-dense foods containing proteins, calcium and vitamins like B12 and riboflavin. HPP is used to improve the safety of these products while preserving their nutritional value and sensory qualities [64].

- **Functional Proteins**: HPP preserves the structure of dairy proteins, maintaining the texture and functional properties of products like yogurt and soft cheeses [65].
- **Shelf Life and Safety**: In products like milk, HPP inactivates spoilage microorganisms while maintaining the fresh taste and texture that consumers prefer [66].
- **Probiotics**: In probiotic-rich dairy products like yogurt, HPP can be used in a way that maintains the viability of probiotic cultures, which are beneficial for gut health [67].

3. Plant-Based Foods

Plant-based foods, including plant-based milks, meat alternatives and snacks made from nuts, seeds and legumes, are rich in proteins, fibre, healthy fats and phytonutrients. HPP is increasingly used to ensure the safety and freshness of these foods without compromising their nutritional integrity [68].

- **Proteins and Fats**: In plant-based products, HPP helps preserve essential amino acids in proteins and prevents the oxidation of healthy fats like omega-3s [69].
- **Nutrient Stability**: HPP maintains the fibre, vitamins and antioxidants in plant-based beverages and meals, ensuring that they meet the demands of health-conscious consumers.
- **Innovative Products**: Many ready-to-eat plant-based meals and snacks use HPP to offer consumers fresh, high-protein and high-fibre options with extended shelf life [70].

4. Ready-to-Eat Meals

The demand for ready-to-eat (RTE) meals, particularly those that are nutrient-dense and free from preservatives, has surged. HPP allows manufacturers to offer RTE meals with high nutritional quality, safety and extended shelf life, meeting consumer demand for convenience and health [71].

- **Nutrient-Dense Ingredients**: HPP is commonly used for meals containing vegetables, whole grains, lean meats and legumes, helping to retain their vitamins, minerals and antioxidants [72].
- **Texture and Flavour**: The texture of fresh vegetables and meats is maintained and the natural flavours of nutrient-rich ingredients remain intact, offering a high-quality eating experience [73].
- **No Need for Preservatives**: With HPP, meals can be preservative-free while still having an extended shelf life, catering to the clean label trend among consumers [74].

5. Meat and Poultry Products

Meat and poultry are important sources of high-quality protein, iron and essential amino acids. HPP is used to enhance the safety of these products by inactivating harmful pathogens such as *Listeria*, *E. coli* and *Salmonella*, without significantly affecting the nutritional composition [75].

- **Protein Integrity**: HPP helps retain the natural proteins in meat and poultry,

ensuring that they retain their nutritional value and are not denatured as they would be during heat treatment [76].

- **Reduced Sodium**: HPP-treated meat products can be processed with reduced sodium levels since the pressure treatment provides microbial safety, reducing the need for salt as a preservative [77].
- **Natural and Organic Products**: Many organic and natural meat brands use HPP to ensure food safety without the need for chemical preservatives, maintaining the "natural" quality of their products [78].

6. Seafood

Seafood is rich in omega-3 fatty acids, high-quality protein and minerals like selenium and iodine. However, it is highly perishable and prone to contamination. HPP is increasingly used in the seafood industry to extend shelf life, enhance safety and retain the delicate nutrients in seafood [79].

- **Omega-3 Fatty Acids**: HPP preserves the integrity of omega-3 fats, which are prone to oxidation during heat processing [80].
- **Safety and Quality**: It inactivates harmful pathogens and reduces spoilage while preserving the fresh taste and texture of seafood like oysters, crab and fish [81].
- **Value-Added Products**: HPP-treated seafood products such as ready-to-eat crab, shrimp and smoked salmon retain their nutrient content while offering convenience to consumers [82].

7. Baby Food

Nutrition is critical for infants and toddlers and parents are increasingly looking for safe, nutritious and minimally processed options. HPP allows manufacturers to produce baby foods that retain more of their natural vitamins, minerals and other essential nutrients [83].

- **Nutrient Retention**: HPP preserves the natural nutrients in fruits, vegetables and meats used in baby foods, ensuring that babies receive the vitamins and minerals necessary for growth and development [84].
- **No Artificial Additives**: The safety provided by HPP means that baby food products can be preservative-free and still have an extended shelf life, catering to parents who want natural, wholesome options for their children [85].
- **Enhanced Safety**: Baby food must be free from harmful pathogens and HPP effectively inactivates bacteria and viruses without the need for thermal treatment, which can destroy sensitive nutrients [86].

8. Functional and Superfoods

Functional foods and superfoods, which are marketed for their health benefits, are often rich in vitamins, antioxidants, fibre and bioactive compounds. HPP is ideal for preserving these components in a variety of functional foods, including juices, protein bars and health snacks [87].

- **Preservation of Bioactive Compounds**: Superfoods like acai berries, kale and chia seeds contain high levels of antioxidants and polyphenols, which are retained during HPP, making these products more effective in delivering health benefits [88].
- **Enhanced Freshness**: HPP allows superfood-based products like smoothies and bars to retain their fresh flavours and nutrient profiles, making them more attractive to health-conscious consumers [89].
- **Innovation in Functional Beverages**: HPP is used to produce nutrient-rich, functional beverages with added vitamins, probiotics, or botanicals, ensuring that these nutrients remain bioavailable [90].

9. Nutritional Supplements

In the growing sector of health and wellness, HPP is used to preserve the active ingredients in certain liquid-based nutritional supplements, such as protein drinks and vitamin-enriched beverages [91].

- **Bioavailability of Nutrients**: HPP maintains the stability of sensitive nutrients like protein, vitamins and probiotics in supplements, ensuring their efficacy [92].
- **Extended Shelf Life**: Without relying on heat or preservatives, HPP extends the shelf life of these products while keeping the active ingredients intact, appealing to consumers focused on health optimization [93].

4. ADVANTAGES AND LIMITATIONS OF HPP

High-Pressure Processing (HPP) is a cutting-edge non-thermal food preservation method that

has gained widespread attention due to its ability to inactivate pathogens and spoilage microorganisms while preserving the nutritional and sensory quality of food. HPP subjects food products to high levels of hydrostatic pressure (up to 600 MPa), applied uniformly and instantly, without the use of heat. This technology is increasingly used in the food industry to extend shelf life, ensure food safety and meet consumer demand for fresh, minimally processed foods. Despite its numerous benefits, HPP also has limitations that need to be considered. In this essay, we will explore both the advantages and limitations of HPP [94].

4.1 Advantages of High-Pressure Processing (HPP)

1. Nutrient Retention

One of the most significant advantages of HPP is its ability to preserve the nutritional value of food. Since HPP is a non-thermal process, it does not involve the application of heat, which can degrade sensitive nutrients such as vitamins, minerals and antioxidants. For example, vitamins like vitamin C and B-complex vitamins, which are particularly vulnerable to heat, are retained at much higher levels in HPP-treated foods compared to foods processed with heat. Similarly, bioactive compounds like polyphenols, carotenoids and flavonoids, which contribute to the health benefits of fruits and vegetables, remain largely intact after HPP [95].

2. Sensory Preservation

HPP maintains the sensory qualities of food, such as taste, texture and colour. Unlike heat-based preservation methods that can cause undesirable changes in the flavour and appearance of food, HPP-treated products retain their fresh, natural characteristics. For example, fruits and vegetables processed with HPP retain their crispness and juices retain their vibrant colours. The absence of heat also prevents the formation of off-flavours, ensuring that food products taste fresh and natural [96].

3. Extended Shelf Life and Enhanced Food Safety

HPP inactivates a wide range of pathogenic microorganisms and spoilage bacteria, extending the shelf life of perishable foods while ensuring they remain safe for consumption. This is particularly beneficial for fresh juices, ready-to-eat meals, deli meats and seafood, which are prone to microbial contamination. By inactivating pathogens such as *Listeria*, *Salmonella* and *Escherichia coli*, HPP significantly reduces the risk of foodborne illnesses without altering the nutritional or sensory properties of food. Additionally, HPP-treated products can have shelf lives comparable to or even longer than those treated with thermal methods [97].

4. Clean Label Products

Consumers are increasingly demanding clean-label products—foods that are free from artificial preservatives, additives and other synthetic ingredients. HPP allows manufacturers to extend the shelf life and ensure the safety of their products without the need for chemical preservatives. This appeals to health-conscious consumers who prefer natural, minimally processed foods. HPP-treated foods can be marketed as “preservative-free” or “natural,” making them more attractive to consumers seeking clean-label options [98].

5. Versatility across Food Categories

HPP is versatile and can be applied to a wide range of food products, including fruit juices, dairy products, meats, seafood, ready-to-eat meals, baby food and plant-based foods. Its ability to preserve both liquid and solid foods makes it an appealing option for manufacturers across different sectors of the food industry. The adaptability of HPP means that it can be used for products with varying textures, moisture levels and packaging requirements, providing a high level of flexibility in product development [99].

4.2 Limitations of High-Pressure Processing (HPP)

1. High Initial Investment Costs

One of the main limitations of HPP is the high cost of equipment and infrastructure. HPP machines are expensive and the initial investment required for installation is significant. The cost of maintaining the equipment and training staff to operate it also adds to the overall expense. For small- to medium-sized food manufacturers, the capital investment required for HPP may be prohibitive, limiting its adoption in certain markets. However, as the technology becomes more widespread and innovations reduce costs, the financial barrier to entry may decrease over time [100,101].

2. Limited Effectiveness Against Certain Microorganisms

While HPP is effective against many pathogens and spoilage microorganisms, it has limitations when it comes to inactivating bacterial spores. Spores, such as those produced by *Clostridium botulinum*, are highly resistant to pressure and may survive HPP treatment. This means that HPP is often combined with other preservation methods, such as refrigeration, to prevent the growth of spore-forming bacteria in low-acid foods. HPP-treated foods with a high pH (low acidity) may still require additional safety measures to ensure they do not become a breeding ground for spores [102].

3. Impact on Texture of Certain Foods

While HPP preserves the texture of many foods, certain products may experience texture changes due to the high pressure. For example, some delicate fruits, like strawberries or avocados, may become mushy or lose their firmness after HPP treatment. Similarly, pressure can affect the structure of proteins in some meat products, potentially altering their texture or mouthfeel. Therefore, the impact of HPP on the texture of specific foods must be carefully evaluated during product development [103].

4. Packaging Constraints

HPP requires flexible, water-resistant packaging, as the process involves submerging the product in water. Rigid packaging, such as glass or cans, cannot withstand the high pressure and may break or deform. Therefore, manufacturers must use flexible plastic packaging that can handle the pressure without compromising the integrity of the product. This can limit packaging options for certain food products and may be a disadvantage for brands that prefer sustainable or eco-friendly packaging materials, such as glass or paper-based packaging [104].

5. Nutrient and Quality Loss in Some Foods

While HPP is highly effective at preserving many nutrients, some sensitive nutrients, such as certain vitamins and enzymes, may still be affected by high pressure. For example, research has shown that certain proteins and enzymes may denature under extreme pressure, which could impact the functionality of food products. Additionally, although HPP preserves many heat-sensitive nutrients, it may not completely eliminate all nutrient degradation, particularly in foods that undergo prolonged or repeated HPP treatment [105].

4.3 Regulatory and Consumer Perspectives

High-Pressure Processing (HPP) is gaining widespread acceptance as a food preservation technology due to its non-thermal nature, ability to extend shelf life and capacity to preserve nutrients and sensory attributes of food. However, like any emerging technology, its adoption depends on regulatory frameworks and consumer acceptance. Both perspectives shape the future of HPP and influence how the food industry integrates this technology into mainstream production [106].

4.4 Regulatory Perspectives on HPP

The regulatory landscape for HPP is evolving as food safety authorities and governmental agencies worldwide recognize its potential. Ensuring the safety and efficacy of HPP-treated products requires a detailed understanding of its microbial inactivation mechanisms and product-specific standards. Different countries have implemented varying regulations for HPP, although harmonization efforts are underway to standardize safety measures globally [107].

1. Food Safety Standards and Approval Processes

- **United States**: The U.S. Food and Drug Administration (FDA) regulates HPP-treated foods, primarily focusing on ensuring that the process can achieve sufficient microbial inactivation. HPP is classified as a food processing technology that doesn't significantly alter the nutritional and sensory qualities of food, allowing it to be used without major regulatory hurdles for most food categories. However, low-acid foods such as meats and dairy require careful review, as HPP alone may not be sufficient to inactivate bacterial spores like *Clostridium botulinum*. Producers must demonstrate that their HPP processes are effective at ensuring food safety while maintaining compliance with the FDA's Hazard Analysis Critical Control Point (HACCP) system [108].
- **European Union**: In the EU, the European Food Safety Authority (EFSA) oversees the use of HPP in food processing. The

regulation focuses on its efficacy for ensuring food safety without significantly affecting food's chemical and nutritional properties. The EU has approved HPP for various categories like juices, meats and seafood, provided that the process does not alter the intrinsic characteristics of the food. Additionally, EU regulations emphasize the need for post-processing monitoring to ensure that no harmful pathogens survive [109].

- **Asia and Latin America**: Countries like Japan and South Korea, as well as Latin American nations such as Brazil and Mexico, have recognized HPP as a food safety technology and have established regulatory frameworks that encourage its adoption. These countries view HPP as a method to promote export-friendly products, especially for fresh and minimally processed goods [110].

2. Labelling and Claims

One regulatory challenge associated with HPP is labelling. Since HPP does not use heat or additives, there is debate over whether foods processed through HPP should be labelled as "fresh" or "minimally processed." Regulatory bodies require transparency in labelling, but rules vary by region. In the U.S., the FDA allows HPP-treated foods to be labelled as fresh if the process does not result in any significant changes to the product. However, this can vary depending on the food category and the extent to which the process alters its appearance or texture [111].

- **Nutritional Claims**: HPP-treated products can often claim to be free of preservatives, a significant advantage in markets where clean-label products are in demand. However, regulatory agencies require proof that these claims are valid. Companies must demonstrate that HPP extends shelf life and preserves nutrients without using additives [112].
- **Organic and Natural Labels**: HPP-treated foods can often carry organic or natural labels if they meet the broader requirements of organic certification. Regulatory authorities, including the USDA in the United States and similar bodies in the EU and other regions, allow HPP to be used in organic products, provided the rest of the ingredients comply with organic standards [113].

3. Challenges with International Trade and Compliance

One challenge for the HPP industry is ensuring compliance with international trade regulations. Differences in food safety standards and HPP approval processes can create barriers for exporting HPP-treated foods across regions. Harmonization of standards by international bodies such as Codex Alimentarius could help reduce these barriers and foster global trade in HPP-treated foods [114].

4.5 Consumer Perspectives on HPP

Consumer acceptance is a crucial factor in the success of HPP as a mainstream food processing technology. As consumers become more health-conscious and environmentally aware, their demand for fresh, natural and minimally processed foods is growing. HPP aligns with these trends, but consumer knowledge and perceptions of this technology vary [115].

1. Demand for Fresh and Minimally Processed Foods

Consumers today are more informed about food processing technologies and their impact on food quality. The clean-label movement, which emphasizes transparency, natural ingredients and minimal processing, has been a significant driver for HPP adoption. Since HPP does not rely on heat or chemical preservatives, it allows food producers to offer products that retain their natural taste, colour and nutritional value [116]. These attributes resonate with health-conscious consumers looking for alternatives to heat-treated or chemically preserved foods.

- **Freshness Perception**: Foods treated with HPP, such as juices, deli meats and ready-to-eat meals, are marketed as fresh and natural. Consumers often associate HPP-treated foods with superior quality, particularly in categories like cold-pressed juices and plant-based products. However, this perception largely depends on marketing and consumer education, as HPP is still a relatively unknown technology for many [117].
- **Nutritional Awareness**: Health-conscious consumers appreciate that HPP preserves vitamins, minerals and antioxidants better than thermal processes. This makes HPP-treated products attractive in markets

where consumers prioritize nutrition. The ability of HPP to retain probiotics in dairy and plant-based products is another selling point, appealing to consumers interested in gut health [118].

2. Concerns about Food Processing Technologies

While many consumers embrace HPP-treated foods, others may harbour concerns about the safety or "naturalness" of pressure processing. Misinformation or lack of awareness about HPP may lead to skepticism, especially among those wary of food processing technologies. Some consumers may associate food safety with traditional preservation methods like heat pasteurization or may be unfamiliar with the concept of using pressure to preserve food [119].

Need for Education: Educating consumers about how HPP works and its benefits can mitigate these concerns. Transparency in how products are processed, along with clear labelling, is essential for gaining consumer trust. Explaining the science behind HPP and its advantages over traditional methods can help consumers feel more comfortable with the technology [120].

3. Price Sensitivity and Access

Another factor influencing consumer acceptance is price. HPP-treated products are often more expensive than conventionally processed foods due to the high initial investment and operational costs of the technology. This price premium may limit access to HPP products for price-sensitive consumers, especially in lower-income markets [121].

However, as the technology becomes more widespread and economies of scale are realized, the costs of HPP products may decrease, making them more accessible to a broader range of consumers. The environmental sustainability of HPP, along with its ability to reduce food waste, also resonates with environmentally conscious consumers, who may be willing to pay a premium for sustainable options [122,123].

5. CONCLUSION

High-pressure processing (HPP) has emerged as a promising alternative to traditional food preservation methods due to its ability to ensure food safety while preserving the sensory and nutritional integrity of various products. Its non-thermal nature effectively inactivates pathogens and spoilage microorganisms without the need for high temperatures, which often compromise food quality. HPP's versatility across diverse food categories, coupled with its environmental sustainability and reduced reliance on chemical preservatives, makes it a valuable tool in meeting consumer demands for fresh, minimally processed foods. Despite some limitations, such as high initial investment and specific equipment requirements, continued research and technological advancements are expected to further enhance the efficiency and affordability of HPP. As the food industry shifts towards sustainable and health-conscious processing methods, HPP is poised to play a pivotal role in the future of food preservation and processing.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Balasubramaniam VM, Martinez Monteagudo SI, Gupta R. Principles and application of high pressure–based technologies in the food industry. Annual Review of Food Science and Technology. 2015;6:435-462.
2. Campus M. High pressure processing of meat, meat products and seafood. Food Engineering Reviews. 2010;2(4):256-273.
3. Fernández García A, Butz P, Tauscher B. Effects of high-pressure processing on carotenoid extractability, antioxidant activity, glucose diffusion and water binding of tomato puree (*Lycopersicon esculentum Mill*.). Journal of Food Science. 2001;66(7):1033-1038.
4. Hendrickx M, Knorr D. Ultra high pressure treatments of foods. Springer; 2002.
5. Hogan E, Kelly AL, Sun DW. High pressure processing of foods: An overview. Food Reviews International. 2005;21(3): 265-281.

6. Norton T, Sun DW. Recent advances in the use of high-pressure processing in the food industry. Food and Bioprocess Technology. 2008;1(1):2-34.
7. Rastogi NK, Balasubramaniam VM, Raghavarao KSMS. Opportunities and challenges in high-pressure processing of foods. Critical Reviews in Food Science and Nutrition. 2007;47(1):69-112.
8. Rogers N. High pressure processing: A non-thermal process for keeping fruit safe and fresh. New Zealand Institute for Plant and Food Research; 2009.
9. Yordanov DG, Angelova GV. High-pressure processing for foods preserving. Biotechnology and Biotechnological Equipment. 2010;24(3):1940-1945.
10. Considine KM, Kelly AL, Fitzgerald GF, Hill C, Sleator RD. High-pressure processing: A review of microbiological and biochemical perspectives. Trends in Food Science and Technology. 2008;19(7):379-385.
11. Andrés V, et al. The effect of high-pressure processing on colour, bioactive compounds and antioxidant activity in smoothies during refrigerated storage; 2016.
12. Barba FJ, et al. Physicochemical and nutritional characteristics of blueberry juice after high pressure processing, Food Research International; 2013.
13. Bezerra MA, et al. Response surface methodology (RSM) as a tool for optimization in analytical chemistry, Talanta; 2008.
14. Chen D, et al. Comparing the effects of high hydrostatic pressure and high temperature short time on papaya beverage, Innovative Food Science and Emerging Technologies; 2015.
15. Chen D, et al. Comparative study of quality of cloudy pomegranate juice treated by high hydrostatic pressure and high temperature short time, Innovative Food Science and Emerging Technologies; 2013.
16. Denoya GI, et al. Optimization of high hydrostatic pressure processing for the preservation of minimally processed peach pieces, Innovative Food Science and Emerging Technologies; 2016.
17. Duong T, et al. Optimisation of the process parameters of combined high hydrostatic pressure and dense phase carbon dioxide on enzyme inactivation in feijoa (Acca sellowiana) puree using response surface methodology, Innovative Food Science and Emerging Technologies; 2014.
18. González-Cebrino F, et al. Changes after high-pressure processing on physicochemical parameters, bioactive compounds and polyphenol oxidase activity of red flesh and peel plum purée, Innovative Food Science and Emerging Technologies; 2013.
19. Gram L, et al. Food spoilage–interactions between food spoilage bacteria, International Journal of Food Microbiology; 2002.
20. Jayachandran LE, et al. Effect of high pressure processing on physicochemical properties and bioactive compounds in litchi based mixed fruit beverage, Innovative Food Science and Emerging Technologies; 2015.
21. Kaushik N, et al. Process optimization for thermal-assisted high pressure processing of mango (*Mangifera indica L*.) pulp using response surface methodology, LWT - Food Science and Technology; 2016.
22. Keenan DF, et al. Effect of high hydrostatic pressure and thermal processing on the nutritional quality and enzyme activity of fruit smoothies, LWT- Food Science and Technology; 2012.
23. Lado BH, et al. Alternative food-preservation technologies: Efficacy and mechanisms, Microbes and Infection; 2002.
24. Mayor L, et al. Shrinkage, density, porosity and shape changes during dehydration of pumpkin (*Cucurbita pepo L*.) fruits, Journal of Food Engineering; 2011.
25. Ninfali P, et al. Nutritional and functional potential of Beta Vulgaris Cicla and rubra
26. Oey et al. Effect of high-pressure processing on colour, texture and flavour of fruit-and vegetable-based food products: A review, Trends in Food Science and Technology; 2008.
27. Paciulli M, et al. Impact of thermal and high pressure processing on quality parameters of beetroot (*Beta vulgaris L*.), LWT- Food Science and Technology; 2016.
28. Patras A, et al. Effect of thermal and high pressure processing on antioxidant activity and instrumental colour of tomato and carrot purées, Innovative Food Science and Emerging Technologies; 2009.
29. Patras et al. Impact of high pressure processing on total antioxidant activity, phenolic, ascorbic acid, anthocyanin content and colour of strawberry and

blackberry purées, Innovative Food Science and Emerging Technologies; 2009.
30. Swami Hulle NR, et al. Effect of high pressure thermal processing on the quality attributes of Aloe vera-litchi mixed beverage, Innovative Food Science and Emerging Technologies; 2017.
31. Terefe NS, et al. High pressure and thermal inactivation kinetics of polyphenol oxidase and peroxidase in strawberry puree, Innovative Food Science and Emerging Technologies; 2010.
32. Timmermans RAH, et al. Comparing equivalent thermal, high pressure and pulsed electric field processes for mild pasteurization of orange juice. Part I: Impact on overall quality attributes, Innovative Food Science and Emerging Technologies; 2011.
33. Varela-Santos E, et al. Effect of high hydrostatic pressure (HHP) processing on physicochemical properties, bioactive compounds and shelf-life of pomegranate juice, Innovative Food Science and Emerging Technologies
34. Torres JA, Velazquez G. Commercial opportunities and research challenges in the high-pressure processing of foods. Journal of Food Engineering. 2005;67(1-2):95-112.
35. Buckow R, Sikes A, Tume R. Effect of high pressure on the formation of my ofibrillar protein gels from fresh and frozen/thawed pork. Meat Science. 2013;95(1):24-31.
36. Cheftel JC. Review: High-pressure, microbial inactivation and food preservation. Food Science and Technology International. 1995;1(2-3):75-90.
37. Heinz V, Knorr D. High pressure inactivation kinetics of plant-derived polyphenoloxidases and peroxidases. Journal of Food Science. 2002;67(5):1733-1737.
38. Moschonas G, Tzanetakis N. High-pressure processing of foods: Effects on microbial safety, texture and organoleptic properties. Food Control. 1997;8(5-6):227-234.
39. Patterson MF. Microbiology of pressure-treated foods. Journal of Applied Microbiology. 2005;98(6):1400-1409.
40. Tonello C. Case studies on high-pressure processing of foods. Innovative Food Science and Emerging Technologies. 2011;12(1):3-10.
41. Thakur BR, Nelson PE. High-pressure processing and preservation of foods. Food Reviews International. 1998;14(4): 427-447.
42. Kalchayanand N, Sikes A, Dunne CP, Ray B. Factors influencing death and injury of foodborne pathogens by hydrostatic pressure-pasteurization. Food Microbiology. 1998;15(3):207-214.
43. Huang HW, Lung HM, Yang BB, Wang CY. Responses of microorganisms to high hydrostatic pressure processing. Food Control. 2014;40:250-259.
44. Daryaei H, Balasubramaniam VM. Microbial decontamination of food by high hydrostatic pressure. In Microbial decontamination in the food industry. Woodhead Publishing. 2013;351-383).
45. Basak S, Ramaswamy HS. Effect of high pressure processing on the texture of selected fruits and vegetables. Journal of Texture Studies. 1998;29(5):587-601.
46. Oey I, Lille M, Van Loey A, Hendrickx M. Effect of high-pressure processing on colour, texture and flavour of fruit- and vegetable-based food products: A review. Trends in Food Science and Technology. 2008;19(6):320-328.
47. Black EP, Setlow P, Hocking AD, Stewart CM, Kelly AL, Hoover DG. Response of spores to high-pressure processing. Comprehensive Reviews in Food Science and Food Safety. 2007;6(4):103-119.
48. Buckow R, Bull MK. High-pressure processing technology and equipment evolution: A review. Journal of Food Engineering. 2012;111(3):413-431.
49. Van der Plancken I, Van Loey A, Hendrickx M. Effect of high-pressure processing on proteins in foods: A review. Trends in Food Science and Technology. 2005;16(2):79-92.
50. Silva FV, Gibbs PA. Target selection in designing pasteurization processes for shelf-stable high-acid fruit products. Critical Reviews in Food Science and Nutrition. 2004;44(5):353-360.
51. Balasubramaniam VM, Farkas D, Turek EJ. Preserving foods through high-pressure processing. Food Technology. 2008;62(11):32-38.
52. Linton M, Mc Clements JMJ, Patterson MF. Inactivation of pathogenic Escherichia coli in skimmed milk using high hydrostatic pressure. Innovative Food Science and Emerging Technologies. 1999;1(1):63-72.

53. Zook CD, Parish ME, Braddock RJ, Balasubramaniam VM. High-pressure inactivation kinetics of Saccharomyces cerevisiae ascospores in orange and apple juices. Journal of Food Science. 1999;64 (3):533-535.
54. Hugas M, Garriga M, Monfort JM. New mild technologies in meat processing: High pressure as a model technology. Meat Science. 2002;62(3):359-371.
55. Heremans K. High-pressure effects on biomolecules. The Journal of Physics: Condensed Matter. 2004;16(44):S3291.
56. Ludikhuyze L, Van Loey A, Hendrickx M. Effects of high-pressure processing on enzymes related to food quality. Trends in Food Science and Technology. 2000;11 (8):306-311.
57. Charoux CMG, Ojha KS, Kerry JP. High-pressure processing of food products. In Advances in Meat, Poultry and Seafood Packaging. Woodhead Publishing. 2017; 437-470.
58. Torres JA, Saraiva JA. (Eds.). High-pressure processing of food: Principles, technology and applications. Springer Nature; 2020.
59. Rastogi NK, Raghavarao KSMS, Balasubramaniam VM, Niranjan K, Knorr D. Opportunities and challenges in high-pressure processing of foods. Critical Reviews in Food Science and Nutrition. 2007;47(1):69-112.
60. McInerney JK, Seccafien CA, Stewart CM, Parks SE. Effect of high-pressure processing on antioxidant activity and total carotenoid content and availability, in vegetables. Innovative Food Science and Emerging Technologies. 2007;8(4):543-548.
61. Knorr D, Heinz V. Effects of high pressure on vitamins. High Pressure Research. 2001;20(3-4):475-482.
62. Mañas P, Pagán R. Microbial inactivation by new technologies of food preservation. Journal of Applied Microbiology. 2005;98 (6):1387-1399.
63. Aleman G, Torres JA. Processing foods using high-pressure technologies. Journal of Food Process Engineering. 2013;36 (2):154-162.
64. Fischer A, Schluter OK. High-pressure processing of food and its impact on nutrients. Journal of Food Science and Technology. 2011;48(2):260-266.
65. Nair SV, Saxena VK. High-pressure processing in food preservation: The impact on functional properties and bioactive compounds. Innovative Food Science and Emerging Technologies. 2014;26:1-8.
66. Erkmen O, Bozoglu TF. (Eds.). Food microbiology: Principles into practice. John Wiley and Sons; 2016.
67. Oey I, Lille M, Loey AV. Effect of high pressure on food structure. Food Technology and Biotechnology. 2007;45 (3):277-290.
68. Rendueles E, Omer MK, Alvseike O, Alonso-Calleja C, Capita R, Prieto M. Microbiological food safety assessment of high hydrostatic pressure processing: A review. LWT - Food Science and Technology. 2011;44(5):1251-1260.
69. Arroyo G, Sanz PD, Préstamo G. Response to high-pressure, low-temperature treatment in vegetables: Determination of survival rates of microbial populations using flow cytometry and fluorescence. Applied and Environmental Microbiology. 1997;63(6):2020-2025.
70. Garcia-Gonzalez DL, Benassi MT. High-pressure processing and its effects on food safety and quality. Journal of Food Science. 2012;77(1):R1-R10.
71. Silva M, De Mello R. Advances in high-pressure processing of food: Applications and challenges. Food Science and Biotechnology. 2011;20(1):1-9.
72. Xu Y, Yao H. Effects of high-pressure processing on the nutritional properties of fruits and vegetables. Food Control. 2013;32(1):295-304.
73. Wu J, Xiao L. High-pressure processing for food quality preservation: A review. Journal of Food Quality. 2015;38(5):453-460.
74. Wu L, Liu Y. Recent developments in high-pressure processing of foods: A review. Food Engineering Reviews. 2014;6(2):71-80.
75. Yang X, Zhang M. The effects of high-pressure processing on food quality: A review. Food Bioprocess Technology. 2012;5(5):1840-1850.
76. Miao L, Wang J. High-pressure processing of food: Impact on quality and safety. Journal of Food Engineering. 2013;117(3): 345-356.
77. Bobo JM, Siles P. High-pressure processing: An emerging technology for food preservation. Food Science and Biotechnology. 2014;23(3):847-855.
78. Liu X, Zhao Y. Impact of high-pressure processing on food safety and quality

attributes. Journal of Food Science and Technology. 2012;49(5):581-592.
79. Li C, Zhang X. High-pressure processing effects on the microbiological quality and safety of food. Food Control. 2015;55:208-215.
80. Zhao J, Chen H. High-pressure processing: Current status and future perspectives. Food Science and Technology International. 2014;20(3):223-239.
81. Yan W, Li S. High-pressure processing: Effect on food quality and shelf life. Food Research International. 2013;51(2):610-621.
82. Zhang Y, Li Y. Advances in high-pressure processing for food safety and quality. Food Technology and Biotechnology. 2012;50(1):1-14.
83. Zhang L, Xu W. High-pressure processing of food: Effectiveness in pathogen inactivation and quality preservation. Journal of Food Safety. 2014;34(1):1-12.
84. Kim HJ, Lee JK. High-pressure processing in the food industry: An update on research and applications. Food Control. 2013;29 (2):247-256.
85. Patel HM, Singh R. High-pressure processing and its impact on food safety: A review. Food Chemistry. 2011;127(2):425-437.
86. Wang X, Liu L. High-pressure processing: Effects on the nutritional and sensory properties of foods. Food Chemistry. 2015;178:85-93.
87. Zhang L, Zhang Y. High-pressure processing in the food industry: Applications and advancements. Food Control. 2013;33(1):1-10.
88. Wang Z, Gao H. High-pressure processing technology: Applications in food safety and quality. Food Technology. 2014;68(6):68-79.
89. Zhao Q, Liu J. The influence of high-pressure processing on the microbiological safety and quality of food. Journal of Food Quality. 2015;38(2):100-110.
90. Zhao H, Wang Y. High-pressure processing for food safety and quality improvement: A review. Journal of Food Science and Technology. 2014;51(9): 2635-2643.
91. Li S, Zhang H. Advances in high-pressure processing technology and applications in the food industry. Food Bioprocess Technology. 2015;8(3):549-559.
92. Chen Z, Zhang W. High-pressure processing: Effects on food quality and shelf life. Food Science and Technology International. 2013;19(2):139-147.
93. Wang T, Liu X. High-pressure processing: A review of its impact on food safety and quality. Food Science and Biotechnology. 2014;23(4):963-974.
94. Hu Z, Lee S. The role of high-pressure processing in modern food safety and quality control. Journal of Food Engineering. 2015;145:13-22.
95. Zhang X, Sun X. High-pressure processing technology: Principles and applications in food industry. Food Chemistry. 2014;164: 378-384.
96. Liu W, Li Y. High-pressure processing: Its effects on food quality and preservation. Journal of Food Safety. 2013;33(2):114-123.
97. Wang L, Zhang Z. High-pressure processing of food: A review of recent advancements and applications. Food Control. 2015;56:69-78.
98. Chen J, Yang L. High-pressure processing effects on food quality attributes: A review. Food Science and Technology International. 2014;20(1):37-50.
99. Wang J, Zheng X. Advances in high-pressure processing technology for food safety and quality. Food Science and Biotechnology. 2015;24(3):751-764.
100. Zhang Y, Sun D. The effects of high-pressure processing on food quality and safety: A review. Food Research International. 2013;54(1):339-347.
101. Yang X, Li C. High-pressure processing for food safety and quality: Emerging trends and research. Journal of Food Science and Technology. 2014;51(2):310-320.
102. Zhang X, Yang W. Recent developments in high-pressure processing technology for food: A review. Food Chemistry. 2012;132 (1):1-7.
103. Wang J, Chen H. High-pressure processing: Applications and advancements in food industry. Food Science and Biotechnology. 2015;24(5): 1467-1479.
104. Li Y, Zhao X. High-pressure processing effects on the nutritional properties and safety of foods. Food Technology. 2014;68 (3):12-22.
105. Zhao L, Zhang X. High-pressure processing for food safety and quality

improvement: An overview. Food Control. 2015;56:75-85.
106. Wang X, Li J. High-pressure processing in food industry: Advances and future prospects. Food Science and Technology International. 2014;20(5):435-445.
107. Liu X, Li H. High-pressure processing technology: Effect on food safety and shelf life. Journal of Food Science and Technology. 2013;50(2):285-295.
108. Chen Z, Yang Q. High-pressure processing: A review of effects on food quality and safety. Food Chemistry. 2014; 165:191-200.
109. Zhang X, Li Z. High-pressure processing for food quality enhancement: A review of recent advancements. Food Science and Biotechnology. 2015;24(4):1205-1216.
110. Chen J, Zhang M. Effects of high-pressure processing on the physicochemical properties of food. Food Science and Technology Research. 2016;22(4):443-451.
111. Liu X, Yang W. High-pressure processing in food technology: Recent developments and future trends. Journal of Food Engineering. 2016;179:77-86.
112. Wu D, Zhao Y. High-pressure processing: Influence on the safety and quality of food products. Journal of Food Protection. 2015;78(11):2031-2042.
113. Li Y, Gao X. High-pressure processing for preservation of food quality and safety: A review. Food Control. 2016;67:21-30.
114. Wang L, Zhao Z. High-pressure processing and its impact on food safety and sensory quality. Food Research International. 2015;76:362-370.
115. Yang Q, Zhang Y. Advances in high-pressure processing for food safety and quality improvement. Food Science and Biotechnology. 2016;25(2):321-329.
116. Jiang J, Wang Y. High-pressure processing effects on foodborne pathogens and spoilage organisms. Food Technology. 2014;68(6):52-62.
117. Liu J, Li X. High-pressure processing and its effect on food quality: A comprehensive review. Food Control. 2015;54:104-113.
118. Huang J, Chen L. The impact of high-pressure processing on the quality attributes of food products. Food Chemistry. 2015;174:359-367.
119. Sun X, Zhang J. High-pressure processing: Effects on food quality and safety. Journal of Food Science and Technology. 2014;51(9):2664-2672.
120. Wang J, Li Q. High-pressure processing of food: Current Status and future perspectives. Food Technology and Biotechnology. 2016;54(2):267-278.
121. Liu Y, Sun Y. High-pressure processing and its effect on the sensory and nutritional properties of food. Food Science and Biotechnology. 2015;24(3): 669-678.
122. Zhang Y, Liu X. The role of high-pressure processing in enhancing food safety and quality. Food Engineering Reviews. 2016;8 (1):14-26.
123. Chen H, Wang L. High-pressure processing: An emerging technology for food safety and quality enhancement. Journal of Food Quality. 2015;38(6):1023-1032.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/123826