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Advanced food preservation techniques in developing countries

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Advanced food preservation techniques in developing countries independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 2023

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Ngone Mbow

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Abstract

Food preservation techniques play an essential role in developing countries, where access to fresh food is often limited, and food insecurity is a prevalent issue. The food preservation techniques enable people to store food for an extended period, reducing food waste and allowing them to have access to a variety of nourishment throughout the year.

However, due to the lack of infrastructure and resources, many developing countries face challenges in preserving food. The thesis is a review of some of the food preservation techniques and the evaluation of possibilities and use of the application of some modern methods of food preservation in developing countries. We find out that the most common novel food preservation techniques including high pressure processing, pulsed electric field, ultrasound, irradiation, MAP and aseptic packaging are already being implemented and used in some developing countries but in small scaled due to some factors like the cost, energy, infrastructure and engineering.

Key words: Food preservation, developing countries, novel food processing, advanced food processing technologies, Non-thermal Technologies for Food Processing

1. Table of Contents

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List of the abbreviations used in the thesis.

¢/L- Cost per Liter

FAO- Food and Agriculture Organization

FDA- The U.S. Food and Drug Administration

FM- Florida Memory

HC- Hydrodynamic Cavitation

HPP- High pressure processing

IFT- Italian Food Tech

IMCD- Intermittent Microwave Convective Drying

MAP- Modified Atmosphere Packaging

MPa- Mega Pascal

NM-AIST- The Nelson Mandela African Institution of Science and Technology

OSU- The Ohio State University

PEF- Pulsed electric field

PSI- Pounds Per Square Inch

SEM- Scanning Electron Microscopy

SMEs- Small and Medium-sized Enterprises (SMEs)

TVC- Total Viable Counts

UNIDO- United Nations Industrial Development Organization

US- Ultrasound

WHO- World Health Organization

YMC- Yeast and Mold Cou

2. Introduction

Food preservation is the procedure or method of retaining foods at a desired level of properties or nature in order to preserve their nutritional content (Rahman 2007).

Food can be defined as any substance that is consumed by living organisms to provide the nutrients (WHO 2021) necessary for growth, maintenance, and repair of bodily tissues, and to provide energy for various physiological processes (Liu 2013). In general, it is made up of a combination of macronutrients (such as carbohydrates, proteins, and fats) and micronutrients (such as vitamins and minerals) (Drewnowski 2020), which provide the necessary building blocks and fuel for the body to function properly.

Food can come from both plant and animal sources (Ludwig 2021), and can be consumed in a wide variety of forms, such as raw or cooked, solid or liquid (Rahman 2007).

We preserve foods to ensure safety, convenience, nutritional content and flavour (Gould 2010) as it prevent the growth of harmful microorganisms, make it easier to store, transport, prepare and also allows for seasonal foods to be available year-round (Joardder & Masud 2019), and reduces food waste by preventing spoilage.

The methods of preservation begin with a thorough examination and comprehension of the entire food chain as, in general, each phase of food handling, processing, storage, and distribution impacts the food's qualities (Singh 2023) as shown in the figure 1 due to the physical, microbial, enzymatic reactions and, chemical factors (Joardder & Masud 2019) which may be unfavourable (Hameed 2018). Thus, it is crucial in food processing to understand the impacts of each preservation technique and the foods handling procedure.

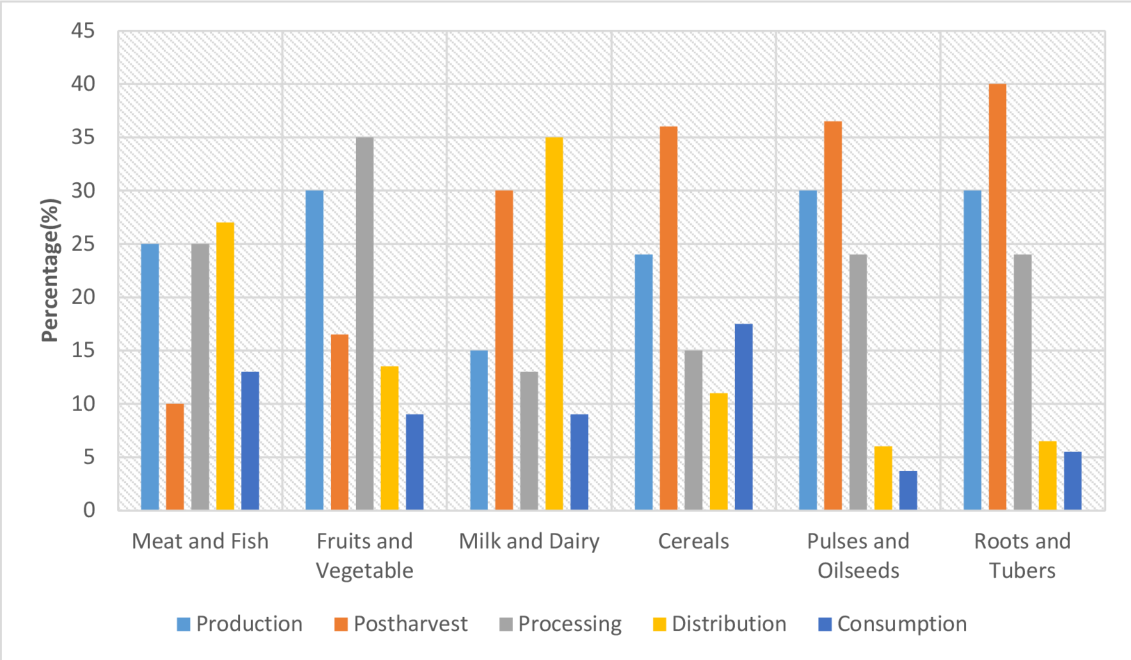

Figure 1 Estimated percentage of waste in different stages of the food chain for various types of foods. Adapted from **(Joardder & Masud 2019)**.

Food preservation techniques play an essential role in developing countries, where access to fresh food is often limited, and food insecurity is a prevalent issue (FAO 2022). The food preservation techniques enable people to store food for an extended period, reducing food waste and allowing them to have access to a variety of nourishment throughout the year (Rahman 2007). However, due to the lack of infrastructure and resources, many developing countries face challenges in preserving food.

There are several traditional and modern food preservation techniques used in developing countries, including drying, smoking, salting, fermentation, canning, and refrigeration (Ayoub 2018). Each technique has its advantages and disadvantages, and their use depends on several factors, including the type of food, the availability of resources, and the economic situation of the community (Mashoko 2022). While traditional preservation techniques have been used for centuries, modern technologies have revolutionized the industry of food preservation in the recent years. However, the adoption of modern techniques in developing countries is often limited due to the high cost of equipment and the lack of infrastructure required to support their use (FAO 2019).

Food preservation is a critical issue that requires attention and innovation to address food insecurity in developing countries (Ayoub 2018). By using a combination of traditional and modern techniques, it is possible to increase access to a variety of food and reduce food waste.

In this literature review, we will outline the major ancient techniques of preservation and the new preservation techniques with their possible use in developing countries.

3. Aims of the Thesis

The aim of the Bachelor's Thesis was to evaluate the current literature on traditional food preservation techniques and to evaluate the possibilities and use of preservation methods considered as advanced preservation techniques with a specific focus on developing countries.

4. Methodology

The thesis was done in the form of a literature review using scientific databases: Web of Science, Scopus, Google Scholar, Hindawi, Wiley, Institute of Food Science Technology, National Library of Technology, Springer nature, Sciendo, Science direct, Research gate, and, a total of 108 literature sources was used for the research.

The research was done by using the keywords and research questions such as " Food preservation; Food preservation techniques; Food preservation techniques in developing countries; Advanced food preservation techniques; Methods of food preservation use in developing countries; Traditional food preservation; use of novel food preservation techniques in developing countries; challenge in food preservation in developing countries; actual food preservation method in developing countries; Salting as food preservation; canning as food preservation; Fermentation as food preservation; Drying as food preservation; Irradiation as food preservation; Ultrasound as food preservation; High pressure processing as food preservation; Pulsed electric field as food preservation; Hydrodynamic cavitation as food preservation; what are the method of food preservation; what is ancient food method; what is novel food technique; in the research section, the use of filters like years or type of paper (if it is article or book).

The methodology used involved selecting relevant articles, analysing and organizing the articles into categories, synthesizing the findings, writing the literature review, and concluding with a summary of the key findings and their implications.

5. Literature Review

5.1. Traditional food preservation techniques

Traditional food preservation techniques, also called ancient food preservation techniques or old method of food preservation, refer to methods of preserving food that have been developed from the prehistoric times (Desrosier & Singh 2023) and passed down from generation to generation and have played an essential role in the survival of human societies. These techniques involve using processes as shown in the TABLE 1. They help to extend the shelf life of food, prevent spoilage, and ensure food safety (Pace et al. 1989).

Traditional food preservation techniques are often simple and do not require the use of modern technology (Rahman 2007). They have been used for thousands of years and continue to be used in many cultures around the world (Mashoko 2022). These techniques are a vital part of our culinary heritage and contribute to the diversity of flavours and textures in our food (Onyeaka & Nwabor 2022).

In this chapter, we will explore some of the most common traditional food preservation techniques such as salting and curing, smoking, fermentation, drying, canning, identified through a combination of literature review, historical research, consultation of books, academic journals, and articles on the history of food preservation to identify the oldest and most widely used methods of food preservation.

The factors such as the availability of resources, the climatic conditions of different regions, and the cultural traditions and preferences of different communities was also taken into consideration.

Table 1 Traditional food preservation methods adapted from (Linares-Morales et al. 2018; Rahman 2007)

Methods	Characteristics	References
Salting **Curing**	Non thermal; reduce water activities of microorganisms	(Peñarubia 2021; Kanagaraj & Chandra Babu 2002; Rahman 2007)
Drying **Osmotic dehydration** **Smoking**	Thermal	(FAO 2009 ; Nonclercq et al. 2009 ; Taheri et al. 2012)
Fermentation	Inhibition of microorganism	(Joardder & Masud 2019 ; Kwon et al. 2014)
Canning **Sugaring**	Destroy microorganisms and enzymes	(Desrosier & Singh 2023; Teixeira 2015; Verkhivker & Miroshnychenko 2020)
Freezing **Chilling; refrigeration**	Inhibit microorganism	(Desrosier & Singh 2023; Rahman 2007)
Sterilization **Pasteurization** **Magnetic field**	Thermal	(Desrosier & Singh 2023; Joardder & Masud 2019; Teixeira 2014)
Food additives	Organic acid or esters	(Linares-Morales et al. 2018 ; Rahman 2007)
Thermalization **Cooking** **Blanching**	Kills vegetative microorganism; thermal	(Rahman 2007; Hameed 2018 (Joardder & Masud 2019)
Clarification	Remove microbial cells and spores	(Rahman 2007)

Pickling	Inhibition of microorganism	(Desrosier & Singh 2023)
Boxing **Bulking** **Undergrown storage**	Minimal damages Inhibition of microorganism	(Joardder & Masud 2019)

5.1.1. Salting and curing

Salting and curing are traditional food preservation techniques that have been used for centuries to extend the shelf life of various foods, including meats, fish, and vegetables (Kanagaraj 2002). These methods work by reducing the water activity and creating an environment that is inhospitable to the growth of bacteria and other microorganisms that cause spoilage (Rahman 2007). While modern preservation techniques have largely replaced these traditional methods, salting and curing are still used in many parts of the world to produce unique and flavourful foods.

5.1.1.1. Salting

Salting is one of the oldest and most basic methods of food preservation (Kanagaraj 2002). The technique involves covering the food in salt or brine, which draws moisture out of the food and lowers its water activity (Peñarubia 2021). The figure 2 shows the application of salt to preserve fishes (FAO 2013), according to the Codex Alimentarius Code of Practice for Fish and Fishery Products.

Figure 2 Fish salting (FAO 2021)

This makes it difficult for bacteria to grow and multiply, thereby extending the shelf life of the food. Salting is most effective in preserving foods with a low moisture content, such as meats and fish, as the salt can effectively remove enough water to create an inhospitable environment for bacteria (Rahman 2007).

There are two main types of salting: dry salting and brining. In dry salting, the food is coated with salt as shown in figure 3 and left to cure for a period of time. This method is often used for preserving meats, such as ham and bacon (García 2004). In brining, the food is soaked in a saltwater solution as shown in figure 4, which helps to distribute the salt more evenly and can add flavour to the food. This method is often used for preserving fish, such as salmon and herring (Toyohara 1999).

Figure 3 A leg of sheep prepared for dry salting. It will be totally covered with salt and stored for 2-5 days at a cool place, depending on weight (Michelsen 2015).

Figure 4 Salmon in brine (Wordpress 2023).

5.1.1.2. Curing

Curing is a method of food preservation that involves the addition of salt, as well as other ingredients such as sugar, nitrates, and spices (Xiao-Hui et al. 2022). The goal of curing is not only to preserve the food but also to add flavour and colour. Cured meats, such as bacon and prosciutto, are prized for their rich flavour and distinctive texture.

The addition of nitrates to the curing mixture can also help to inhibit the growth of bacteria and prevent the development of botulism (Sindelar 2012). However, there is some concern about the potential health risks associated with nitrates, particularly in large amounts. As such, some producers are now using natural alternatives (Leistner 2000), such as celery juice or powder, which also contain nitrates but in smaller amounts.

5.1.2. Smoking

Smoking is a traditional food preservation technique that has been used for centuries. It involves exposing food to smoke from burning wood, which helps to preserve it by drying it out and imparting flavour (FAO 2013). Smoking was used in the past to preserve meats and fish, but today it is also used to add flavour to food.

The smoke produced by burning wood contains chemicals such as phenols, which have antimicrobial properties that can help to prevent the growth of harmful bacteria on the food (Rahman 2007). This can help to extend the shelf life of the food and make it safer to eat. Smoking can also help to reduce the moisture content of the food, which can inhibit the growth of microorganisms that require moisture to survive. This can help to prevent spoilage and can make the food more stable for storage (Hameed 2018).

There are different methods of smoking, including cold smoking and hot smoking (FAO 2013). Cold smoking involves smoking the food at a temperature of less than 37.8°C for several hours (FAO 2013), while hot smoking involves smoking the food at a temperature of between 51.7°C and 121.1°C for several hours.

It is important to note that smoking can also produce harmful chemicals, such as polycyclic aromatic hydrocarbons (PAHs) and heterocyclic amines (HCAs), which can be carcinogenic (FAO 2009.). Therefore, it is important to follow safe smoking practices, such as using the right type of wood, controlling the temperature and duration of smoking, and using a smoke generator that produces clean smoke.

Figure 5 Sri Lanka, Kopalapillai Theivarmallar using traditional smoking method of fish in her village (FAO 2017).

5.1.3. Fermentation

Fermentation is a traditional food preservation technique that has been used for centuries to preserve a variety of foods such as fruits, meat, vegetables and milk. It involves the use of microorganisms (Joardder & Masud 2019) such as bacteria, yeasts, and fungi to convert sugars and other carbohydrates in the food into acids, alcohols, and other compounds that inhibit the growth of harmful bacteria and other microorganisms.

The fermentation not only preserves the food but also improves its flavour, texture, and nutritional value (Kwon et al. 2014). It is a natural and healthy method of food preservation that has gained popularity in recent years due to its numerous health benefits.

Fermentation can occur in various ways, including natural fermentation, in which microorganisms naturally present on the food initiate the process, and inoculated fermentation, in which a starter culture is added to the food to initiate the process (Hameed 2018).

Examples of fermented foods include sauerkraut, kimchi, yogurt, kefir, sourdough bread, cheese, wine, and beer (Galimberti et al. 2021).

As the fermentation is a complex process that involves various biochemical and microbiological changes in the food (Rahman 2007), the key factors that influence the fermentation process include the type and concentration of microorganisms, temperature, pH, and the presence of oxygen.

It is important to note that while fermentation can improve the safety and quality of food, it can also pose some risks if not done properly (Abiola et al. 2022). It is important to follow safe fermentation practices, such as using the right type and concentration of microorganisms, controlling the temperature and pH of the fermentation, and ensuring hygienic conditions to prevent the growth of harmful bacteria (Kwon et al. 2014).

Figure 6 Fermentation by brining of fish (Fall 2019)

5.1.4. Drying

Drying is one of the oldest food preservation techniques (Joadder et al. 2019), which involves the removal of moisture from the food to inhibit the growth of microorganisms and preserve the food (Rahman 2007). This technique has been used for thousands of years and is still widely used today to preserve fruits, grains, meat, and vegetables. There are several methods of drying food, including sun drying, air drying, oven drying, and freeze drying (Rifna et al. 2022). Each method has its own advantages and disadvantages, and the choice of method depends on the type of food being dried, the quantity of food, and the available resources.

Drying can preserve the food for a long period, depending on the moisture content of the food and the storage conditions (Kumar et al. 2022). Dried foods can be stored at room temperature, which makes them convenient for long-term storage and transport.

The process not only preserves the food but also concentrates its flavour and nutrients (Rahman 2007). However, the drying process can also result in the loss of some nutrients, such as vitamins and minerals, so it is important to balance the benefits and drawbacks of the technique (FAO 2009).

Figure 7 Drying of meat in Angola, (FAO 2023).

5.1.5. Canning

Canning is a popular food preservation technique that involves heating food in airtight containers to destroy microorganisms and enzymes that cause food spoilage (Rahman 2007). The process creates a vacuum seal that prevents air and bacteria from entering the container, allowing the food to be stored for extended periods of time (Hameed 2018).

There are two principal categories of canning methods: water bath canning and pressure canning (Teixeira 2014). Water bath canning is suitable for high-acid foods such as jams, fruits, and pickles while pressure canning is used for low-acid foods such as meats, poultry and vegetables (Verkhivker & Miroshnychenko 2020). Canning requires careful attention to detail to ensure that the food is properly processed and the containers are sealed correctly. Failure to follow safe canning practices can result in the growth of harmful bacteria such as Clostridium botulinum, which can cause botulism, a potentially deadly illness (Pflug 2018). When done correctly, canning can preserve the quality and nutritional value of food. Canned foods are convenient and can be stored at room temperature, making them a popular choice for home food preservation (Joardder & Masud 2019).

Figure 8 African American woman selling canned foods at Market Days - Tallahassee (FM 1986).

5.2. Advanced food preservation techniques

Advanced food preservation techniques can be defined as a group of novel or new, non-thermal technologies that use physical, chemical, or biological methods to inactivate microorganisms, enzymes, or other factors that contribute to food spoilage (Rahman 2007). These techniques are designed to improve the safety, quality, and shelf life of food products while minimizing the impact on their nutritional and sensory properties (Desrosier & Singh 2023). The TABLE 2 shows the advanced food preservation techniques in food industry.

Table 2 Advanced food preservation techniques adapted from (Hameed 2018; Linares-Morales et al. 2018; Rahman 2007).

Methods	Characteristics	References
High pressure processing	Non thermal	(Hameed 2018; Joadder et al. 2019)
Microwave	Thermal	(Hameed 2018 ; Linares-Morales et al. 2018)
Pulsed electric fields	Non thermal	(Arshad 2021; Hameed 2018)
Radio frequency	Thermal	(Hameed 2018)
Irradiation	Non thermal	(Bisht 2021; Hameed 2018)
Ohmic heating	Thermal	(Hameed 2018)
Ultrasound	Non thermal	(Ferreira-Lazarte 2023 ; Hameed 2018)
Inductive heating	Thermal	(Hameed 2018)
Hydrodynamic cavitation	Non thermal	(Hameed 2018; Ranade 2022)
Cold plasma	Non thermal	(Hameed 2018 ; Manzoor 2023)
Ozone Supercritical water	Thermal	(Hameed 2018)
Essential oils	Cell wall degradation	(Heydari et al. 2015 ; Linares-Morales et al. 2018)
Edible films and coatings	Economic, non toxic	(Corbo et al. 2015; Linares-Morales et al. 2018)

Modified atmosphere packaging	Affect the balance of microenvironment	(Chaudhary et al. 2015 Linares-Morales et al. 2018 ; Rahman 2007)
Active packaging **Vacuum packaging**	Non thermal	Corbo et al. 2010 ; Linares-Morales et al. 2018 ; Lu et al. 2015)
Bioprotection	Decrease pH	(Linares-Morales et al., 2018 ; Adam et al. 2016)
Aseptic processing	Thermal	(Desrosier & Singh 2023; Rahman 2007)
Nanotechnology	Non thermal	(Suthar et al. 2023)

Advanced food preservation techniques are becoming increasingly important in the food industry as consumer demand for minimally processed, high-quality, and safe food products grow (Sridhar et al. 2021). These techniques have the potential to revolutionize the way food is preserved and distributed, improving food safety, extending shelf life, and reducing waste while satisfying consumer preferences and future demands (Rahman 2007).

In this chapter, we will explore some of the most common advanced food preservation techniques such as vacuum packaging, irradiation, high pressure processing, pulse electric field, cold plasma processing, ultrasound and hydrodynamic cavitation. They were identified through a combination of literature review and industry research, academic journals, industry reports, and news articles to find the latest advancements in food preservation technology and to assess their popularity and effectiveness.

Some factors such as the frequency of use of the preservation techniques in the food industry and their availability in different geographic regions was also taken into consideration.

5.2.1. Vacuum packaging

Vacuum packaging is a process that involves removing air from the packaging of food products (Angiolillo 2016). It can be considered a subset of modified atmosphere packaging (MAP) due to the fact that a portion of the typical headspace is eliminated, resulting in an unregulated initial environment following packaging (Rahman 2007). This process helps to protect the food from oxidation, which can cause spoilage, and inhibit the growth of aerobic bacteria that require oxygen to grow (Joardder & Masud 2019b).

Vacuum packaging is commonly used for perishable food products such as meat, cheese, and fish, as well as for non-food products like pharmaceuticals products and electronics (Souza 2017). The technique involves sealing the food in a plastic film or pouch and then removing the air from the package using a vacuum sealer machine.

The benefits of vacuum packaging include extended shelf life, reduced food waste, and improved food safety. It Eliminate the oxygen and prevent from oxidation, conserve the flavour, prevent from freezer burn, regulate the natural moisture and help in the inhibition of mold (Angiolillo et al. 2016).

However, it is important to note that vacuum packaging is not a substitute for proper food handling and storage practices. Foods that are vacuum packaged still require proper refrigeration or freezing to maintain their quality and safety.

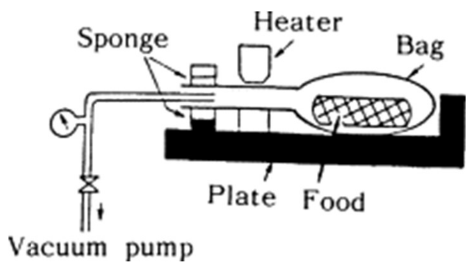

Figure 9 Nozzle-type machine for vacuum packaging (Wani et al. 2014).

5.2.2. Irradiation

Food irradiation is a non-thermal, energy-efficient, non-chemical and physical method of food preservation in which the food is exposed to various ionizing and non-ionizing radiations (Bisht 2021). The technique helps to kill bacteria and other microorganisms that cause food spoilage (Ajibola 2020) and can also reduce the number of pathogens such as Salmonella and E. coli in foods, improving their safety (Wei 2022).

The ionizing radiation used in food irradiation is typically produced by gamma rays, X-rays, or electron beams (Wei et al. 2022). The food is exposed to the radiation for a specific amount of time, depending on the type of food and the desired level of preservation. Irradiation can be used to preserve a variety of foods, including meats, fruits, vegetables, and spices (Dominic 2022). The process does not add any chemical preservatives to the food and does not make the food radioactive (Dominic 2022).

The U.S. Food and Drug Administration (FDA) has approved the use of irradiation for a number of food products, and the World Health Organization (WHO) and other international organizations have also recognized the safety and effectiveness of the technique (WHO 2023). However, some consumer groups and food safety advocates have raised concerns about the potential long-term effects of irradiated foods on human health and the environment.

5.2.3. High-pressure processing

High pressure processing (HPP) is a non-thermal preservation technique that involves applying high pressure to food products to inactivate bacteria as shown in figure 10, viruses, and other microorganisms that cause the food spoilage (Hameed 2018). It has proven to be an effective alternative to conventional food preservation technologies to enhance safety and shelf life of perishable foods (Dattaa & Deeth 2018). The process can also help to maintain the nutritional and sensory quality of the food.

The high pressure is typically applied using a machine that subjects the food to pressures of up to 1400 MPa on a laboratory scale and up to 600 MPa on an industrial scale (Marszałek et al. 2018) for a few seconds to several minutes. The process can be used for a wide range of foods, including fruits, vegetables, meats, seafood, and juices.

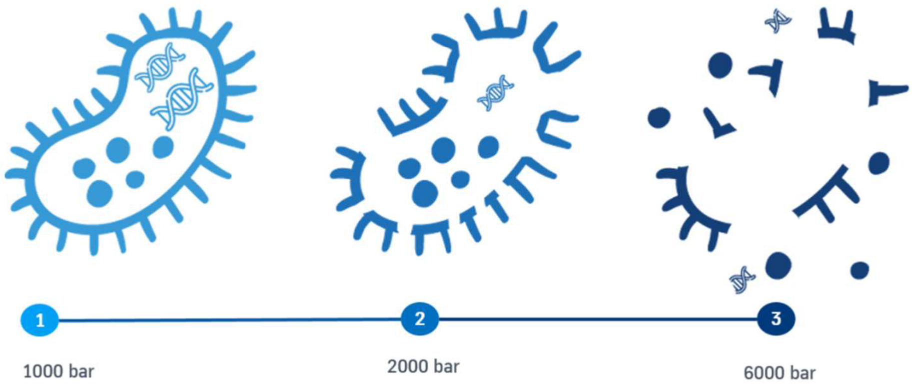

Figure 10 The process of inhibition of bacteria by HPP (Thyssenkrupp 2023)

HPP has several advantages over other food preservation techniques. It does not use heat or chemicals, which can affect the nutritional and sensory quality of the food (Dattaa & Deeth 2018). It also does not produce any waste products, making it an environmentally friendly preservation method. We can state in general that the HPP can extend the shelf life of foods, improve food safety, and allow food manufacturers to produce fresh-like, minimally processed products that require fewer additives and preservatives (Rahman 2007.).

5.2.4. Pulsed electric field processing.

Pulsed electric field (PEF) processing is a non-thermal food preservation technique that induces pore generation (electroporation phenomenon) by exposing tissues to short bursts of high-voltage electric fields in the range of 10-80 KV/cm (Hameed 2018), resulting in permeabilization of the cell membrane. The process can inactivate microorganisms, enzymes, and spoilage-causing bacteria, helping to extend the shelf life of the food (Razola-Díaz et al. 2023).

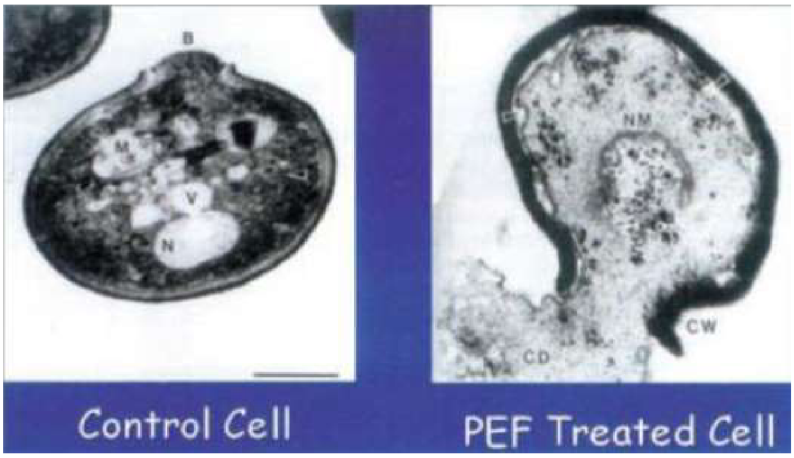

Figure 11 Comparison of a reference cell with a PEF- treated cell, showing the damage to the cell membrane (IFT 2016).

During PEF processing, food products are placed between two electrodes and then exposed to brief, high-intensity pulses of electric fields. The electric fields disrupt the cell membranes of microorganisms and other cells in the food, causing them to lose their ability to grow and reproduce (Zhou et al. 2022) and at the same time, maintaining the structures and durability of the molecules including polyphenols, vitamin C, minerals, amino acids, lipids and carbohydrates (Razola-Díaz et al. 2023).

The use of PEF in biological cells is based on the principle of electro permeabilization caused by an induced transmembrane potential. It differences as a function of time ΔΨm(t) (V) (Buchmann et al. 2019) and can be calculating using Equation 1 with form factor f (-) (1.5 for a spherical cell) (Buchmann et al. 2019).

Equation 1: (Bushmann et al. 2019)

$$\Delta\Psi m(t) = f \cdot E(t) \cdot am \cdot cos\theta \cdot (1 - e - t/\tau m)$$

The electric field strength, denoted by E(t) in the equation Y, is determined by the membrane capacitance per unit area (Cm in F), extracellular conductivity (σe in S m−1), intracellular conductivity (σi in S m−1), cell radius (am in m), angle with respect to the direction of the electric field (θ in degrees), treatment time (t in s), and membrane charging time (τm in s) (Buchmann et al. 2019).

Equation 2 (Bushmann et al. 2019)

$$\tau m = am \cdot Cm \cdot (1/2\sigma e + 1/\sigma i)$$

The PEF processing can be used for a variety of food products, including juices, dairy products, meats, and fruits and vegetables (Arshad et al. 2021). The technique has several advantages over other preservation methods, including minimal impact on the nutritional and sensory quality of the food (Karki et al. 2023), and the ability to extend shelf life without the use of chemicals or heat.

The technology is still being developed and refined, and further research is needed to fully understand its potential and limitations (Hameed 2018).

5.2.5. Cold plasma processing

Cold plasma processing is an emerging non-thermal food preservation technique that involves exposing food products to ionized gas, or plasma, at low temperatures. The process helps to inactivates microorganisms, enzymes, and spoilage-causing bacteria on foods and packing materials with the use of highly reactive gaseous molecules and species (Birania et al. 2022). The term 'plasma' refers to a quasi-neutral ionized gas, primarily composed of electrons, ions and reactive neutral species in their fundamental or excited states (Hameed 2018).

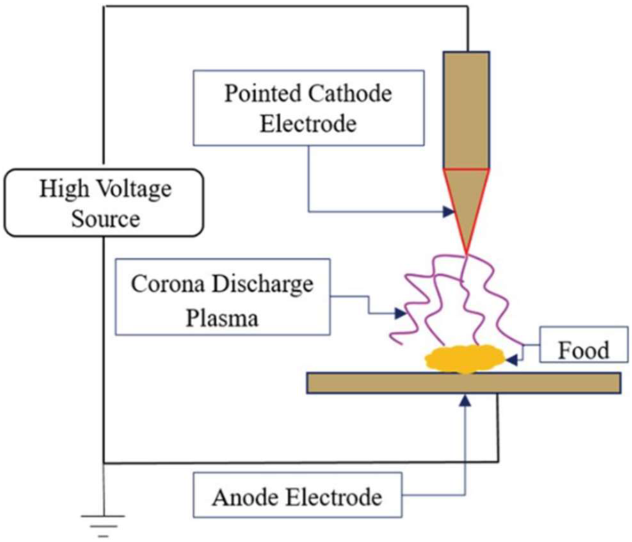

Figure 12 Corona discharge plasma generation (Birania et al. 2022)

During cold plasma processing, a high voltage is applied to a gas, such as air or nitrogen, creating a plasma. The plasma is then directed towards the food as shown in figure 12, where it interacts with the surface of the food and disrupts the cell membranes of microorganisms and other cells (Birania et al. 2022). This disrupts the cell structure and metabolic pathways of the microorganisms, leading to their inactivation. The cold plasma processing can be used for a variety of food products, including fruits, vegetables, meats, and dairy products (Farooq et al. 2023). The technique has several advantages over other preservation methods, including minimal impact on the nutritional and sensory quality of the food, and the ability to extend shelf life without the use of chemicals or heat. It is still being developed and refined, and further research is needed to fully understand its potential and limitations.

5.2.6. Hydrodynamic cavitation

Hydrodynamic cavitation (HC) is as a underexplored non-thermal preservation technique in the food industry (Hameed 2018). It is regarded as being more physically effective and energy efficient than treatment with ultrasound, and can be an alternative to traditional thermal methods, such as pasteurization and sterilization, as it can preserve the quality of the food while maintaining its nutritional value (Gogate 2011). The process include a rapid changes in pressure and temperature occur due to the formation and inclusion of vapor bubbles in a fluid medium (Ranade et al. 2022) . These extreme conditions can cause physical and chemical changes in the surrounding environment, which can be harnessed for various applications, including food processing and preservation. The method is safer, healthier and the food is minimally treated according to the consumers' needs (Castro-Muñoz et al. 2023).

HC can be used for different food types, including liquids, solids, and even gases. For liquids, it can cause shear and shock waves that can disrupt the cell walls of microorganisms, leading to their inactivation (Gogate 2011). The process can also cause the release of reactive oxygen species that can further damage the microorganisms. In solid foods, HC can be used to enhance mass transfer and diffusion, which can increase the efficiency of antimicrobial treatments (Asaithambi et al. 2019). In gases, HC can be used to enhance the solubility of gases, such as oxygen, which can help to preserve the quality of food.

According to the Bernoulli's equation as shown in equation 3, the increase of the linear velocity increases the dynamic pressure, which lower the static pressure to maintain the energy balance in the fluid (Castro-Muñoz et al. 2023). The equation 3 also explains, in terms of the cavitation number, the extend of cavitation taking place in all systems. The Bernoulli's theorem is expressed by the following equation:

Equation 3: (Gogate 2011)

$$Cv = \frac{P2 - Pv}{\frac{1}{2}\rho V^2}$$

Where:

P2 is fully recovered downstream pressure (Gogate 2011)

Pv is the vapor pressure of the liquid (Hameed 2018)

V is the velocity of the liquid at constriction where cavitation takes place

Several studies have demonstrated the potential of HC as a food preservation technique. For example, researchers have used HC to inactivate E. coli in apple juice, grapefruit juice, and soy milk, achieving a 5-log reduction in microbial counts with an exposure of 3 min using energy input of 490 W/L. The division of E. coli cells stopped by 75% (Gogate 2011). Another study showed that HC treatment of milk could extend its shelf life by up to 14 days while maintaining its nutritional value.

One of the advantages of HC as a food preservation technique is its scalability. It can be easily integrated into existing food processing lines, making it a cost-effective solution for large-scale food production. Additionally, HC can be used in combination with other preservation techniques, such as high-pressure processing and pulsed electric field, to enhance their effectiveness (Asaithambi et al. 2019).

5.2.7. Ultrasound

Ultrasound is a non-polluting and environmentally friendly green technique that has shown potential for use in food preservation (Ahmad et al. 2023). It's a modern technology that is widely recognized for its dependable and cost-efficient utilization of energy and time, and it distinguishes itself from conventional methods due to its non-invasive nature, its negligible thermal damage as well as its high performance (Ferreira-Lazarte & Villamiel 2023). It's a type of energy is generated through longitudinal mechanical waves with frequencies exceeding 20 kHz, which is beyond the range of human auditory perception. The waves can penetrate food products and cause mechanical vibrations, which can lead to a range of physical and chemical effects (Molaee-aghaee et al. 2022). These effects can be harnessed to inhibit the growth of microorganisms and other spoilage agents in food products, thereby extending their shelf life.

The Ultrasonic spectrum can be classified into two types based on the frequency and intensity of the waves: low-frequency high-power Ultrasound, where we have less than 100 kHz for the frequency and more than 1W/cm2 for the power, and high frequency- low power Ultrasound, where we have more than100 kHz for the frequency and less than 1W/cm2 for the power (Molaee-aghaee et al. 2022). The TABLE 1 shows the most popular applications of the two types of Ultrasounds.

Table 3: Applications of high-power ultrasound and low-power Ultrasound in the food industry adapted from (Molaee-aghaee et al. 2022)

Type of Ultrasound	Applications	
High frequency- Low power	Honey	
	Vegetables + fruits + juice	
	Dairy products+ milk	
	Cereal products	
	Food proteins	
	Meat products	
	Emulsion products and Fat	
	Aerated foods	Desserts
		Whipped cream
		Bread dough
		Ice cream
		Confectionary
	Food gels	
	Monitoring of food freezing	
Low frequency- High power	Food cutting	
	Food preservation	Microbial and enzyme inactivation
		Microbial decontamination and surface cleaning
	Mass transfer	Extraction
		Drying and dehydration
	Energy transfer	Heating
		Freezing
		Thawing
	Degassing and Foaming capacity	
	Texture modification	
	Filtration	
	Emulsion formation	

There are several ways in which Ultrasound technology can be used for food preservation. Some examples include:

Inactivation of microorganisms: Ultrasonic waves can be used to kill bacteria, yeast, mold, and other microorganisms in food products (Ahmad et al. 2023). This can help to reduce the risk of foodborne illness and extend the shelf life of the product.

Enzyme inactivation: Ultrasonic waves can be used to inactivate enzymes in food products that cause spoilage or ripening (Ferreira-Lazarte & Villamiel 2023). This can help to extend the shelf life of fruits, vegetables, and other perishable products.

Enhancement of mass transfer: Ultrasonic waves can be used to enhance the diffusion of substances such as water, nutrients, and preservatives into food products (Hameed 2018). This can help to improve the preservation of the product and reduce the amount of preservatives needed.

Texture modification: Ultrasonic waves can be used to modify the texture of food products (Jiang et al. 2020), making them more resistant to spoilage and improving their overall quality.

One of the advantages of Ultrasound technology is that it is non-thermal, meaning that it does not involve the use of heat (Molaee-aghaee et al. 2022). And the fact that it is relatively low-cost, it can be easily integrated into existing food processing systems.

5.3. Advanced food preservation techniques in Developing countries.

In the tropical regions of Africa and South-eastern Asia, food product preservation was done through various methods including sun drying, salting, smoking, and cooling (Onyeaka & Nwabor 2022). Many developing countries continue to depend on traditional methods for preserving food. as the example of Nigeria, where more than 70% of food is preserved or processed traditionally (Joardder & Masud 2019). There are several advanced food preservation techniques, that are being explored and implemented in Africa, Asia and South America to help reduce food waste, increase food security, and improve the economic sustainability of the agriculture industry (Tirivangasi & Rankoana 2021). It is important to note that the adoption of these techniques in developing countries may be limited by factors such as those related to cost, infrastructure, technical expertise, regulatory issues, and cultural preferences.

5.3.1. High Pressure Processing in developing countries

There are some examples of HPP being used in developing countries, particularly in the context of small and medium-sized enterprises (SMEs) that specialize in high-value food products (Komolprasert 2016). For instance, HPP technology has been used in the production of fruit juices, sauces, and ready-to-eat meals in countries such as Mexico, India, and Brazil (Aneesh et al. 2017).

The adoption of HPP may vary significantly across different regions, the figure 12 shows the use of high pressure processing technology in food industry in the world (Huang et al. 2017) . It appear clearly that the North America and Mexico has the highest percentage of use of the HPP followed by the Europe. The major challenge of the implementation in developing countries is mostly related to the financial aspect as a set of HPP equipment costs between $600,000 to $4 million dollars, depending on its capacity and operational parameter range (OSU 2023).

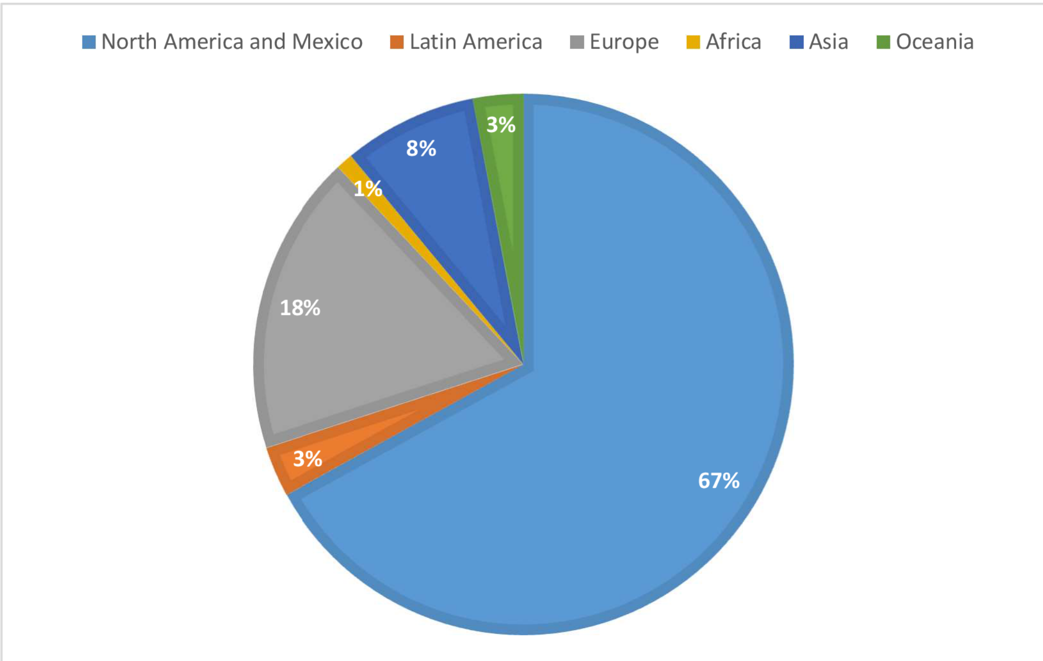

Figure 13 The food industry use of high-pressure processing technology. Adapted from (Huang et al. 2017)

5.3.2. The use of Pulse Electric Field in developing countries

Pulse Electric Field technology is also being developed in some developing countries, however, it's implementation faced several challenges (UNIDO 2019). The initial cost of equipment and infrastructure may be prohibitively high for small-scale food producers as a PEF system (monopolar, square wave pulses, three pairs of chambers with heat recovery) is estimate to be $2,100,000¢/l (Sampedro et al. 2014). Additionally, the lack of technical expertise and trained personnel may hinder the adoption of this technology, as the PEF processing necessitates a multidisciplinary strategy, encompassing knowledge of revolutionary ideas in biology, electrical engineering and fluid dynamics (Buchmann et al. 2019).

The potential benefits of PEF technology for food processing and preservation in developing countries are significant and to expand its implementation, It was found that inadequate reporting of process protocols and insufficient characterization and regulation of pulse parameters need to be addressed.

5.3.3. The use of Ultrasound in developing countries

Another example of implemented new technology in developing countries is Ultrasound, which is the easiest implementation due to its low-cost characteristics (Molaee-aghaee et al. 2022). We have as example the following cases:

The preservation of fruits and vegetables in Tanzania: The researchers from the Nelson Mandela African Institution of Science and Technology in Tanzania have used Ultrasound technology to preserve fruits and vegetables (Kayange 2019). The researchers found that Ultrasound treatment helped to extend the shelf life of fruits and vegetables by inhibiting the growth of microorganisms that cause spoilage (Ahmed et al. 2022). The TABLE 2 shows the numerous ways in which Ultrasound can be used to destroy microorganisms in fruits and vegetables. Its ability to inactivate cells is linked to intracellular cavitation (Jiang et al. 2020) and mechanical shocks, which can harm cells' structural and functional elements until they lyse (Chemat et al. 2011).

Table 4: Shelf life extension and microbial reduction of fruits and vegetables by Ultrasound treatment (Ahmed et al. 2022).

Products	Treatments	Parameters	Microbial reductions (log10CFU/g	Shelf life
Araçá-boi fruits	US	5min	-	3-6 days
Cherry (Prunus avium)	US	20-40min	-	15 days
Strawberry	US	35 kHz, 120 W, 15°C	YMC: 1.4 TVC: 0.6	13 days
Strawberry	US	40 kHz, 350 W/L, 20°C, 10 min	YMC: 0.5 TVC: 0.6	8 days
Peach (Prunus persica L. Batsch)	US	32 kHz,60 W/L,10 min	-	28 days
Fresh tomato juice	US	20 kHz, 750 W, 10 min	<10 CFU/g	10 days
Carrots and spinach	US	20 kHz, 100 W, 15 min	5 log reduction	10 weeks

YMC: Yeast and Mold Counts ; TVC: Total Viable Counts.

Preservation of milk in India: In India, researchers from the National Dairy Research Institute have used Ultrasound technology to preserve milk (Chaudhari et al. 2015). The researchers found that ultrasound treatment helped to reduce the number of bacteria in milk, thereby extending its shelf life.

Preservation of fish in Bangladesh: In Bangladesh, researchers from the Bangladesh Agricultural University from the department of fisheries have used Ultrasound technology to preserve fish (Islam 2019). The researchers found that Ultrasound treatment helped to reduce the number of bacteria in fish, thereby extending its shelf life and reducing the risk of foodborne illness.

Preservation of traditional foods in Nigeria: In Nigeria, researchers from the University of Nigeria have used Ultrasound technology to preserve traditional foods such as cassava and yam (Oladejo et al. 2021). The researchers found that ultrasound treatment helped to reduce the microbial load in the foods, thereby extending their shelf life and preserving their nutritional quality.

Overall, Ultrasound technology has shown promise as a low-cost and effective method for food preservation in developing countries. However, further research and development is needed to optimize the technology for different types of foods (Ayoub 2018) and to ensure that it can be easily implemented by small-scale food producers.

5.3.4. Improved drying systems in developing countries

5.3.4.1. Advanced solar drying

Improved solar drying system is also a possible helpful and quite modern technology, as it involves placing the food in an enclosed chamber rather than directly exposing it in open areas (Taheri et al. 2012). This involves using solar energy to dry and preserve fruits, vegetables, and grains, while insuring their safety from outside damages and contaminations due to unexpected rainfall, birds, dust and insects (Joardder & Masud 2019e). This technique is especially useful in regions with high levels of sunlight, as it is low-cost, sustainable, and does not require electricity or fuel. In some cases, solar dryers have been designed and built to improve the efficiency and effectiveness of the process.

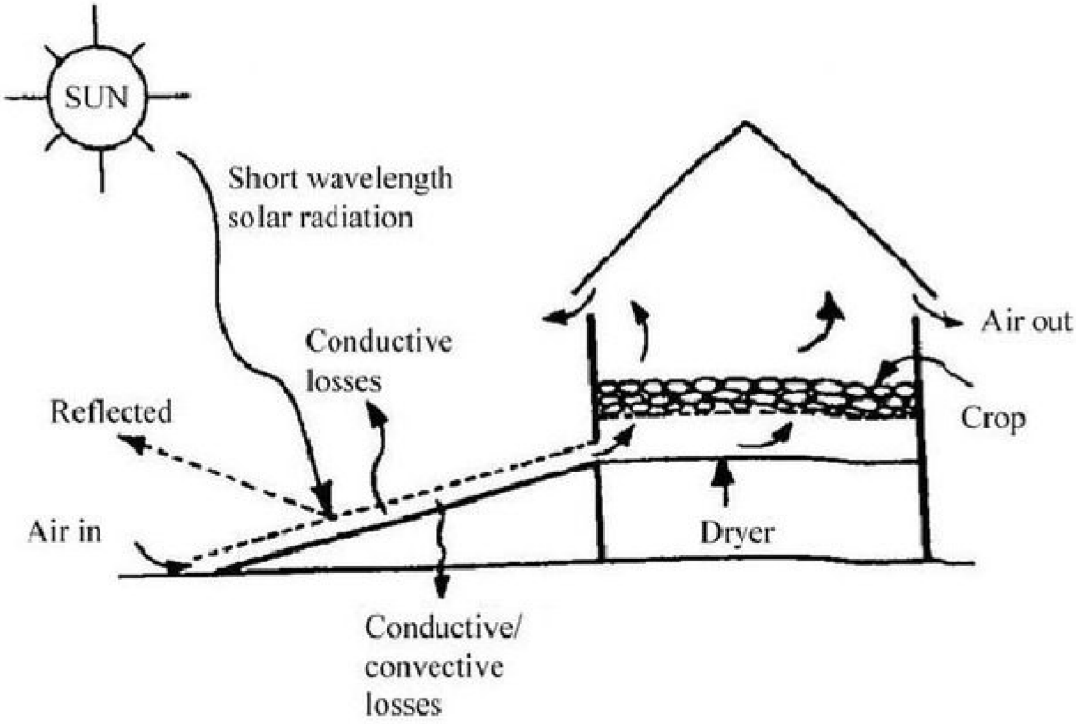

Figure 14 Improved Solar Drying (Taheri et al. 2012)

5.3.4.2. Microwave drying

Microwave drying is also a solution for new preservation method for developing countries, but as the continuous microwave heating is not uniform, for a good drying it must be intermittent. Compared to the continuous drying process, the Intermittent Microwave Convective Drying method is characterized by higher energy efficiency. (Joardder & Masud 2019b).

5.3.5. The packaging processing in developing countries

5.3.5.1. Use of Aseptic processing in developing countries

Another example is aseptic processing, which involves sterilizing food and packaging separately and then filling the sterile food into sterile packaging in a sterile environment (Rahman 2007). This technique can help to extend the shelf life of packaged foods and reduce the risk of contamination. Some companies in Africa are using aseptic processing to produce packaged fruit juices, dairy products, and tomato paste.

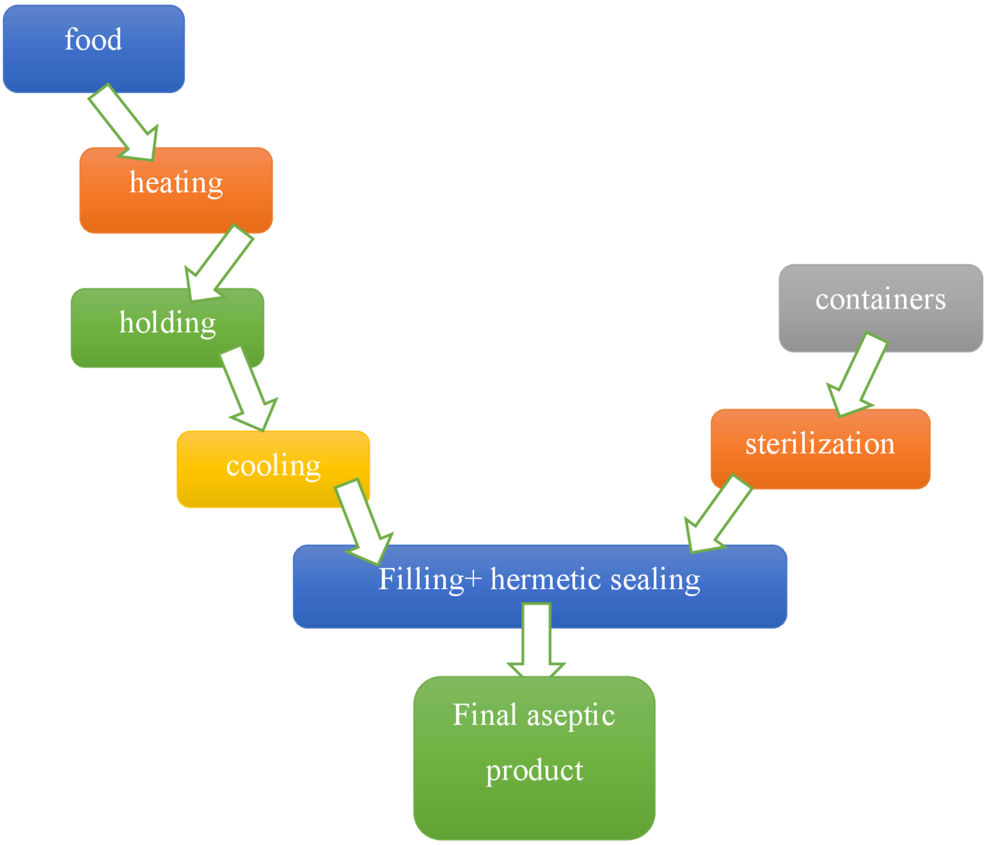

Figure 15 Aseptic process with the use of heat

5.3.5.2. Implementation of Modified Atmosphere Packaging in developing countries

There are already some successful implementations of MAP in some developing countries including Nigeria, India and Bangladesh, for the preservation of vegetables and fruits.

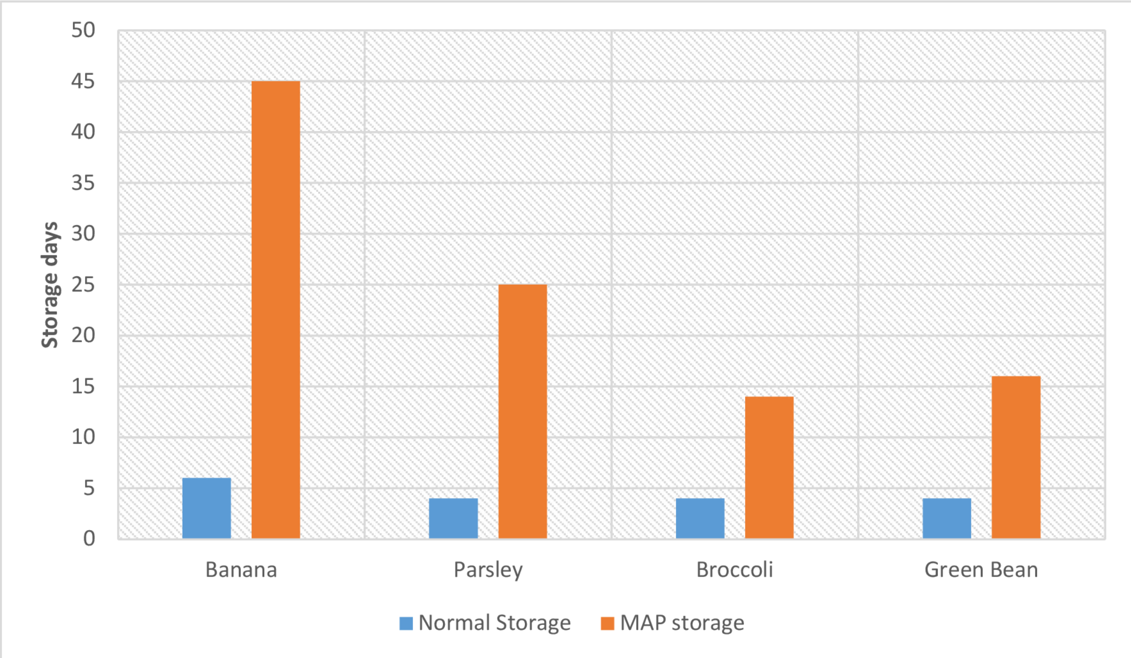

Figure 16 Successful implementation of MAP, adapted from (Joardder & Masud 2019b)

5.3.6. Implementation of irradiation in developing countries

Some developing countries have successfully implemented irradiation for food preservation. For example:

In India, the government has approved the use of irradiation and the country has a number of facilities that use irradiation for food preservation, including a facility in Mumbai that processes spices, dried fruits, and vegetables (Ahmed et al. 2020). Similarly, in Thailand, where irradiation is used to preserve a range of food products including fruits, vegetables, and seafood (FAO 2019).

Vietnam: In Vietnam, irradiation is used to preserve a variety of food products, including fruits, vegetables, and seafood (Jayathilakan et al. 2012).

Costa Rica: Costa Rica has been using irradiation to preserve fruits and vegetables since the early 2000s. The country's irradiation facility is located in the capital city of San Jose. (WHO 2019)

South Africa: South Africa has been using irradiation to preserve a variety of food products, including fresh produce and meat, since the 1980s. The country's largest irradiation facility is located in Gauteng province (FAO 2019)

One of the benefits of irradiation is that it can help reduce food waste, which is a major problem in developing countries where food shortages are common (Akinloye et al. 2015). By extending the shelf life of food, irradiation can help prevent spoilage and reduce food losses. However, there are also concerns about the safety and efficacy of irradiation, particularly among consumers who may be wary of the technology (Dominic 2022). It is important for governments and food safety authorities to provide education and information about the benefits and safety of irradiation to help address these concerns.

Irradiation seems to be an effective food preservation technique in developing countries, but it requires infrastructure, technical expertise, and public acceptance to be successful (Akinloye et al. 2015).

6. Conclusions

Advanced food preservation techniques are important for improving the efficiency and sustainability of the agriculture industry in developing countries and can help to address food insecurity and reduce food waste. The traditional methods of preservation of food have been offering lot of advantages since the prehistoric era, therefore, there are lot of challenges and issues that cannot be resolved with the existing ancient technologies practiced in developing countries.

However, many novel food preservation techniques are able to overcome those challenge and issues effectively as the new researches and studies have proven the successful implementation and use in developing countries. Thus, some factors such as the cost, the energy, the socio-cultural aspect must be addressed for a complete accommodation of new technologies in developing countries.

7. References

Abiola RR, Okoro EK, Sokunbi O. 2022. Lactic Acid Bacteria and the Food Industry - A Comprehensive Review. International Journal of Health Sciences and Research **12**:128-142.

Ahmad F, Mohammad ZH, Zaidi S, Ibrahim SA. 2023. A comprehensive review on the application of ultrasound for the preservation of fruits and vegetables. Journal of Food Process Engineering DOI: 10.1111/jfpe.14291.

Ahmed MA, Ahmed RS, Al-Yousef Y. 2020. Food irradiation: a potential tool for the preservation of fresh fruits and vegetables in developing countries. Food Reviews International **36**:60-75.

Ahmed S, Akther S, Alam SMS, Ahiduzzaman M, Islam MN, Azam MS. 2022. Individual and combined effects of electrolyzed water and ultrasound treatment on microbial decontamination and shelf life extension of fruits and vegetables: A review of potential mechanisms. Journal of Food Processing and Preservation **46**:1-13.

Akinloye MK, Olasunkanmi SK, Okunade DA, Isola GA. 2015. Irradiation as a Food Preservation Method in Nigeria: Prospects and Problems. International Journal for Research in Applied Science & Engineering Technology **3**:85-94

Aneesh TP, Jain S, Jadhav A, Visakh P. 2017. High-Pressure Processing for the Production of High-Quality and Safe Food Products in Developing Countries. Food Engineering Reviews **9**:223-239.

Angiolillo L, Conte A, Nobile MAD. 2016. Impact of Vacuum packaging, modified and controlled atmosphere on the microbial ecology of foods. University of Foggia. Italy.

Arshad RN, Abdul-Malek Z, Roobab U, Munir MA, Naderipour A, Qureshi MI, El-Din Bekhit A, Liu ZW, Aadil RM. 2021. Pulsed electric field: A potential alternative towards a sustainable food processing. Trends in Food Science & Technology **111**:43-54.

Asaithambi N, Singha P, Dwivedi M, Singh SK. 2019. Hydrodynamic cavitation and its application in food and beverage industry: A review. Journal of Food Process Engineering **42**:1-14.

Birania S, Attkan AK, Kumar S, Kumar N, Singh VK. 2022. Cold plasma in food processing and preservation: A review. Journal of Food Process Engineering DOI: 10.1111/jfpe.14110.

Bisht B, Bhatnagar P, Gururani P, Kumar V, Tomar MS, Sinhmar R, Rathi N, Kumar S. 2021. Food irradiation: Effect of ionizing and non-ionizing radiations on preservation of fruits and vegetables – A review. Trends in Food Science & Technology **114**:372-385.

Buchmann L, Frey W, Gusbeth C, Ravaynia PS, Mathys A. 2019. Effect of nanosecond pulsed electric field treatment on cell proliferation of microalgae. Bioresource Technology **271**:402-408.

Castro-Muñoz R, Boczkaj G, Jafari SM. 2023. The role of hydrodynamic cavitation in tuning physicochemical properties of food items: A comprehensive review. Trends in Food Science & Technology, **134**:192-206.

Chaudhari CB, Prajapati JP, Pinto SV. 2015. Ultrasound Technology for Dairy Industry. SMC College of Dairy Science. India.

Chemat F, Huma Z, Khan MK. 2011. Applications of ultrasound in food technology: Processing, preservation and extraction. Ultrasonics Sonochemistry **18**:813-835.

Dattaa N, Deeth HC. 2018. Non-thermal Technologies: High Pressure Processing. Reference Module in Food Science. Elsevier DOI: 10.1016/b978-0-08-100596-5.22570-5

De-Souza SA. 2017. Quantitative Microbiology in Food Processing: Modeling the Microbial Ecology. John Wiley & Sons, Inc.

Desrosier NW, Singh RP. 2023. Food preservation. Encyclopedia Britannica. Available from https://www.britannica.com/topic/food-preservation (accessed March 2023).

Dominic MD. 2022. Irradiation-A novel food preservation technique. National Dairy Research Institute India **2**:25-31.

Drewnowski A. 2020. The Nutrient Rich Foods Index helps to identify healthy, affordable foods. The American Journal of Clinical Nutrition **111**:929-930.

FAO. 2009. CODE OF PRACTICE FOR THE REDUCTION OF CONTAMINATION OF FOOD WITH POLYCYCLIC AROMATIC HYDROCARBONS (PAH) FROM

SMOKING AND DIRECT DRYING PROCESSES. FAO, Rome. Available from https://www.fao.org/fao-who-codexalimentarius/codex-texts/codes-of-practice/en/ (accessed February 2023).

FAO. 2019. Food irradiation: a key tool for safer food and reducing food loss. FAO, Rome. Available from https://www.fao.org/policy-support/policy-themes/food-loss-food-waste/en/ (accessed March 2023).

Farooq S, Dar AH, Dash KK, Srivastava S, Pandey VK, Ayoub WS, Pandiselvam R, Manzoor S, Kaur M. 2023. Cold plasma treatment advancements in food processing and impact on the physiochemical characteristics of food products. Food Science and Biotechnology DOI: 10.1007/s10068-023-01266-5

Ferreira-Lazarte A, Villamiel M. 2023. Green Technologies for Sustainable Food Production and Preservation: Ultrasounds. Reference Module in Food Science DOI: 10.1016/B978-0-12-823960-5.00057-3.

Galimberti A, Bruno A, Agostinetto G, Casiraghi M, Guzzetti L, Labra M. 2021. Fermented food products in the era of globalization: tradition meets biotechnology innovations. Current Opinion in Biotechnology **70**:36–41.

García-Rey RM, García-Garrido JA, Quiles-Zafra R, Tapiador J, Luque de Castro MD. 2004. Relationship between pH before salting and dry-cured ham quality. Meat Science **67**:625-632.

Gogate PR. 2011. Hydrodynamic Cavitation for Food and Water Processing. Food and Bioprocess Technology **4**:996-1011.

Gould GW. 2010. Preservation of food. Doyle & Buchanan (Eds.) in Food Microbiology. Springer.

Hameed F, Anjum Ayouband A, Neeraj Gupta N. 2018 Novel food processing technologies: An overview. International Journal of Chemical Studies **6**:770-776.

Huang HW, Wu SJ, Lu JK, Shyu YT, Wang CY. 2017. Current status and future trends of high-pressure processing in food industry. Food Control Elsevier Ltd **72**:1-8

Pflug JI. 2018. Report: Controlling Clostridium Botulinum In Heat-Preserved Food. Nutrition and Food Processing **1**:01-03.

Jayathilakan K, Sultana K, Radhakrishna K. 2012. Utilization of irradiation technology for food preservation in developing countries. Journal of Food Science and Technology **49**:435-445.

Jiang Q, Zhang M, Xu B. 2020. Application of ultrasonic technology in postharvested fruits and vegetables storage: A review. Ultrasonics Sonochemistry **69**:1-9.

Joardder MUH, Masud MH. 2019. A Brief History of Food Preservation in Food Preservation in Developing Countries: Challenges and Solutions. Springer Nature, Switzerland.

Joardder MUH, Masud MH. 2019. Food Preservation in Developing Countries: Challenges and Solutions. Springer Nature, Switzerland.

Joardder MUH, Masud MH. 2019. Food Preservation Techniques in Developing Countries in Food Preservation in Developing Countries: Challenges and Solutions Springer Nature, Switzerland.

Joardder MUH, Masud MH. 2019. Foods and Developing Countries in Food Preservation in Developing Countries: Challenges and Solutions. Springer Nature, Switzerland.

Kanagaraj J, Chandra BNK. 2002. Alternatives to Salt Curing Techniques-A Review. Journal of Scientific & Industrial Research **61**:339-348.

Karki R, Oey I, Bremer P, Silcock P. 2023. Understanding the effect of meat electrical conductivity on Pulsed Electric Field (PEF) process parameters and the ability of PEF to enhance the quality and shorten sous vide processing for beef short ribs. Food Research International **163**:112-251.

Komolprasert V. 2016. High-Pressure Processing of Foods in Developing Countries: Opportunities and Challenges. Comprehensive Reviews in Food Science and Food Safety **15**:355-370.

Kumar A, Singh KU, Singh MK, Kushwaha AKS, Mahato S. 2022. Design and Fabrication of Solar Dryer System for Food Preservation of Vegetables or Fruit. Journal of Food Quality **2022**:1-14.

Kwon DY, Nyakudya E, Jeong YS. 2014. Fermentation: Food Products. Encyclopedia of Agriculture and Food Systems **2014**:113-123.

Leistner L. 2000. Basic aspects of food preservation by hurdle technology. International Journal of Food Microbiology **55**:181-186.

Linares-Morales J R, Gutiérrez-Méndez N, Rivera-Chavira BE, Pérez-Vega SB, Nevárez-Moorillón GV. 2018. Biocontrol Processes in Fruits and Fresh Produce, the Use of Lactic Acid Bacteria as a Sustainable Option. Frontiers in Sustainable Food Systems **2**:1-11.

Liu RH. 2013. Health-promoting components of fruits and vegetables in the diet. Advances in Nutrition **4**:384S-392S.

Liu X, Liao W, Xia W. 2023. Recent advances in chitosan based bioactive materials for food preservation. Food Hydrocolloids **140**:108-612.

Ludwig DS. 2021. The importance of dietary composition in preventing chronic disease. The New England Journal of Medicine **383:**1737-1738.

Marszałek K, Szczepa NA, Łukasz J, Zniak W, Ska S, Barba FJ, Brn-Ci CCM, Brn-Ci CCSR. 2018. The Preservation of Fruit and Vegetable Products Under High Pressure Processing. Encyclopedia of Food Security and Sustainability DOI: 10.1016/B978-0-12-812687-5.22258-2.

Mashoko D. 2022. Indigenous Knowledge and Food Preservation: A Case of "Collective Responsibility" for the Murambwi Locality in Chivi, Zimbabwe. IntechOpen, Zimbabwe. Available from www.intechopen.com (accessed December 2022).

Molaee-aghaee E, Salehi A, Karami L, Zomorodiyan N. 2022. Ultrasound as a modern preservation technique in food safety: a review. Journal of Food Safety and Hygiene DOI: 10.18502/jfsh.v7i4.9282.

Nonclercq A, Spreutels L, Boey C, Lonys L, Dave B, Haut B. 2009. Construction of a solar drying unit suitable for conservation of food and enhancement of food security in West Africa. Food Security **1**:197-205.

Ajibola OJ. 2020. An overview of irradiation as a food preservation technique. Novel Research in Microbiology Journal **4**:779-789.

Oladejo AO, Ekpene MAM, Onwude DI, Assian UE, Nkem OM. 2021. Effects of ultrasound pretreatments on the drying kinetics of yellow cassava during convective hot air drying. Journal of Food Processing and Preservation (e15251) DOI: 10.1111/jfpp.15251.

Onyeaka HN, Nwabor OF. 2022. Conventional preservation and preservatives. Pages 51-56 in Food Preservation and Safety of Natural Products. Elsevier,UK.

Pace RD, Plahar WA, Lu JY. 1989. STATUS OF TRADITIONAL FOOD PRESERVAllON METHODS FOR SELECTED GHANAIAN FOODS. Food Reviews International **5**:1-12.

Rahman MS. 2007. Handbook of Food Preservation Second Edition. Taylor & Francis Group, London.

Ranade VV, Bhandari VM, Nagarajan S, Sarvothaman VP, Simpson AT. 2022. Hydrodynamic Cavitation. Wiley Online Library.

Razola-Díaz MC, Tylewicz U, Rocculi P, Verardo V. 2023. Application of pulsed electric field processing in the food industry. Pages 257-298 in Non-thermal Food Processing Operations. Elsevier.

Rifna EJ, Dwivedi M, Chauhan OP. 2022. Role of Water Activity in Food Preservation. Advances in Food Chemistry DOI: 10.1007/978-981-19-4796-4_2.

Sampedro F, McAloon A, Yee W, Fan X, Geveke DJ. 2014. Cost Analysis and Environmental Impact of Pulsed Electric Fields and High Pressure Processing in Comparison with Thermal Pasteurization. Food and Bioprocess Technology **7**:1928-1937.

Sindelar JJ, Milkowski AL. 2012. Human safety controversies surrounding nitrate and nitrite in the diet. Nitric Oxide **26**:259-266.

Sridhar A, Ponnuchamy M, Kumar PS, Kapoor A. 2021. Food preservation techniques and nanotechnology for increased shelf life of fruits, vegetables, beverages and spices: a review. Environmental Chemistry Letters **19**:1715-1735.

Suthar S, Kaushik N, Jambheshwar G. 2023. Recent Advanced Techniques for Food Preservation and Processing. ResearchGate publication, India.

Taheri O, Mobadersani F, Sadeghi G, Mobadersani F. 2012. NEW TECHNOLOGIES OF SOLAR DRYING SYSTEMS FOR AGRICULTURAL AND MARINE PRODUCTS Dynamics of Encapsulated Microbubbles View project NEW

TECHNOLOGIES OF SOLAR DRYING SYSTEMS FOR AGRICULTURAL AND MARINE PRODUCTS. ResearchGate punlication, Iran.

Teixeira AA. 2014. Thermal Food Preservation Techniques (Pasteurization, Sterilization, Canning and Blanching). Pages 115-128 in Conventional and Advanced Food Processing Technologies. John Wiley & Sons, Ltd.

Tirivangasi MH, Rankoana AS. 2021. Sustainable Food Security through Indigenous Food Processing and Preservation in Four rural Communities of Limpopo Province, South Africa. African Journal of Development Studies **11**:243-257.

Toyohara M, Murata M, Ando M, Kubota S, Sakaguchi M, Toyohara H. 1999. Texture changes associated with insolubilization of sarcoplasmic proteins during salt-vinegar curing of fish. Journal of Food Science **64**:804-807.

Verkhivker Y, Miroshnychenko Y. 2020. CANNING FOOD IN SEMI-RIGID POLYMERIC AND COMPOSITE CONTAINERS. Food Science and Technology DOI: 10.15673/fst.v14i2.1719

Wani AA, Singh P, Langowski HC. 2014. Food Technologies: Packaging. Encyclopedia of Food Safety **3**:211-218.

Wei Q, Mei J, Xie J. 2022. Application of electron beam irradiation as a non-thermal technology in seafood preservation. LWT DOI: 10.1016/J.LWT.2022.113994.

WHO. 2019. Food irradiation. WHO. Available from https://www.who.int/news-room/questions-and-answers/item/food-irradiation (accessed November 2022).

World Health Organization. 2021. Healthy diet. WHO. Available from https://www.who.int/news-room/fact-sheets/detail/healthy-diet (accessed March 2023).

Xiao-Hui G, Jing W, Ye-Ling Z, Ying Z, Qiu-Jin Z, Ling-Gao L, Dan C, Yan-Pei H, Sha G, Ming-Ming L. 2022. Mediated curing strategy: An overview of salt reduction for dry-cured meat products. Food Reviews International DOI: 10.1080/87559129.2022.2029478.

Zhou J, Wang M, Berrada H, Zhu Z, Grimi N, Barba FJ. 2022. Pulsed electric fields (PEF), pressurized liquid extraction (PLE) and combined PEF + PLE process evaluation: Effects on Spirulina microstructure, biomolecules recovery and Triple

TOF-LC-MS-MS polyphenol composition. Innovative Food Science & Emerging Technologies DOI: 10.1016/J.IFSET.2022.102989.