

A MINI REVIEW ON APPLICATION OF NON-THERMAL TECHNIQUES FOR PROTECTION OF FRUIT JUICES

Samreen Ahsan¹, Ayesha Siddiqi¹, Farhan Chughtai¹, Adnan Khaliq¹, Farrukh Makhmudov*², Sanavar Azimova³, Maksim Rebezov^{4,5}, Gulnara Zhumanova⁶, Botakoz Kulushtayeva⁶, Mohammad Ali Shariati⁷

Address(es):

¹ Institute of Food science and Technology, Khwaja Fareed University of Engineering and information technology Rahim Yar Khan.

² Department Equipment and technologies of food production, International Engineering Technological University, 89/21 Al-Farabi Avenue, Almaty, 050060, Kazakhstan.

³ Department of Food Safety and Quality, Almaty Technological University, 100 Tole bi Str., Almaty, 050000, Kazakhstan.

⁴ Department of Scientific Research, V. M. Gorbатов Federal Research Center for Food Systems, 26 Talalikhin Str., Moscow, 109316, Russia.

⁵ Faculty of Biotechnology and Food Engineering, Ural State Agrarian University, 42 Karl Liebknecht str., Yekaterinburg, 620075, Russia.

⁶ Department of Food Technology, Shakarim University, 20a Glinka str., Semey, 071412, Kazakhstan.

⁷ Kazakh Research Institute of Processing and Food Industry, Semey Branch of the Institute, 238«G» Gagarin Ave., Almaty, 050060, Kazakhstan.

*Corresponding author: f.makhmudov@autodom-t.kz

<https://doi.org/10.55251/jmbfs.11879>

ARTICLE INFO

Received 1. 10. 2024

Revised 19. 11. 2024

Accepted 20. 11. 2024

Published xx.xx.201x

Regular article



ABSTRACT

Abstract: Globally, fruit juices are widely consumed due to their nutritional and health benefits. With increased consumer knowledge about health and safety demand for nutritious fresh like juices is also increased. Fruit juices are more susceptible to spoilage mostly by spoilage microorganisms or by intrinsic enzymatic reactions that adversely affect the sensory attributes of juices. Conventional thermal pasteurization is effective to control spoilage, but it also affects heat sensitive functional compounds and the nutritional value of juices. Therefore, to meet increased consumer demand and requirements, it is necessary to process a variety of fruits for juice preparation with improved preservation techniques to control spoilage. Non-thermal preservation like high pressure processing, pulse electric field, ultraviolet radiations and cold press, etc., are recognized as best alternatives to thermal pasteurization as they have substantial potential to completely inactivate spoilage microbes by causing cell disruption either during processing or after juice has packaged. One of the promising features of employing non-thermal preservation methods is that they do not affect nutritional and organoleptic characteristics of processed juice. Also, most of the methods are relatively less expensive and efficient cause maximum microbial load reduction and improve shelf life.

Keywords: Non-thermal Pasteurization; High Pressure Processing; Pulse Electric Field; Cold Plasma; Irradiation; Fruit Juice Preservation

INTRODUCTION

Recent trends of academia and the food industry have revealed the great potential of using innovative non thermal techniques for food preservation (Prokhasko *et al.*, 2018; Anggono *et al.*, 2022; Rebezov *et al.*, 2022). Among food groups, highly perishable foods like milk and fruit juices are more susceptible to microbial and enzymatic spoilage (Chughtai *et al.*, 2021; Sarkar *et al.*, 2021; Meinert *et al.*, 2023). Thermal pasteurization is usually performed to improve shelf life of juices through the destruction of spoilage agents, but it also has an adverse effect on its functional, nutri-tional and sensory attributes (Bhattacharjee *et al.*, 2019). Therefore, research has shown great interest in exploring alternate non thermal techniques in juice preservation that cause maximum enzymatic and microbial load reduction along with preserva-tion of sensory attributes while using minimal heat. Non-thermal preservation techniques are gaining importance as consumer preferences and requirements for quality foods having 'fresh-like' attributes are increasing. These techniques, including Irradiation, Cold Plasma, Pulsed Electric Field, Ultrasound Waves, and High-Pressure Processing can preserve foods in a better way and re-place the traditional preservation techniques (Pina-Pérez *et al.*, 2016; Osintseva *et al.*, 2017; Tretyak *et al.*, 2017). One of the most important concerns of modern food processing industries is to ensure food safety by preserving food through the inactivation of microorganisms and reduction or inhibition of enzymatic activities (Petrucci *et al.*, 2017).

Spoilage can be defined as a chemical process causing food or food products to be unappealing or objectionable for human consumption due to variations in sensory attributes. Such foods might be considered safe to consume as they are not harmful to our health due to the absence of pathogens or toxins, however, they may be rejected or dis-carded owing to the changes in sensory characteristics i.e., appearance, taste, flavor, aroma, or texture (Sahu and Bala, 2017). Spoil-age of fruits and their products can happen at any step of the food chain and may arise due to insect damage, phys-ical damage, enzymatic reactions, or microbial activity (Petrucci *et al.*, 2017).

Enzymatic spoilage: Enzymes are chemical compounds, proteinaceous in nature, and exhibit structural variability (Siddiqui, 2017). Enzymatic browning is one of the major food spoiling mechanisms occurring in fresh fruits. There-fore, it is mandatory to control enzymatic activities during fruit juice processing operations. The enzymatic activi-ties of polyphenol oxidase and peroxidase were found to be stopped due to the disruptions in the α -helical structure of enzymes. Polyphenol oxidase (PPO) catalyzes the oxidation and hydroxylation of phenolic compounds and re-sults in the browning of fruits. Figure 1 is showing enzymatic reactions that are catalyzed by PPO and peroxidase. Enzymes also cause undesirable changes in color and sensory attributes of fruits and vegetables. They interact with atmospheric oxygen and deteriorate the natural color and produce off-flavors in the fruits (Ağcam *et al.*, 2018). Peroxidase enzymes, members of the oxidoreductases group, cause enzymatic browning and undesirable changes in the color and flavor of fruit juices. They use hydrogen peroxide and facilitate the oxidation of phenolic compounds which are naturally present in the fruits. These enzymes have been found to deteriorate the sensory aspects of fruit juices quicker than other enzymes. Polyphenol oxidases, after oxidation form unstable o-quinones which interact with proteins and other molecules and impart a brown, black, or red color to the fruit juices. They have also been reported to alter the flavor of food commodities (Murtaza *et al.*, 2019). Thus, in order to maintain the fresh sensory and nutritional value of processed juic-es, a high level of enzymatic inactivation is required (Marszalek *et al.*, 2016; Murtaza *et al.*, 2019; Benito-Román *et al.*, 2020).

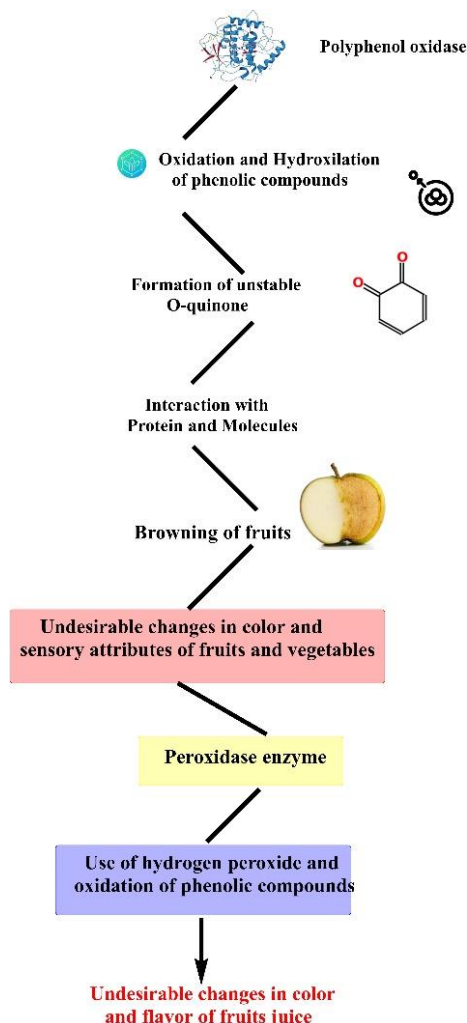


Figure 1 Enzymatic effect on fruits and their juices

Bacterial spoilage

Chemical reactions occurring in foods and resulting in various sensory changes are facilitated by a wide range of microbes, including bacteria, yeasts, molds, and others. Owing to the nature of microbes, some are usually pre-sent in spoiled foods, whereas others exist in a specific type of food. Numerous microbial species could be present in a single spoiled food or there may be a particular species responsible for deteriorating the sensory attributes of foods especially liquid foods. Microbes deteriorate the sensory characteristics of fruit products by producing off-odors, affecting the appearance and development of off-flavors (Petruzzi et al., 2017).

Major spoilage Bacteria of Fruit juices

In the past few decades, gram-positive nonpathogenic spore-forming bacteria such as *Alicyclobacillus* spp. have been found to cause spoilage in commercially processed fruit juices. Various bacterial species have been re-reported to produce mousy, malty, buttery, or acidic off-flavors which render the food product unacceptable by consumers (Cai et al., 2015).

Many spoilage microorganisms particularly, *A. acidoterrestris* bacterial species have been found to produce off-flavors in fruits and vegetable products. The spores of *A. acidoterrestris* have ability to withstand commercial pasteurization temperatures and germinate even in low pH environments. They produce volatile and undesirable odorous compounds, known as guaiacol, in various fruit juices. This sour type of spoilage is identified as having a medicinal or antiseptic off flavor without the production of gas or other gaseous compounds (Pornpukdeewattana et al., 2020).

Other spoilage agents of juices are mostly yeasts that are classified into four main groups: (a) *Saccharomyces* spp.: these species spoil wine and alcoholic beverages by producing off-flavors and gassiness. (b) *Zygosaccharomyces*: these species spoil salad dressings, dried fruits and vegetables, jams, and soy sauce. These species exhibit slow growth, produce off-odor, off-flavor compounds, and carbon dioxide gas causing the food containers to burst. (c) *Candida* species: these species are involved in the spoilage of fruits and dairy products. They deteriorate the appearance and taste of fresh and processed fruits and vegetables. (d) *Dekkera/Brettanomyces*: these species cause damage to fermented foods, such as alcoholic drinks and certain dairy products by producing volatile phenolics and these compounds spoil the flavor of fruit juices (Campos et al., 2015; Abdel-Aziz et al., 2016). The genus *Zygosaccharomyces* comprises six species. Among these, *Z. bailii*, *bisporus*, and *rouxii* are associated with the spoilage of fruits and beverages. These species cause fermentative spoilage in fruit juices, fruit concentrates, honey, and confectionery products. The growth of *Saccharomyces pombe* renders malic acid in fruit juices unavailable. This increases the pH and ultimately affects the taste and stability of the fruit juice (Petruzzi et al., 2017; Howell, 2016). Table 1 is showing effect of microorganisms on quality of juice.

Table 1 Effect of Microorganisms on quality of juice

Microbes	Organisms	Effects on Juice Quality	Spoilage Type	pH Range	References
Acetobacter spp.	<i>Acetobacter aceti</i>	Increased acidity due to acetic acid production Vinegar-like aroma and flavor	Sour taste	3.5 - 4.5	(Gomes et al., 2018)
Lactic Acid Bacteria	<i>Lactobacillus</i> spp., <i>Leuconostoc</i> spp.	Increased acidity due to lactic acid production Cloudiness and off-putting odor	Sour taste	3.2 - 4.0	(Da Silva, 2017)
Alicyclobacillus spp.	<i>Alicyclobacillus acidoterrestris</i>	Off-flavors, often described as medicinal or phenolic Browning of juice due to enzymatic reactions	Undesirable aroma	3.0 - 4.0	(Pornpukdeewattana et al., 2020)
Pectinolytic Bacteria	<i>Erwinia</i> spp., <i>Pectobacterium</i> spp.	Pectin degradation leading to juice clarification Changes in color and texture	Loss of turbidity	3.0 - 4.5	(Shrestha et al., 2021)
Yeasts and Molds	<i>Saccharomyces cerevisiae</i> , <i>Aspergillus</i> spp., <i>Candida</i> spp., <i>Zygosaccharomyces</i> , <i>Dekkera/Brettanomyces</i> , <i>Zygosaccharomyces bailii</i> , <i>Pichia bisporus</i> , <i>Candida rouxii</i>	Fermentation leading to alcohol and CO ₂ production Changes in aroma, taste, and color	Fizziness	2.5 - 5.0	(Zilelidou and Nisiotou, 2021)

Non thermal techniques for Fruit juice preservation

High Pressure Processing

One of the novel nonthermal processing techniques widely employed for the preservation of liquid foods is high pressure processing that involves high pressure treatment (100-600 Mpa) at room temperature resulted the inactivation of spoilage agents (Lai et al., 2021).

Principle of HPP

It works on principle of degradation of the microbial cell membrane, its protein and vegetative cells that eventually lead to cell death (Lado and Yousef, 2002). HPP not only inactivates spoilage agents like microorganisms and enzymes but also preserves the organoleptic and nutritional properties of processed food.

Uses

HPP is used as an alternative to conventional thermal treatments to preserve food, especially liquid foods like juices and milk. Numerous databases confirmed high pressure processing attain the same level of preservation as achieved with conventional thermal preservation methods like pasteurization (Huang et al., 2018). The Food and drug administration (FDA) has also listed HPP as one of the most effective alternatives to thermal pasteurization (FDA, 2010). One additional benefit of employing HPP is that it preserves not only the nutritional and organoleptic characteristics of fruit juices but also protects the functional components of juices. Therefore, employed for almost all types of foods particularly for heat sensitive fruit juices to preserve their functional ingredients while maintaining taste (Wang et al., 2016).

Application of HPP

The high-pressure range varies from 100 Mpa to 1000 Mpa for ultra high-pressure treatment for inactivation of spoilage microorganisms. Pressure has an important functional role when applied at 300 Mpa showed no significant reduction but when it increased to 400 Mpa or above then it inactivates almost all microorganisms (18). Temperature also plays a critical role in high pressure processing particularly in terms of preservation for microbial inactivation. Mostly temperature maintained at room temperature or somehow above and below that give efficient results in HPP.

Processing of apple juice

In a recent research temperature effect in HPP is evaluated by processing apple juice at low temperature 5 °C and room temperature 20 °C. Results confirmed that a substantial reduction of inoculated spoilage organisms (*E. coli*, *Salmonella* and *Listeria monocytogenes*) was observed with room temperature HPP treatment (Cheng et al., 2018).

Current and future trends of the food industry revealed that pasteurization of fruit juices by non-thermal techniques like high pressure processing is now becoming more popular due to its better preservation potential of functional and microbiological characteristics, satisfying both consumer and processor demands (Huang et al., 2017).

Processing of Shiikuwasha juice

In a research study, Shiikuwasha (*Citrus depressa*) juice was processed at high pressure 600 Mpa for 150 seconds at room temperature to improve microbiological shelf life of the juice. Evaluated results for 28 days storage period confirmed substantial microbial load reduction of Psychrotrophs and *E. coli* O157:H7 (5.15 log reduction) in HPP processed citrus juice. Also, HP processed juice compared with HTST pasteurized juice that confirmed Shiikuwasha has better shelf stability and microbial safety status than HTST processed (Lai et al., 2021).

Apple juice preservation by HPP was achieved best at high pressure (>400 MPa) for 110 seconds that effectively inactivates all spoilage microorganisms by cell disruption (Petrus et al., 2020). Whereas in some cases recovery of spore former fungi was observed in refrigerated storage of preserved apple juice. A recent research database evaluated HP (600 MPa) treatment and reported substantial reduction (5.3 log reduction) of fungal spp. In apple juice along with modifications in the concentration (aw) and pH of juice (Buerman et al., 2020).

Processing of Acai juice

In another recent database, Acai juice (pH 4, Brix 2.9) was preserved by high pressure processing to inactivate its common spoilage microorganisms i.e., *E. coli* O157:H7, *Listeria monocytogenes* and *Salmonella* spp. The study confirmed that high pressure (400 Mpa) treatment for 3 minutes at 5°C efficiently inactivates all spoilage microorganisms and improved juice shelf life. HPP cause cell injury and lethality of bacterial cells in such a manner that even no recovery is observed in long refrigeration storage (42 days) period of juice (24).

White Grape juice Processing

Chang et al. conducted research aimed to assess HPP as an alternate to TP for white grape juice as it has limited shelf life due to microbial and enzymatic deteriorative reactions. High pressure (600 MPa) applied for 3 minutes resulted in the same microbial load reduction as thermal pasteurization however, other functional, quality and sensory attributes of juice score higher in HPP than TP. Additionally, study results also confirmed that HPP has the potential to limit (50 %) deteriorative activities of polyphenol oxidase and peroxidase that are responsible for quality deterioration and spoilage of grape juice (Chang et al., 2017).

Processing of mango juice

Mango juice is one of the most widely consumed juice due to its appreciable flavor and antioxidant potential. Thermal pasteurization of juice can cause losses of its sensory and antioxidant profile therefore novel non thermal techniques adopted to

preserve its value. In a research database, high isostatic pressure (Guerrero-Beltrán et al., 2005), a form of HPP (600 MPa, 300 sec, 25 °C) is adopted as an alternative to thermal pasteurization resulted increased shelf life of juice through complete inactivation of spoilage microorganisms while preserving nutritional and sensory attributes of the product (Moreira et al., 2017).

Processing of other juices

Furthermore, high pressure (550 MPa) processing of carrot juice was performed for 6 minutes resulted into complete inactivation of yeast and mold. Results confirmed that HPP not only improves the shelf storage period of juice by microbial inactivation but also resulted in better sensory attributes than conventional TP (Zhang et al., 2016). Similarly, sugarcane high pressure (600 MPa for 6 minutes) pasteurization was evaluated in comparison to thermal pasteurization revealed that HP processing resulted in significant microbial load reduction (4.6 log) potential (Huang et al., 2015). In a research study, when grapefruit juice processed at high pressure (250 MPa) and high temperature (60 °C) for 3 minutes it resulted in significant microbial (aerobic plate count, yeast and mold) and enzymatic (Polyphenol oxidase, Pectin methyl esterase) reduction (Lado and Yousef, 2002).

Pulse electric field

Pulse electric field (PEF) has been the most investigated and studied technology of interest by researchers. PEF treatment is thought to be an affordable, environmentally benign method of deactivating microbes and enhancing mass transfer in food items (Arshad et al., 2021). A unique non-thermal preservation technique holds the promise of producing foods with superior nutritional value, sensory appeal, and shelf life. PEF technology is said to be better than conventional heat treatment for food since it prevents or significantly lessens the negative alterations to food's sensory and physical qualities (Z. H. Zhang et al., 2019).

Benefits

This non-thermal technique has been used for microbial inactivation in a wide range of fruit as well as vegetable-based drinks, also this technique has no negative impact on the organoleptic properties of these drink. This non-thermal technology keeps the nutritional properties of juice preserved just like fresh juices. This technique has been the center of interest for scientists as the efficiency of PEF is similar to that of thermal treatments without impacting physicochemical or sensory properties of treated product. If PEF is applied continuously for a specific time period, then it will rupture microbial cell-membranes and will ultimately these cells will be destroyed (Soliva-Fortuny et al., 2009).

Limitations

Despite PEF has been known for its wide range of pros in producing best quality products especially fresh juices, along with a significant reduction in microbial load, but this technique cannot be adopted widely in food industry due to its high cost than other conventional treatments such as thermal treatments (Sampedro et al., 2013).

Utilizing PEF Technology

The functioning of PEF technique basically depends on electroporation that leads to the de-polymerization of microorganism's cell membranes' macromolecules (Arshad et al., 2021).

This de-polymerization of macromolecules results in the inactivation of microorganisms thus reducing overall microbial load in juices without imparting any negative impact on organoleptic or nutritional properties of juices. Researchers have reported that pulse electric field collapse the cell-membranes of microorganisms, alter the overall morphology as well as structure of cell, impacts the functioning of enzymes that are responsible for cell metabolism, destroy the genetic material present in the cell and alter the gene expression of microbial cell (Huang et al., 2014).

PEF treatment inactivates the microorganisms by multiple aspects and these aspects can be categorized into different groups such as methods of processing, microbial load or nature of microbes and nature of product. The basic parameters involved in different methods of processing are time of treatment, temperature, and width, EFS, shape and pulse polarity. All these parameters play a role in inactivating microorganisms by PEF. Research has evidenced that microbial inactivation is directly related with the treatment time and EFS, as by increasing the treatment time and EFS the inactivation of microorganisms has been observed at a greater level. Electro-permeability, on the other hand, has been found reversible and irreversible depending on the intensity of PEF treatment (30). Microorganisms cannot be inactivated completely if the electro-permeability of microbial cell membranes is reversible, which is basically due to the suboptimal conditions of PEF treatment (Demirci and Ngadi, 2012). Along with all these aspects, the product related factors also play a significant role in inactivating microbial cells. These factors include pH of product, ionic strength and electrical

conductivity of product, while microbes related factors include their growth stage, species, size and shape of cell and concentration of microorganisms (Huang et al., 2012). In all these microbes related parameters, the most critical one is their specie, as it imparts a great impact on PEF efficiency for microbial cells inactivation. Pulse electric field has been found effective against all the vegetative cells of bacteria, yeast and moulds, while it is inefficient against bacterial spores. PEF treatment has best efficiency against yeasts (Huang et al., 2014).

Processing of Grape juice

Research study has reported that PEF treatment of 35kV/cm was applied with a frequency of 303Hz, pulse width for almost 1 μ s on grape juice and it resulted in a

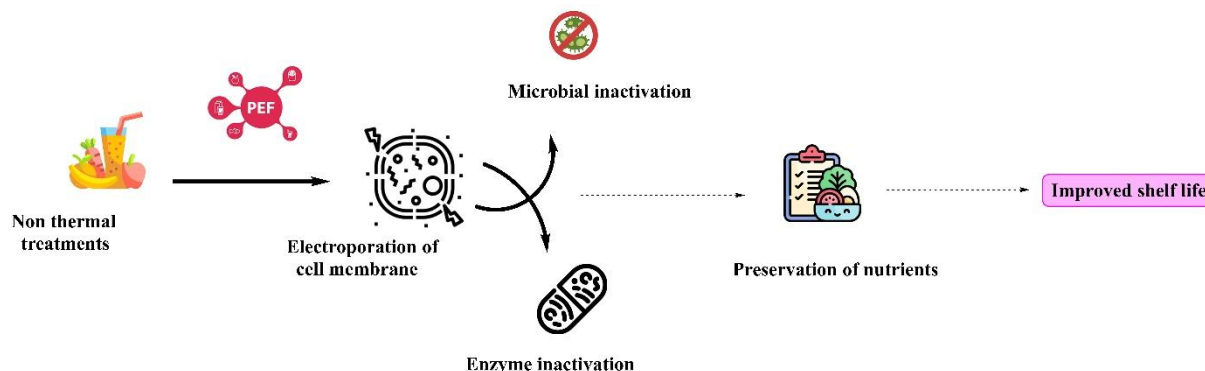


Figure 2 Mechanism of Pulse Electric Field (PEF) to increase shelf life of juice

Processing of APPLE juice

Research on estimating the efficiency of PEF on apple juice revealed that by applying a slight field strength of just 50kV/cm on apple juice with 16 pulses resulted in a strong pasteurizing effect and reduced the cell count up to 4 to 6 logs of yeast, aerobic plate counts and moulds (Saldana et al., 2011).

Processing of Strawberry juice

Studies conducted for strawberry juice evidenced the reduction of *E. coli* by almost 3.8 logs by applying PEF of 18.6kV/cm for around 150 μ s (Gurtler et al., 2011). A slight increase in the intensity of PEF treatment was also studied and resulted in the higher level of microbial inactivation. Scientists have suggested that the inactivation of microbes can be increased if these treatments are coupled with mild thermal treatments (Geveke et al., 2015). The efficiency of PEF against microbial load has been investigated by multiple researchers on different juices including apple juice (Saldona et al., 2011), grape juice (Huan et al., 2014), tomato juice (Kim et al., 2017), and orange juice (Timmermans et al., Roobab et al., 2018) etc., along with processing conditions are shown in table 1.

Irradiation

Irradiation refers to the use of ionizing radiations and these include the applications of electromagnetic rays including high-energy gamma rays, accelerated electrons, and X-rays. These rays are administered according to the Codex General Standard for Irradiated Foods (Commission, 2003). Irradiation helps increase the shelf life via the inactivation of microorganisms in foods and food products. Gamma X-rays and UV rays, among the other types of electromagnetic rays, are generally used by food processors for preserving fruit juices (Roboob et al., 2018).

Limitations

Generally, the radiation dose below 1 kGy is considered sufficient to inhibit the growth of microorganisms however, to kill or remove microbes completely from foods, a radiation dose of 1-10 kGy is required (Mesquita et al., 2020). Gamma X-rays are particularly used by the fruit juice processors to limit the growth the microorganisms, such as bacteria, yeast, and mold. When used at 5 kGy dose, gamma rays resulted in complete elimination of bacterial and yeast and mold count (Kalaiselvan et al., 2018).

Application of UV rays

Another important aspect of irradiation is the application of UV rays. UV rays, in the electromagnetic spectrum, lie in the range of 200-800 nm and have a lethal effect on microbial growth (Roboob et al., 2018). Bacteria included in Alicyclobacillus genus cause serious damage to the quality of fruit juices due to their spore forming ability. UV-C rays have been reported to be very effective in decreasing and limiting the spores of these species in orange juices (do Prado et al., 2019).

reduction of around 2.5-3.95 logs cell number. The microbes present initially in grapes juice were *Lactobacillus plantarum*, *S. cerevisiae*, *Gluconobacter oxydans*, *Lactobacillus hilgardii* and *Kloeckera apiculata* (Marsellés-Fontanet et al., 2009).

In another study, the total count of microorganisms in grape juice was found to be reduced by the application of around 20 pulses with 80kV/cm, keeping the temperature 50 °C and no anti-microbial agent was introduced. This treatment resulted in the reduction of almost 3.9 logs of *Zygosaccharomyces bailii* ascospores, *Neosartorya fischeri* ascospores, and *Byssoschlamys fulva* conidiospores (Wu et al., 2005). Likewise, Figure 2 is showing how PEF inactivate microbes and enzyme to extend the shelf life of juices.

The mechanism of inactivating growth of microorganisms begins as the DNA absorbs electromagnetic rays followed by the formation of cross-linked nitrogenous bases which causes a mutation in the microbial DNA. This mechanism impairs the normal functioning of DNA and reproductive capacities of the microorganism. Application of UV rays at an energy concentration of 400 J/m² is sufficient to control microbial growth. Exposure time, nature of microorganism, irradiation concentration, and dimensions of food are important factors of irradiation. The application of gamma radiations causes radiolysis and results in the formation of a series of reactive compounds, such as oxygen species, radicals, and ionized water. These reactive compounds facilitate the formation of secondary products i.e. hydrogen peroxide (Mesquita et al., 2020). These cell-damaging reactive compounds generate a chain of reactions causing oxidative damage to the biological molecules. The outcomes of these propagating reactions are impairment of physiological functions which inhibit the growth of microorganisms and development of off-flavors (Roboob et al., 2018).

The application of UV irradiation has been found to be effective for enzyme inactivation in different fruit juices, including apple, pear, and grape juices (Mesquita et al., 2020). The influence of UV-Vis irradiation on quality attributes and enzymatic activities of nectarine juices was observed by (Aguilar). Irradiation was applied for 2 hours using a power lamp of 460-W, emitting rays in the range of 250-740 nm. Results showed that irradiation was effective in inactivating enzymes such as polyphenol oxidase (PPO) and peroxidase by up to 60%. The impact of UV irradiation on microbial and enzymatic inactivation in apple juice treated with UV rays by using a UV device for 40 minutes was investigated (Akgün et al., 2017). The UV device is comprised of four LEDs with different peak and coupled emissions. Results showed a significant decline in antimicrobial and enzymatic activity. Polyphenol oxidase activity was reduced to 65.62% when a combination of 280-365 nm and 280-405 nm were used. The efficiency of enzymatic inactivation in fruit juices using UV irradiation is dependent on the juice composition and its matrix (Wang et al., 2020).

Uses

Gamma X-rays and UV rays were widely used to inactivate microorganisms such as *E. coli* and *S. cerevisiae* in apple juice at 60 W/m² and 254 nm. Results showed a significant reduction count in spoilage yeasts (Gabriel, 2012) and a 4- to 5- log reduction. The sensitivity of microbes also affects these results. For instance, a similar log reduction level was observed for *A. acidoterrestris* at 13.44 W/m² (Gabriel, 2012; Tremarin et al., 2017). The application of UV at different radiation concentrations to limit the growth of *E. coli* in apple juice was studied. Results showed a 2- to 5-log reduction in viability of these pathogenic microbes (Usaga et al., 2015; Yin et al., 2015). In another study, the effect of UV-C radiation to inactivate the spores of *A. acidophilus* and the growth of yeast and molds were studied (Tremarin et al., 2017). Results showed a 5-log reduction at the maximum treatment dose, which was 13.44 W/m². Watermelon juice irradiated by UV-C showed a log reduction of 2.6, 1.47, and 0.99 at a concentration of 2.7 and 37.5 J/mL in Total Plate Count of coliforms and yeast and molds without affecting the physicochemical properties (pH, TSS, lycopene, phenolic content) of juice (Feng et al., 2013). The impact of UV irradiation was studied for the pasteurization of orange juice. Results showed a log reduction of 2.8- and 0.34- in

the aerobic plate count and yeast and mold count respectively (Pala and Toklucu, 2013). The application of centrifugal UV to pasteurize grapefruit was studied at the following conditions: 4.8 to 24 mJ/cm² and 450-750 rpm. Results showed a log reduction of 5.1- in *E. coli* and 6.0- in *S. cerevisiae* species (Geveke and Torres, 2012).

Ultrasound

During the last decade, ultrasonication has emerged to the greater extent as innovative and eminent technology that can be utilized as a perpetual alternative to thermal techniques (Dolas et al., 2019). Ultrasounds are sound waves or pressure waves having a frequency greater than the threshold for human hearing (≥ 16 kHz) or about 20 kHz.

Types of ultrasonication

It is divided into three types depending upon the frequency range: power ultrasound also known as high power ultrasound utilizes the sound waves ranges from 16 to 100 kHz; high-frequency ultrasound (0.1–1 MHz) and diagnostic ultrasound with wider frequency ranges from 1 to 10 MHz (Zhang et al., 2019).

Mechanism of ultrasonication

When the sound waves propagated through the liquid medium, they produce gas bubbles, and their bursting (cavitation) results in a rise in temperature and pressure. These bubbles have greater surface area during the expansion cycle that enhances the diffusion rate of gas thus causing bubbles to expand. Afterward, prompt condensation occurred at a point when ultrasound energy is not enough to maintain the vapor phase in the bubble. Finally, resulting in the intense collisions of condensed molecules, generating shock waves raising the temperature and pressure of the liquid medium up to 5500 °C and 50 MPa respectively (Jan et al., 2017). The microbial destruction caused by ultrasonic waves is mainly due to the pressure changes that occur during these implosions (collapse or falling or air bubbles), thus hastening the mass transfer, disruption of the particles, and destruction of the microbial cell membrane (Kentish and Feng, 2014; Shen et al., 2017). Though the temperature rise is also responsible for the bactericidal effect but it is very confined and does not affect the large surface area.

Application

Succinctly, numerous ultrasound systems with varying ranges of frequency and energy density are employed with widespread application in food preservation (destruction of microorganisms and enzymes), food processing (defoaming, degassing, emulsification and filtration), and also assist in the extraction of active ingredients or bioactive from various food products (Aliashghari Aghdam et al., 2015; Kumari et al., 2017).

Ultrasonic is a novel technique that has discovered its widespread application in the food industry especially the fruit juice and beverage industry due to its multidimensional positive effects on fruit juice processing and preservation. It is a simple, economical, and reliable method that exerts a minimal negative effect on the environment. Ultrasonication is a profoundly utilized technique for the preservation of fruit juices while keeping the nutritional quality and sensory attributes intact. It has proved to have strong antimicrobial potential against a wide continuum of microorganisms and thus has been perceived as an imminent technology that meets the FDA requirement of safety for fruits and vegetables. Fruits have a short shelf life because they are highly susceptible to microbial and enzymatic spoilage that may result in the loss of color and nutritional quality attributes. Subsequently, sonication is an impending technology that can be employed to preserve fruit juices without affecting nutritional quality. Sonication has been investigated for its utilization on a wide range of fruit juices including apple, melon, pomegranate, blueberry, and orange juice (Dolas et al., 2019).

Pomegranate fruit is highly nutritious and rich in bioactive compounds. Thermal processing of pomegranate juice for its preservation and microbial destruction considerably affects its nutritional profile or reduces its functional ingredients. Thus, the application of sonication at frequency of 20 kHz at 100% amplitude level for 15 min has been reported to significantly reduce the microbial count especially *E. coli* and *S. cerevisiae* in pomegranate juice thus extending its shelf life. Moreover, the results showed that the lower amplitude levels were not found effective in reducing microbial count (Alighourchi et al., 2014).

Similarly, an ultrasonication probe was employed by Pala et al. (2015) (надо вставить не год, а номер ссылки), to study the effect of ultrasonication on the microbial inactivation and physicochemical properties of pomegranate juice. The application of 20 kHz for 30 min at an amplitude level of 100% was found to be effectual in the inactivation of *E. coli* ATCC 25922 to 5 log and *S. cerevisiae* ATCC 2366 to 1.36 log with no significant change in the phenolic count, pH, and soluble solids. However, the anthocyanin count showed 92% and 89% retention at amplitude levels of 75 and 100% respectively. Thus, ultrasound technology was found potent in improving the quality and safety of pomegranate juice.

In another research, the effect of continuous ultrasound treatment (US) by intensifying the amplitude and flow rate on reduction of microbial count in

blueberry juice was investigated. It was concluded that the continuous application of US resulted in a substantial reduction of total count, aerobic plate count, yeast, and mold count. Moreover, continuous US treatment exerts no negative effect on the colour and the anthocyanin content of juice thus preserving the quality and safety of juice. So, it can be considered as an alternative to thermal treatment (Mohideen et al., 2015).

Moreover, juice blend (apple+strawberry+Lemon) was treated with ultrasound at 376 W/10 min/35 °C and its effect on the safety and quality of juice was evaluated. The results showed a significant reduction in the microbial count during the 10 days storage at 4°C (Feng et al., 2020). Oliveira et al. (2018) observed the effect of ultrasound, ozone, and their combined treatment on the quality and microbiological safety of acai juice. Assay with ultrasound treatment at an energy density of 700 J·mL⁻¹ and no ozonation showed maximum potential in a significant reduction in mesophilic bacteria, molds and yeasts count (Oliveira et al., 2018).

Comparison of thermal and non-thermal technologies

Ultrasonication (non-thermal) and thermal heat treatment both were employed as preservation technologies that significantly reduced the microbial count. But the thermal treatment was reported to have adverse effect on the nutritional characteristics of food. A comparative study was conducted by Farhadi Chitgar et al. (2017), to evaluate the effect of sonication and heat treatment on the quality and safety attributes of barberry juice that is rich in anthocyanin and antioxidants. Results showed that sonication was reported to enhance the total phenolic count and antioxidant profile of barberry juice and showed very less effect on the colour and anthocyanin content in comparison to thermal treatment. Moreover, both the treatments resulted in the reduction of microbial count below the detection limit. The greater efficiency of sonication treatment to exert the lethal effect on microorganisms was accomplished by intensifying the amplitude and increasing the time of sonication (Farhadi Chitgar et al., 2017). Likewise, Saikia et al. (2016) also reported the positive effect of ultrasound treatment on the total phenolic count and antioxidant activity of juices from five fruits (carambola, pineapple, litchi, black jamun and watermelon) in comparison to thermal pasteurization (Saikia et al., 2016).

Furthermore, the high-power ultrasound in combination with slight heating (thermosonication) showed its potential in significantly reducing the count of selected mold and yeast in apple, blueberry, cranberry juice. Application of ultrasound of 20 kHz, at 60°C for the period of 3, 6 and 9 min resulted in the complete reduction of yeast and mold that was not visible at lower temperatures (20 or 40 °C). It was concluded that temperature is an important factor that significantly influences the inactivation of yeasts and molds in fruit juices (Jambrak et al., 2018). Guerrouj et al. (2016) (надо вставить не год, а номер ссылки), also reported the positive impact of thermosonication in reducing the microbial account along with the positive impact on the nutritional quality of orange juice. As it also resulted in the general augmentation of bioactive compounds such as flavonoids, total phenolics, carotenoids, vitamin C and anthocyanin in orange juice. Conclusively, ultrasonication in combination with mild heat allowed the inactivation of microorganisms in various fruit juices and can be adopted on a pilot scale (juice processing industries) for the production of safe, nutritious and high-quality fruit juices with extended shelf life (Guerrouj et al., 2016).

Pulsed Light

Pulsed light treatment is an emerging non-thermal food processing and preservation technique that can be employed in the replacement of conventional thermal pasteurization techniques. It is composed of white light with a wide spectrum of wavelength (200-1100nm) including ultraviolet (UV) ranges from 200 to 400 nm, the visible light spectrum from 400 to 700 nm, and near-infrared spectra from 700-1100 nm (Bhavaya and Umesh Hebbar, 2017). It involves the discharge of high energy and high voltage electric pulses upto 70 kV/cm for every short interval of time (picosecond or femtosecond). Pulsed light is generated by various sources including ytterbium ions doped silica fibers and flash lamps filled with inert gas (xenon or krypton) (Santamera et al., 2020).

Limitations

Pulsed light treatment must not exceed 12 J/cm² for the duration of 2 milliseconds for the treatment of food to control surface microorganisms has been approved by the Food and Drug Administration (FDA). The efficiency of pulsed light treatment on microbial destruction has been significantly influenced by the wavelength of the light spectrum, number of pulses generated (amount of energy), and fluence level applied on the sample. The exposure of the sample to pulsed light treatment with higher intensity and pulse number resulted in microbial inactivation to a greater extent (Shankar et al., 2014).

Utilization

It is most commonly reported as an appropriate technique for surface decontamination or sterilization of raw and fresh-cut fruits and vegetables or meat cuts, processing equipment, and food packaging materials. Pulsed light has also found its application for the inactivation of foodborne pathogens in liquid foods including fruit juices, milk and infant foods (Bhavaya et al., 2017).

Preetha et al. (2021) investigated the effect of continuous flow pulsed light treatment (flow rate of 100 ml/sec) on the inactivation of *E. coli* in fruit juices including coconut water, pineapple and orange juice. The maximum reduction of *E. coli* in fruit juices was reported, at the dose of 95.2 J/cm² as it resulted in the damage to cell integrity examined by scanning electron microscopy (SEM). Moreover, pulsed light treatment was found more effective for clear juices such as coconut water as compared to cloudy juices (Preetha et al., 2021).

Currently, another research was conducted to investigate the effect of pulsed light treatment on the microbiological safety and phytochemical composition of pineapple juice in comparison to thermally pasteurized juice. Results showed that pulsed light treatment was found effective in the reduction of the microbial count to acceptable level (5 log reduction) along with preserving the colour and antioxidant profile of pineapple juice. Moreover, thermal pasteurization has also completely inactivated the microorganism but exerted adverse effects on antioxidant activity, colour and ascorbic acid content. Thus, pulsed light can be adopted as an alternative to other thermal techniques of juice preservation (Vollmer et al., 2020).

Moreover, pulsed light treatment alone or in combination with ultrasound treatment showed great potential in ensuring the microbiological safety and sensory characteristics of the product. Ferrario et al. (2016) investigated the effect of continuous pulsed light treatment used alone or combined with ultrasound treatment on the quality and microbial safety of apple juice. The combined treatment improved microbial reduction rate, delayed browning and showed wide consumer acceptance comparison to when applied alone (Ferrario et al., 2016). Previously, a similar study was conducted to evaluate the effect of combined treatment (pulsed light and thermosonication) on the inactivation of *E. coli* and results showed its reduction to 6 log cfu/ml in apple juice (Muñoz et al., 2012). Therefore, pulsed light treatment can be used alone or in combination with other non-thermal techniques and is considered an efficacious alternative to thermal pasteurization techniques.

Cold Plasma

Plasma is defined as the fourth state of matter and it is entirely different from the other three (solid, liquid, gas) states of matter (Bourke et al., 2018). The basic difference among the states of matter is energy due to which the states can be changed. Energy breaks and shapes the structures between molecules and atoms and during this process free electrons and ions are generated.

Plasma is categorized as an ionized gas comprising uncharged molecules, free electrons, and a mixture of oppositely charged ions. This matrix of different molecules interacts with one another and gas molecules and transfer of energies take place. This results in the formation of highly reactive compounds (radicals, hydrogen peroxide, ozone, and UV radiation) which interact with the food surface (Carrillo et al., 2017).

Uses

Cold plasma technology is being used extensively at various stages of food production (Ozen and Singh, 2020). There are various ways to ionize the gas and generate plasma, including the use of heat, electricity, and the application of lasers. Thus, the composition and nature of plasma is distinct and depends on the type of carrier gas (which could be air, nitrogen, argon, or helium), plasma generator (which could be a microwave, plasma jet, or dielectric), and external conditions under which it is generated (pressure, humidity, and temperature) (Bourke et al., 2018). Generally, cold plasma is produced at or around room temperature and is not dependent on heat to destroy the pathogens, so it poses no threat to the quality of food products (Ozen and Singh, 2020). The Cold Plasma technique uses a carrier gas, such as air, oxygen, or nitrogen to which electrical energy is provided via electrodes. The CP generation system comprises a carrier gas, power supply, and electrodes (Misra et al., 2016).

Application

Depending on the food product or stage of application, the cold plasma technique can be direct, indirect, or in-package. Direct cold plasma finds its applications for bulk food products and is administered by a conveyor belt system (85). Indirect cold plasma finds its application through plasma-activated water and is applied in the form of sprays. It can be applied for the preservation of fresh produce or disinfection of various food equipment where liquid chemicals are commonly used (Schnabel et al., 2014; Shen et al., 2016).

In-package cold plasma is used for packaged foods and provides a decontamination effect by generating reactive species for a longer period of time and prevents recontamination. Cold plasma has been found to inactivate microorganisms and

inhibit their growth with minimum impact on the quality characteristics of fruit juices (Ozen and Singh, 2020).

Among others, the most observed mechanism is the interaction of cell membrane components with free radicals, excited molecules, or charged particles. These reactive species are generated by the breakdown of O₃, peroxides, or hydroxide radicals and play a significant role in the inactivation of microorganisms. Oxides of nitrogen, NO and NO₂, have been found to play an important role in limiting microbial growth by disrupting the chemical components like proteins and lipid. A study revealed that argon plasma, when used as a carrier gas, generated OH, N₂, and O radicals. These reactive species significantly limited the growth of *Bacillus subtilis* species. OH radicals produced in water, when Helium-oxygen is used as a carrier gas, had a significant role in the inactivation of *S. aureus* species (Edelblute et al., 2015). Reactive oxygen species, particularly O₃ and NO₂ were found to be effective for bacterial inactivation when used with atmospheric plasma. An ionic compound peroxyionite ion produced by the reaction of plasma-generated radicals has been reported to play an important role in bacterial inactivation (Misra et al., 2014).

Recent studies have shown the effectiveness of UV photons in limiting the growth of microorganisms by CP technology (Guo et al., 2015). These photons disrupt the genetic material of microorganisms and prevent DNA replication. There are various ways by which plasma damages the microbial DNA, such as moderation of nucleo-bases, formation of thymine dimers, and oxidation by reactive species (84). The application of cold plasma is independent of surface irregularities of foods as it can flow around the edges and ensure effective treatment. However, the texture of the product surface can affect the efficacy of cold plasma treatment (Mandal et al., 2018). It is a quick and contact-free pathogen removing technique from the food surfaces. The penetrating capacity of cold plasma and reactive species generated by it is limited. CP has been applied for the surface decontamination of various food products, such as tomatoes (Schnabel et al., 2015; Kim and Min, 2017). The nature of microorganisms affects the efficiency of decontamination with cold plasma technology. Microorganisms inhabiting the surface of foods are easily removed as compared to the ones that reside inside the seeds or form spores (Butscher et al., 2016). Due to its potential to inhibit microbial growth, cold plasma can prolong the shelf life of fruit juices by delaying food spoilage processes. Microbial inactivation by atmospheric cold plasma has been studied for various fruit juices, such as apple juice (Liao et al., 2017; Xiang et al., 2018) orange juice (Xu et al., 2017), white grape juice (Pankaj et al., 2017), and blueberry juice (Hou et al., 2019). The detailed effects of cold plasma application on microbial inactivation in different fruit juices along with processing conditions are shown in Table 2.

The cold plasma technique has been found to control the PPO activity and enzymatic browning in fruits (Surovsky et al., 2014; Han et al., 2019). The impact of cold plasma on the PPO activity in fresh-cut apples was investigated. Results showed that the application of plasma technology was effective in reducing the PPO activity by about 62%. Pectin methylesterase (PME) is an enzyme present in the cell wall that de-esterifies pectin and produces pectic acids (Bufler et al., 2017). Recent studies have addressed the sensory attributes of plasma-treated fruit juices and the effects of cold plasma on the appearance and color of fruit juices. A significant effect of cold plasma treatment on the appearance of fruit juices has been observed depending on the treatment application and juice type (Ozen and Singh, 2020). An increased treatment time of cold plasma results in color degradation of fruit juices (Pankaj et al., 2018). The effect of gas flow on the color profile of pomegranate juice was observed by (Kovačević et al., 2016). Results showed that the color of cloudy pomegranate juice changed significantly and increasing gas flow raised the total anthocyanin content in the juice. Overall, color comparisons of different juices (apple juice, orange juice, white grape juice, and pomegranate juice) showed no significant variation upon treatment with atmospheric cold plasma (Almeida et al., 2015; Kovačević et al., 2016; Pankaj et al., 2017; Liao et al., 2018). The quality of processed fruit juices depends mainly on pH and acidity. Changes in these attributes could result in an undesirable effect on consumer preference. The acidity in fruit juices is affected by the solubility of OH radicals produced during the cold plasma generation process (Pankaj et al., 2018) and the change in pH could be due to the production of nitric acid and related nitrogen oxides. Various studies described that the application of cold plasma affects the pH and acidity of apple, orange, and white grapefruit juices (Xu et al., 2017; Pankaj et al., 2017; Liao et al., 2018).

CONCLUSION

As reported research databases have confirmed that non-thermal techniques have a promising and effective avenue in fruit juice preservation by meeting the increasing demand for nutritious and fresh-like products while ensuring safety and extending shelf life. They have been proven to be effective in microbial inactivation to the acceptable limit without disturbing the nutritional profile, functional ingredients, and sensory attributes of the fruit juices. Therefore, they can be used alone or in combination with other non-thermal techniques to obtain more nutritious, safer products to address food safety and security issue. Traditional thermal techniques were effective in controlling spoilage but often compromises the nutritional quality and sensory attributes of juices due to its impact on heat-sensitive compounds. Non-thermal methods such as high-pressure

processing, pulse electric field, ultraviolet radiation, and cold pressing offer viable alternatives by effectively inactivating spoilage microorganisms without compromising nutritional or sensory characteristics. Moreover, these techniques are relatively cost-effective, efficient, and have potential of achieving significant microbial load reduction, thereby enhancing the overall quality and shelf life of

fruit juices. Embracing non-thermal preservation methods signifies a pre-emptive approach to meeting consumer expectations for safe, nutritious, and high-quality fruit juice products in an increasingly health-conscious market.

Table 2 Application of non-thermal techniques and their potential for microbial load reduction at specific conditions

Sr #	Juice	Technique	Experimental Conditions	Target microorganism	Microbial Reduction	Improved Period of storage	Reference
1	Shiikuwasha (Citrus depressa) juice	HPP	600 MPa, 150 sec, 25 °C >400 MPa, 110 sec	<i>E. coli O157:H7</i> <i>E. coli O157:H7</i> <i>L. monocytogenes</i>	5.15-log 5 log	28 days 28 days	(Lai et al., 2021)
2	Apple Juice	HPP	600 MPa 90 sec	<i>Fungal spp.</i> Mostly <i>Penicillium spp.</i> <i>Aspergillus niger</i> , <i>Candida parapsilosis</i>	5.3 log		(Buerman et al., 2020; Petrus et al., 2020)
3	Açaí juice	HPP	400 Mpa, 180 sec, 5 °C 600 Mpa , 60 sec	<i>E. coli</i> <i>L.monocytogenes</i> <i>Salmonella spp.</i>	5 log - 6 log reduction	42 days	(Gouvea et al., 2020)
4	White Grape juice	HPP	600 MPa, 180 sec	Aerobic bacteria Yeast/Mold Yeast / mold count	2 log CFU/mL <1.0 log CFU/mL -1	20 days	(Chang et al., 2017)
5	Mango Juice	HPP	600 MPa, 300 sec, 25 °C	Total plate count Aerobic mesophiles Salmonella spp. Yeast and mold	5 log 1 log CFU/mL	30 days	(Moreira et al., 2017)
6	Carrot Juice	HPP	550 MPa, 360 sec	TPC Yeast	4.3 log Complete inactivation	20 days	(Zhang et al., 2016)
7	Grapefruit juice	HPP	250 MPa, 180 sec, 60 °C	Total plate count Yeast and Mold	2.5 log	-	(Aadil et al., 2017)
8	Sugar cane juice	HPP	600 MPa, 360 sec, 20 °C	Aerobic plate count Coliforms Yeast and mold	1.1 log 4.6 log <1.0 CFU/mL	28 days	(Huang et al., 2015)
9	Grapefruit juice	PEF	1 kHz 600µs 25 kV cm ⁻¹ 40 °C	Total plate count Yeast and Mold	1.72 log 1.66 log	-	(Aadil et al., 2015)
10	Grape juice	PEF	120 Hz 34 µs - 275 µs 9-27 kVcm ⁻¹ 40°C	<i>Staphylococcus aureus</i> <i>Staphylococcus cerevisiae</i> <i>E.coli</i>	3.36 log 2.27 log	-	(Huang et al., 2014)
11	Strawberry juice	PEF	150µs 18.6 kVcm ⁻¹ 45°C,50°C,55°C	<i>Escherichia coli</i>	5 log	90 days	(Geveke et al., 2015)
12	Tomato juice	PEF	80 kVcm ⁻¹ 50 °C	Total plate count	4.4 log	28 days	(Nguyen and Mittal, 2007)
13	Blueberry juice	PEF	36 kV/cm, 100 µs	Total plate count	50 %	-	(Barba et al., 2017)
14	Orange juice	PEF	30kVcm ⁻¹ 240µs 480µs	Total plate count Yeast and mold	5 log	60 days	(Sampedro et al., 2013)
15	Apple juice	PEF	40 kj per Kg 7.86µs 55°C	<i>Escherichia coli</i>	6 log	-	(Saldana et al., 2011)
16	Watermelon juice	PEF	188Hz 35 kVcm ⁻¹ 1727 µs 40 °C	<i>E. coli</i> <i>L.monocytogenes</i>	3.6 log 3.5 log	91 days	(Bhattacharjee et al., 2019)
17	Sour cherry juice	Irradiation (gamma rays)	Gamma rays 6 kGy , 4°C for 2 months	Bacteria, yeast and mold	Complete reduction in microbial at ≥3 kGy	-	(Arjeh et al., 2015)

18	Pitaya juice	Irradiation (UV-C rays)	UV 57 μ W/cm ²	<i>Zygosaccharomyces bailii</i>	1.8-log		(Ochoa-Velasco and Beltrán, 2013)
19	Apple juice	Irradiation (UV-C rays)	UV-C rays 254 nm 90 s	<i>Bacteria</i> <i>E. coli</i> Spoilage yeast species	0.13-2.4 log 0.20 log	-	(Gabriel, 2012)
20	Apple juice	Irradiation (UV-C rays)	Irradiance at 13.44 W/m ²	<i>A. acidoterrestris</i>	5 log	-	(Tremarin et al., 2017a, 2017b)
21	Apple juice	Irradiation (UV rays)	Irradiance at 14 mJ/cm	<i>E. coli</i>	5 log	-	(Usaga et al., 2015)
22	Apple juice	Irradiation (UV rays)	Irradiance at 75 mJ/cm ²	<i>E. coli</i>	>2 log	-	(Yin et al., 2015)
23	Watermelon juice	Irradiation (UV-C rays)	Irradiance at 2.7 and 37.5 J/mL	TPC Yeast and Mold	1.47 log 0.9 log	-	(M. Feng et al., 2013)
24	Grapefruit juice	Irradiation (Centrifugal UV rays)	Irradiance at 24 mJ/cm ² at 750 rpm	<i>E. coli</i> Spoilage yeast	5.1 log 6.0 log	-	(Geveke and Torres, 2012)
25	Orange juice	Irradiation (UV-C rays)	Irradiance at 73.8 mJ/cm ²	Aerobic Plate Count Yeast and Mold	2.8 log 0.34 log	-	(Pala and Toklucu, 2013)
26	Chokanan Mango Juice	Irradiation (UV-C rays)	Irradiance at 254 nm up to 60 min with intervals	APC Yeast and Mold	1.22 0.77 log	-	(Santhirasegaram et al., 2015)
27	Pummelo fruit juice	Irradiation (UV-C rays)	Irradiance at 254 nm	<i>S. typhimurium</i>	>5 log	-	(Shah et al., 2014)
28	Pineapple juice	Irradiation (UV-C rays)	Irradiance at 10.76 mJ/cm ²	TPC Yeast and Mold	1.91 log 1.4 log	-	(Shamsudin et al., 2014)
29	Pineapple juice	Irradiation (UV-C rays)	Irradiance at 10.10 mJ/cm ²	<i>S. typhimurium</i>	5 log	-	(Mansor et al., 2014)
30	White grape and apple juice	Irradiation (UV-C rays)	Irradiance at 0.38 mW/cm ² and 15 min	<i>A. acidoterrestris</i> spores	5.5 log 2 log	-	(Baysal et al., 2013)
31	Blended Carrot and orange juice	Irradiation (UV-C rays)	Irradiance at 10.6 kJ/m ²	<i>E. coli</i> , Yeasts <i>P. fluorescens</i>	2.6 6.0 log	-	(Carrillo et al., 2017)
32	Blended Lemon and melon juice	Irradiation (UV-C rays)	Irradiance at 2.46 J/mL for 71 s	<i>E. coli</i>	>6 log	-	(Kaya et al., 2015)
33	Pomegranate Juice	Ultrasound	20 kHz/100%/15 min/25 \pm 1 $^{\circ}$ C	<i>E.coli</i>	3.47 log	-	(Alighourchi et al., 2014)
34	Pomegranate Juice	Ultrasound	20 kHz/100%/500 W/30 min	<i>S. cerevisiae</i> <i>E. coli</i>	1.86 log 5 log	-	(Pala et al., 2015)
35	Blueberry juice	Ultrasound	20kHz/93.5 mL/min/100A/25 $^{\circ}$ C \pm 0.5.	<i>S. cerevisiae</i> APC TCC	1.36log 1.36 log cycles	-	(Mohideen et al., 2015)
36	Juice Blend (Strawberry + Apple + Lemon)	Ultrasound	US at 376 W/10 min/35 $^{\circ}$ C	Y&M Total Aerobic Bacteria Y&M TCC	> 2 log ₁₀ 1.3 log ₁₀ (MPN/100 mL) was less than 3 Significant	10 days at 4 $^{\circ}$ C	(X. Feng et al., 2020)
37	Açai Juice	Ultrasound	19 kHz/5 min/700 J·mL ⁻¹ /500W/32 \pm 1.2 $^{\circ}$ C	Mesophilic Bacteria Y & M	-	-	(Oliveira et al., 2018)
38	Barberry Juice	Ultrasound	20 kHz/70%, 100%/15 min/200 W	APC Y & M	-	4C for 42 days	(Farhadi Chitgar et al., 2017)
39	Apple Blueberry Cranberry juice	Ultrasound+ Thermosonication	20 kHz/120 μ m/600 W 60 $^{\circ}$ C	<i>A. ochraceus</i> <i>Rhodotorula</i> sp. <i>S. cerevisiae</i> <i>Penicillium expansum</i>	5 log	-	(Jambrak et al., 2018)
40	Orange Juice	Thermosonication	24 kHz/105 μ m/ 33.31 W ml ⁻¹ /46 $^{\circ}$ C	TPC Y&M	1.6 log 0.9 log	10 days at 5 $^{\circ}$ C.	(Guerrouj et al., 2016)
41	Pineapple Juice	Pulsed Light Treatment	2.4 kV Number of pulses-94 or 187 pulses Dose-757/1479 J·cm ⁻²	Aerobic count Mesophilic Y & M	5-log	-	(Vollmer et al., 2020)
42	Orange Juice Pineapple juice	Pulsed Continuous Treatment System	Flow rate-100 ml/s Dose-95.2 J/cm ²	<i>E.coli</i>	4 log 4.5 log	-	(Preetha et al., 2021)

	Coconut Water					5.33 log		
43	Apple Juice	Pulsed Light Continuous Treatment	Max Fluence-0.73 J/cm ² , 155 mL/min	<i>E.coli</i>	<i>Salmonella</i>	1.8–4.2 log		
		Pulsed Light+ Ultrasound Treatment	Pulse rate-3 pulses/s Pulse width-360 μ	<i>S. cerevisiae</i>	Indigenous flora	3.7–6.3 log	-	(Ferrario and Guerrero, 2016)
44	Apple Juice	Pulse Light	PL Fluenc-4 J/cm ² / 1.20 μs/3 Hz	<i>E.coli</i>		4.9 log		
		Pulsed light+ Thermosonication	5.1 J/cm ² / 1.52 μs/ 3 Hz			6 log	-	(Muñoz et al., 2012)
45	Orange juice	Cold Plasma	HVACP Direct Treatment for 30 s			>5		
		Cold Plasma	HVACP Direct treatment for 120 s	Bacteria		2.9	-	(Xu et al., 2017)
46	Apple juice	Cold Plasma	Treatment: 3 mL juice for 30 s	<i>Escherichia coli</i>	<i>O157:H7</i>	4.3	-	(Liao et al., 2018)
47		Cold Plasma	Treatment: 3 mL juice for 140 s	<i>Zygosaccharomyces rouxii</i>		5	-	(Xiang et al., 2018)
48		Cold Plasma	Treatment: 11 mL juice for 120s	<i>Escherichia coli</i>		4	-	(Dasan and Boyaci, 2018)
49	White grape juice	Cold Plasma	Treatment: Packaged sample for 4 min	<i>Saccharomyces cerevisiae</i>		7.4	-	(Pankaj et al., 2017)
50	Blueberry juice	Cold Plasma	Treated for 6 min	<i>Bacillus sp.</i>		7.2	-	(Hou et al., 2019)

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data may be available upon request.

Acknowledgments: The authors are highly thankful to the Department of Food Science and Technology for the contribution and all authors are agreed to publish this final version of the manuscript.

Conflicts of Interest: The authors declare that they have no conflict of interest.

REFERENCES

- Aadil, R. M., Zeng, X.-A., Jabbar, S., Nazir, A., Mann, A. A., Khan, M. K. I., & Ramzan, A. (2017). Quality evaluation of grapefruit juice by thermal and high pressure processing treatment. *Pakistan Journal of Agricultural Research*, 30(3). <https://doi.org/10.17582/journal.pjar/2017.30.3.249.257>
- Aadil, R. M., Zeng, X. A., Ali, A., Zeng, F., Farooq, M. A., Han, Z., . . . Jabbar, S. (2015). Influence of different pulsed electric field strengths on the quality of the grapefruit juice. *International Journal of Food Science & Technology*, 50(10), 2290-2296. <https://doi.org/10.1111/ijfs.12891>
- Alighourchi, H., Barzegar, M., Sahari, M. A., & Abbasi, S. (2014). The effects of sonication and gamma irradiation on the inactivation of *Escherichia coli* and *Saccharomyces cerevisiae* in pomegranate juice. *Iranian journal of microbiology*, 6(1), 51.
- Anggono, A., Rebezov, M., Mironov, S., Thangavelu, L., Aravindhan, S., Aljeboree, A. M., Al-Janabi, S., Alrazzak, N., Alkaim, A., & Kamal, A. W. (2022). Fruit preservation packaging technology based on air adjustment packaging method. *Food Science and Technology (Brazil)*, 42, e29221. <https://doi.org/10.1590/fst.29221>
- Arjeh, E., Barzegar, M., & Sahari, M. A. (2015). Effects of gamma irradiation on physicochemical properties, antioxidant and microbial activities of sour cherry juice. *Radiation Physics and Chemistry*, 114, 18-24. <https://doi.org/10.1016/j.radphyschem.2015.05.017>
- Arshad, R. N., Abdul-Malek, Z., Roobab, U., Munir, M. A., Naderipour, A., Qureshi, M. I., . . . Technology. (2021). Pulsed electric field: A potential alternative towards a sustainable food processing. 111, 43-54. <https://doi.org/10.1016/j.tifs.2021.02.041>
- Barba, F. J., Koubaa, M., do Prado-Silva, L., Orlien, V., & de Souza Sant'Ana, A. (2017). Mild processing applied to the inactivation of the main foodborne bacterial pathogens: A review. *Trends in Food Science & Technology*, 66, 20-35. <https://doi.org/10.1016/j.tifs.2017.05.011>
- Baysal, A. H., Molva, C., & Unluturk, S. (2013). UV-C light inactivation and modeling kinetics of *Alicyclobacillus acidoterrestris* spores in white grape and apple juices. *International journal of food microbiology*, 166(3), 494-498. <https://doi.org/10.1016/j.ijfoodmicro.2013.08.015>
- Bhattacharjee, C., Saxena, V., & Dutta, S. <https://doi.org/10.1016/j.tifs.2019.09.015> (2019). Novel thermal and non-thermal processing of watermelon juice. *Trends in Food Science & Technology*, 93, 234-243. <https://doi.org/10.1016/j.tifs.2019.09.015>
- Buerman, E. C., Worobo, R. W., & Padilla-Zakour, O. I. (2020). High pressure processing of spoilage fungi as affected by water activity in a diluted apple juice

- concentrate. *Food Control*, 107, 106779. <https://doi.org/10.1016/j.foodcont.2019.106779>
- Carrillo, M. G., Ferrario, M., & Guerrero, S. (2017). Study of the inactivation of some microorganisms in turbid carrot-orange juice blend processed by ultraviolet light assisted by mild heat treatment. *Journal of food engineering*, 212, 213-225. <https://doi.org/10.1016/j.jfoodeng.2017.06.005>
- Chang, Y. H., Wu, S. J., Chen, B. Y., Huang, H. W., & Wang, C. Y. (2017). Effect of high-pressure processing and thermal pasteurization on overall quality parameters of white grape juice. *Journal of the Science of Food and Agriculture*, 97(10), 3166-3172. <https://doi.org/10.1002/jsfa.8160>
- Chughtai, M., Farooq, M., Ashf-aq, S., Khan, S., Khaliq, A., Antipov, S., Rebezov, M., Khayrullin, M., Vorobeva, A., Nelyubina, E., Thiruvengadam, M., & Shariati, M.A. (2021). Role of Pascalization in milk processing and preservation: A potential alternative towards a sustainable food processing. *Photonics*, 8, 498. <https://doi.org/10.3390/photonics8110498>
- Da Silva, R. R. (2017). Bacterial and fungal proteolytic enzymes: production, catalysis and potential applications. *Applied biochemistry and biotechnology*, 183, 1-19. <https://doi.org/10.1007/s12010-017-2427-2>
- Dasan, B. G., & Boyaci, I. H. (2018). Effect of cold atmospheric plasma on inactivation of *Escherichia coli* and physicochemical properties of apple, orange, tomato juices, and sour cherry nectar. *Food and bioprocess technology*, 11(2), 334-343. <https://doi.org/10.1007/s11947-017-2014-0>
- Farhadi Chitgar, M., Aalami, M., Maghsoudlou, Y., & Milani, E. (2017). Comparative study on the effect of heat treatment and sonication on the quality of barberry (*Berberis vulgaris*) juice. *Journal of Food Processing and Preservation*, 41(3), e12956. <https://doi.org/10.1111/jfpp.12956>
- Feng, M., Ghafoor, K., Seo, B., Yang, K., & Park, J. (2013). Effects of ultraviolet-C treatment in Teflon®-coil on microbial populations and physico-chemical characteristics of watermelon juice. *Innovative food science & emerging technologies*, 19, 133-139. <https://doi.org/10.1016/j.ifset.2013.05.005>
- Feng, X., Zhou, Z., Wang, X., Bi, X., Ma, Y., & Xing, Y. (2020). Comparison of high hydrostatic pressure, ultrasound, and heat treatments on the quality of strawberry–apple–lemon juice blend. *Foods*, 9(2), 218. <https://doi.org/10.3390/foods9020218>
- Ferrario, M., & Guerrero, S. (2016). Effect of a continuous flow-through pulsed light system combined with ultrasound on microbial survivability, color and sensory shelf life of apple juice. *Innovative Food Science & Emerging Technologies*, 34, 214-224. <https://doi.org/10.1016/j.ifset.2016.02.002>
- Gabriel, A. A. (2012). Microbial inactivation in cloudy apple juice by multi-frequency Dynashock power ultrasound. *Ultrasonics Sonochemistry*, 19(2), 346-351. <https://doi.org/10.1016/j.ulsonch.2011.06.003>
- Geveke, D. J., Aubuchon, I., Zhang, H. Q., Boyd, G., Sites, J. E., & Bigley, A. B. (2015). Validation of a pulsed electric field process to pasteurize strawberry purée. *Journal of food engineering*, 166, 384-389. <https://doi.org/10.1016/j.jfoodeng.2012.02.026>
- Geveke, D. J., & Torres, D. (2012). Pasteurization of grapefruit juice using a centrifugal ultraviolet light irradiator. *Journal of food engineering*, 111(2), 241-246. <https://doi.org/10.1016/j.jfoodeng.2012.02.026>
- Gomes, R. J., de Fatima Borges, M., de Freitas Rosa, M., Castro-Gómez, R. J. H., & Spinosa, W. A. (2018). Acetic acid bacteria in the food industry: systematics,

- characteristics and applications. *Food technology and biotechnology*, 56(2), 139. <https://doi.org/10.17113/ftb.56.02.18.5593>
- Gouvea, F. S., Padilla-Zakour, O. I., Worobo, R. W., Xavier, B. M., Walter, E. H., & Rosenthal, A. (2020). Effect of high-pressure processing on bacterial inactivation in açai juices with varying pH and soluble solids content. *Innovative Food Science & Emerging Technologies*, 66, 102490. <https://doi.org/10.1016/j.ifset.2020.102490>
- Guerrouj, K., Sánchez-Rubio, M., Taboada-Rodríguez, A., Cava-Roda, R. M., & Marín-Iniesta, F. (2016). Sonication at mild temperatures enhances bioactive compounds and microbiological quality of orange juice. *Food and Bioprocess Technology*, 99, 20-28. <https://doi.org/10.1016/j.fbp.2016.03.007>
- Hou, Y., Wang, R., Gan, Z., Shao, T., Zhang, X., He, M., & Sun, A. (2019). Effect of cold plasma on blueberry juice quality. *Food Chemistry*, 290, 79-86. <https://doi.org/10.1016/j.foodchem.2019.03.123>
- Huang, H.-W., Chang, Y. H., & Wang, C.-Y. (2015). High pressure pasteurization of sugarcane juice: evaluation of microbiological shelf life and quality evolution during refrigerated storage. *Food and Bioprocess Technology*, 8(12), 2483-2494. <https://doi.org/10.1007/s11947-015-1600-2>
- Huang, H.-W., Lung, H.-M., Yang, B. B., & Wang, C.-Y. (2014). Responses of microorganisms to high hydrostatic pressure processing. *Food Control*, 40, 250-259. <https://doi.org/10.1016/j.foodcont.2013.12.007>
- Huang, K., Yu, L., Wang, W., Gai, L., & Wang, J. (2014). Comparing the pulsed electric field resistance of the microorganisms in grape juice: Application of the Weibull model. *Food Control*, 35(1), 241-251. <https://doi.org/10.1016/j.foodcont.2013.12.007>
- Jambrak, A. R., Šimunek, M., Evačić, S., Markov, K., Smoljanić, G., & Frece, J. (2018). Influence of high power ultrasound on selected moulds, yeasts and Alicyclobacillus acidoterrestris in apple, cranberry and blueberry juice and nectar. *Ultrasonics*, 83, 3-17. <https://doi.org/10.1016/j.ultras.2017.02.011>
- Kaya, Z., Yıldız, S., & Ünlütürk, S. (2015). Effect of UV-C irradiation and heat treatment on the shelf life stability of a lemon-melon juice blend: multivariate statistical approach. *Innovative food science & emerging technologies*, 29, 230-239. <https://doi.org/10.1016/j.ifset.2015.03.005>
- Lai, Y.-Y., Chen, J.-H., Liu, Y.-C., Hsiao, Y.-T., & Wang, C.-Y. (2021). Evaluation of microbiological safety, physicochemical and aromatic qualities of shiikuwasha (*Citrus depressa* Hayata) juice after high pressure processing. *Journal of food science and technology*, 1-11. <https://doi.org/10.1007/s13197-021-05103-7>
- Liao, X., Li, J., Muhammad, A. I., Suo, Y., Chen, S., Ye, X., . . . Ding, T. (2018). Application of a dielectric barrier discharge atmospheric cold plasma (Dbd-Acp) for *Escherichia coli* inactivation in apple juice. *Journal of food science*, 83(2), 401-408. <https://doi.org/10.1111/1750-3841.14045>
- Mansor, A., Shamsudin, R., Adzahan, N. M., & Hamidon, M. N. (2014). Efficacy of ultraviolet radiation as non-thermal treatment for the inactivation of *Salmonella typhimurium* TISTR 292 in pineapple fruit juice. *Agriculture and Agricultural Science Procedia*, 2, 173-180. <https://doi.org/10.1016/j.aaspro.2014.11.025>
- Meinert, C., Bertoli, S. L., Rebezov, M., Zhakupbekova, S., Maizhanova, A., Spanova, A., Bakhtybekyzy, S., Nurlanova, S., Shariati, M. A., Hoffmann, T. G., & Krebs de Souza, C. (2023). Food safety and food security through predictive microbiology tools: a short review. *Potravinarstvo Slovak Journal of Food Sciences*, 17, 324-342. <https://doi.org/10.5219/1854>
- Mohideen, F. W., Solval, K. M., Li, J., Zhang, J., Chouljenko, A., Chotiko, A., . . . Sathivel, S. (2015). Effect of continuous ultra-sonication on microbial counts and physico-chemical properties of blueberry (*Vaccinium corymbosum*) juice. *LWT-Food Science and Technology*, 60(1), 563-570. <https://doi.org/10.1016/j.lwt.2014.07.047>
- Moreira, R. M., Martins, M. L., Júnior, B. R. d. C. L., Martins, E. M. F., Ramos, A. M., Cristianini, M., . . . Canuto, J. W. (2017). Development of a juçara and Ubá mango juice mixture with added *Lactobacillus rhamnosus* GG processed by high pressure. *LWT*, 77, 259-268. <https://doi.org/10.1016/j.lwt.2016.11.049>
- Muñoz, A., Caminiti, I. M., Palgan, I., Pataro, G., Noci, F., Morgan, D. J., . . . Lyng, J. G. (2012). Effects on *Escherichia coli* inactivation and quality attributes in apple juice treated by combinations of pulsed light and thermosonication. *Food Research International*, 45(1), 299-305. <https://doi.org/10.1016/j.foodres.2011.08.020>
- Nguyen, P., & Mittal, G. (2007). Inactivation of naturally occurring microorganisms in tomato juice using pulsed electric field (PEF) with and without antimicrobials. *Chemical Engineering and Processing: Process Intensification*, 46(4), 360-365. <https://doi.org/10.1016/j.cep.2006.07.010>
- Ochoa-Velasco, C. E., & Beltrán, J. Á. G. (2013). Short-wave ultraviolet-C light effect on pitaya (*Stenocereus griseus*) juice inoculated with *Zygosaccharomyces bailii*. *Journal of food engineering*, 117(1), 34-41. <https://doi.org/10.1016/j.jfoodeng.2013.01.020>
- Oliveira, A. F. A., Mar, J. M., Santos, S. F., da Silva Júnior, J. L., Kluczkowski, A. M., Bakry, A. M., . . . Campelo, P. H. (2018). Non-thermal combined treatments in the processing of açai (*Euterpe oleracea*) juice. *Food Chemistry*, 265, 57-63. <https://doi.org/10.1016/j.foodchem.2018.05.081>
- Osintseva D., Osintsev E., Rebezov M., Prokhasko L., Seilgazina S., Kurmanbayev S., Nurzhumanova Z., Yessimbekov Zh., Voytsekhovskiy V., Maksimiuk N., & Zalilov R. (2017). Ozonation and microwave treatments as new pest management methods for grain crop cleaning and Disinfection. *Annual Research & Review in Biology*, 20, 5, 1-6. <https://doi.org/10.9734/ARRB/2017/37741>
- Pala, Ç. U., & Toklucu, A. K. (2013). Microbial, physicochemical and sensory properties of UV-C processed orange juice and its microbial stability during refrigerated storage. *LWT-Food Science and Technology*, 50(2), 426-431. <https://doi.org/10.1016/j.lwt.2012.09.001>
- Pala, Ç. U., Zorba, N. N. D., & Özcan, G. (2015). Microbial inactivation and physicochemical properties of ultrasound processed pomegranate juice. *Journal of food protection*, 78(3), 531-539. <https://doi.org/10.4315/0362-028X.JFP-14-290>
- Pankaj, S. K., Wan, Z., Colonna, W., & Keener, K. M. (2017). Effect of high voltage atmospheric cold plasma on white grape juice quality. *Journal of the Science of Food and Agriculture*, 97(12), 4016-4021. <https://doi.org/10.1002/jsfa.8268>
- Petrus, R., Churey, J., & Worobo, R. (2020). High-pressure processing of apple juice: the most effective parameters to inactivate pathogens of reference. *British Food Journal*.
- Pornpukdeewattana, S., Jindaprasert, A., & Massa, S. (2020). Alicyclobacillus spoilage and control-a review. *Critical reviews in food science and nutrition*, 60(1), 108-122. <https://doi.org/10.1080/10408398.2018.1516190>
- Preetha, P., Pandiselvam, R., Varadharaju, N., Kennedy, Z. J., Balakrishnan, M., & Kothakota, A. (2021). Effect of pulsed light treatment on inactivation kinetics of *Escherichia coli* (MTCC 433) in fruit juices. *Food Control*, 121, 107547. <https://doi.org/10.1016/j.foodcont.2020.107547>
- Prokhasko, L., Zinina, O., Rebezov, M., Zalilov, R., Yessimbekov, Zh., Dolmatova, I., Somova, Yu., Peryatinskiy, A., Zotov, S., & Tumbasova, E. (2018). Mathematical model of a hydrodynamic cavitation device used for treatment of food materials. *ARPN Journal of Engineering and Applied Sciences*, 13, 24, 9766-9773.
- Rebezov, M.; Farhan Jahangir Chughtai, M.; Mehmood, T.; Khaliq, A.; Tanweer, S.; Semenova, A.; Khayrullin, M.; Dydykin, A.; Burlankov, S.; Thiruvengadam, M.; Shariati, M.A., & Lorenzo, J.M. (2022). Novel Techniques for Microbiological Safety in Meat and Fish Industries. *Applied Sciences*, 12, 319. <https://doi.org/10.3390/app12010319>
- Sarkar, T., Salauddin, M., Pati, S. Rebezov, M., Khayrullin, M., Piotrovsky, D., Ponomareva, L., Nikitin, I., Shariati, M.A. & Lorenzo, J.M. (2022). Expert Knowledge-Based System for Shelf-Life Analysis of Dairy Cheese Ball (Rasgulla). *Food Analytical Methods*, 15, 1945-1960. <https://doi.org/10.1007/s12161-022-02261-y>
- Saldana, G., Puertolas, E., Monfort, S., Raso, J., & Alvarez, I. (2011). Defining treatment conditions for pulsed electric field pasteurization of apple juice. *International journal of food microbiology*, 151(1), 29-35. <https://doi.org/10.1016/j.ijfoodmicro.2011.07.033>
- Sampedro, F., McAloon, A., Yee, W., Fan, X., Zhang, H., & Geveke, D. (2013). Cost analysis of commercial pasteurization of orange juice by pulsed electric fields. *Innovative Food Science & Emerging Technologies*, 17, 72-78. <https://doi.org/10.1016/j.ifset.2012.10.002>
- Santhirasegaram, V., Razali, Z., George, D. S., & Somasundram, C. (2015). Comparison of UV-C treatment and thermal pasteurization on quality of Chokanan mango (*Mangifera indica* L.) juice. *Food and Bioprocess Technology*, 94, 313-321. <https://doi.org/10.1016/j.fbp.2014.03.011>
- Shah, N. N. A. K., Shamsuddin, R., Rahman, R. A., & Adzahan, N. M. (2014). Effects of physicochemical characteristics of pummelo fruit juice towards UV inactivation of *Salmonella typhimurium*. *Agriculture and Agricultural Science Procedia*, 2, 43-52. <https://doi.org/10.1016/j.aaspro.2014.11.007>
- Shamsudin, R., Adzahan, N. M., Yee, Y. P., & Mansor, A. (2014). Effect of repetitive ultraviolet irradiation on the physico-chemical properties and microbial stability of pineapple juice. *Innovative food science & emerging technologies*, 23, 114-120. <https://doi.org/10.1016/j.ifset.2014.02.005>
- Shrestha, S., Rahman, M. S., & Qin, W. (2021). New insights in pectinase production development and industrial applications. *Applied Microbiology and Biotechnology*, 105, 9069-9087. <https://doi.org/10.1007/s00253-021-11705-0>
- Tremarin, A., Brandão, T. R., & Silva, C. L. (2017a). Application of ultraviolet radiation and ultrasound treatments for *Alicyclobacillus acidoterrestris* spores inactivation in apple juice. *Lwt*, 78, 138-142. <https://doi.org/10.1016/j.lwt.2016.12.039>
- Tremarin, A., Brandão, T. R., & Silva, C. L. (2017b). Inactivation kinetics of *Alicyclobacillus acidoterrestris* in apple juice submitted to ultraviolet radiation. *Food Control*, 73, 18-23. <https://doi.org/10.1016/j.foodcont.2016.07.008>
- Tretyak, L., Rebezov, M., Toshev, A., Zalilov, R., Prokhasko, L., Abuova, A., Loretts, O., Okuskhanova, E., & Zaitseva, T. (2017). The use of ozone-air mixture for reduction of microbial contamination in grain brewing raw material. *Annual Research & Review in Biology*, 14, 6, 1-9. <https://doi.org/10.9734/ARRB/2017/33292>
- Usaga, J., Worobo, R. W., Moraru, C. I., & Padilla-Zakour, O. I. (2015). Time after apple pressing and insoluble solids influence the efficiency of the UV treatment of cloudy apple juice. *LWT-Food Science and Technology*, 62(1), 218-224. <https://doi.org/10.1016/j.lwt.2015.01.014>
- Vollmer, K., Chakraborty, S., Bhalerao, P. P., Carle, R., Frank, J., & Steingass, C. B. (2020). Effect of pulsed light treatment on natural microbiota, enzyme activity, and phytochemical composition of pineapple (*Ananas comosus* [L.] Merr.) juice.

- Food and Bioprocess Technology*, 13, 1095-1109. <https://doi.org/10.1007/s11947-020-02460-7>
- Xiang, Q., Liu, X., Li, J., Liu, S., Zhang, H., & Bai, Y. (2018). Effects of dielectric barrier discharge plasma on the inactivation of *Zygosaccharomyces rouxii* and quality of apple juice. *Food Chemistry*, 254, 201-207. <https://doi.org/10.1016/j.foodchem.2018.02.008>
- Xu, L., Garner, A. L., Tao, B., & Keener, K. M. (2017). Microbial inactivation and quality changes in orange juice treated by high voltage atmospheric cold plasma. *Food and bioprocess technology*, 10(10), 1778-1791. <https://doi.org/10.1007/s11947-017-1947-7>
- Yin, F., Zhu, Y., Koutchma, T., & Gong, J. (2015). Inactivation and potential reactivation of pathogenic *Escherichia coli* O157: H7 in apple juice following ultraviolet light exposure at three monochromatic wavelengths. *Food microbiology*, 46, 329-335. <https://doi.org/10.1016/j.fm.2014.08.015>
- Zhang, Y., Liu, X., Wang, Y., Zhao, F., Sun, Z., & Liao, X. (2016). Quality comparison of carrot juices processed by high-pressure processing and high-temperature short-time processing. *Innovative Food Science & Emerging Technologies*, 33, 135-144. <https://doi.org/10.1016/j.ifset.2015.10.012>
- Zhang, Z. H., Wang, L. H., Zeng, X. A., Han, Z., Brennan, C. S. J. I. J. o. F. S., & Technology. (2019). Non-thermal technologies and its current and future application in the food industry: a review. 54(1), 1-13. <https://doi.org/10.1111/ijfs.13903>
- Zilelidou, E. A., & Nisiotou, A. (2021). Understanding wine through yeast interactions. *Microorganisms*, 9(8), 1620. <https://doi.org/10.3390/microorganisms9081620>