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Review Article

Impact of Thermal and Non-Thermal Pasteurization on the Microbial Inactivation of Fruit Juice: Review

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ABSTRACT

Because of their exceptional qualities and high nutritional content, fruit and vegetable juices are an indispensable component of a healthy diet. The juices must first go through the process of pasteurization, which is the fundamental step in ensuring their quality, safety, and longevity. Although heat pasteurization is the most frequent approach for rendering bacteria inactive, it results in a number of unwanted side effects that contribute to a decline in the juice's overall quality. As a result, a number of non-thermal techniques of pasteurization have been devised, each of which assures the juice's safety while causing very minimal modifications to the juice's qualities. Yet, the high cost of installation and operation presented by these systems is the primary barrier that prevents their widespread use in industrial settings. Methods of non-thermal pasteurization, such as membrane filtration, pulsed electric field, ultraviolet, and sonication treatments, are discussed in this article. Other non-thermal pasteurization techniques are also discussed.

Keywords: Fruit juice; Pasteurization; Membrane filtration; Ultraviolet exposure; Pulsed electric field; Sonication treatment; Microbial inactivation

INTRODUCTION

Fruit juices are the most popular drinks and make up a big part of the food industry's market. This is because they have a unique mix of physical and chemical properties that make them natural and healthy [1]. These low-calorie foods, which are packed with nutrients and bioactive substances like proteins, carbohydrates, polyphenols, enzymes, minerals, fibers, and antioxidants, vitamins, can fit into today's hectic lifestyle [2]. Most acidic fruits are perishable because their high water activity promotes microbial and metabolic activities that ruin them. In addition to sanitary procedures, several treatments are applied during processing and/or storage to prevent the growth of undesirable bacteria. Fruit juices come in a wide range and are a vital source of complex nutrients for good health. Both foodborne pathogens and microorganisms that cause spoilage can grow well in the presence of these nutrients. *Salmonella*, *Cryptosporidium*, *Listeria monocytogenes*, and *Escherichia coli* are all relevant pathogens for procedures intended to regulate the efficacy of disinfection treatments, depending on the type of juice [3]. Thermal pasteurization and the natural acidity of fruit juices are used in treatment methods. The final product's overall quality might be impacted by unfavorable biochemical and nutritional changes brought on by the heat application. To maximize bacterial inactivation and minimize nutrient loss during thermal pasteurization, there have been several attempts to alter

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parameters, including processing time and temperature [4,5]. As a result of the variants' unsuccessful validation, the majority of these methods cannot be applied in the workplace [6].

In order to pasteurize food, a number of non-thermal techniques have been developed, including Ultra Violet (UV) exposure [7-9], high-voltage Pulsed Electric Fields (PEF) [10-12], membrane filtration[13,14], high hydrostatic pressure [15,16], and sonication[17-19]. These technologies have the benefit of preserving food's "fresh-like" qualities while also saving time and energy. The processing of fruit juices, particularly apple juice, has made extensive use of membrane filtration techniques [20]. PEF, which has already been used in an industrial setting, is among the most innovative non-thermal technologies [21]. When treating liquid food, it can inactivate microorganisms [22] and enzymes [23] with a relatively small temperature increase, resulting in a minimal loss of nutrients and minor quality changes. Another non-thermal pasteurization method that is frequently used in food preservation is UV exposure. The DNA of microorganisms can absorb short-wave UV light, which prevents cells from replicating [24].

LITERATURE REVIEW

This article reviews both thermal and non-thermal pasteurization methods for microbial inactivation, including PEF, membrane filtration, UV exposure, and sonication.

Pasteurisation technique in fruit juice preservation

Thermal pasteurization: The most popular method for pasteurizing fruit juice is thermal processing. The most resilient microorganisms of public health concern are reduced by five logs during the pasteurization of juice [25]. This approach depends on the heat that is created outside a meal and then transported into the food *via* conduction and convection processes [26]. By an appropriate time/temperature combination, thermal pasteurization aims to kill pathogens and significantly lower the amount of spoiling microorganisms [27]. Conventional thermal pasteurization may be categorized into High-Temperature/Short-Time (HTST) and Low Temperature/Long-Time (LTLT) procedures. Whereas fruit juices are subjected to HTST pasteurization, which is done at temperatures of about 72°C with holding periods of 15 s and higher, LTLT pasteurization entails heating a meal at around 63°C for no less than 30 min. Both procedures may damage the taste, color, flavor, and nutritional content of meals [28].

Table 1 provides an overview of current research on the impact of heat pasteurization on the microbiological inactivation of fruit juices. Several fruit liquids were subjected to HTST pasteurization at temperatures ranging from 72°C to 108°C, with treatments lasting always one minute or less. Higher temperatures were more effective in preventing bacterial development, but they also caused a greater drop in the amount of phenolic chemicals in the juice. Other elements, such as the product complexity and microorganisms, may also have an impact on the effectiveness of HTST therapy. In less complicated single juices, HTST pasteurization performs much better than on more intricate/viscous juice products. For instance, a 15-second HTST treatment at 72°C led to a 6.0 log reduction in the number of native microorganisms in apple juice [29]; but only a 3.5 log reduction in fruit smoothies. As compared to the product's mixed natural populations of microorganisms, single species of microorganisms were more sensitive to heat treatment. For instance, a 15-second HTST treatment at 72°C resulted in a 6.3 log decrease in Escherichia coli K12 in fruit smoothies [30], but only a 3.5 log reduction in native microorganisms. Technology advancements made it possible to optimize heat processing for greatest effectiveness against microbiological contaminants and the least amount of food quality degradation [31]. Other technologies that aren't thermal, however, provide us with additional options.

Type of juice	Conditions	Microbial inactivation (log_{10})	References
Longan	100°C, 1 min	7.0	[32]
Apple	72°C, 26 s	6.0	[29]
Apple	94°C, 26 s	6.7	[33]
Orange	90°C, 1 min	2.5	[34]
Strawberry	90°C, 30 s	N/A	[35]
	90°C, 60 s	N/A	
Apple/cranberry	72°C, 26 s	N/A	[36]
Tomato	98°C, 40 s	N/A	[37]
	108°C, 40 s	N/A	
	128°C, 40 s	N/A	

Fruit smoothie	72°C, 15 s	3.5	[22]
	72°C, 15 s	*E. coli* 6.3	

Note: N/A, not reported.

Table 1: Effect of thermal pasteurization on microbial inactivation of fruit juice.

Non-thermal pasteurization technologies: For the last 30 years, non-thermal technologies have undergone extensive research [32].

Membrane filtration: The two most common membrane filtration methods for processing fruit juice are Ultra Filtration (UF) and Micro Filtration (MF). They have been used on a commercial scale to clarify fruit liquids. Essentially, the membranes enable tiny molecules like vitamins, salts, carbohydrates, and water to pass through them while retaining big molecules like microorganisms, proteins, lipids, and colloids (UF only). As a result, "cold pasteurized" goods (>5 log decrease or eradication of microorganisms) may be created using this procedure with superior flavors than products that have undergone heat treatment [38, 39].

"Treat and trans" is a term used to describe trans people, depending on the circumstances. The findings showed that while pH, soluble solids and acid content did not change, the smaller pore membrane treatment reduced their variability. Both membranes showed relative color changes, although the bigger pore membrane treatment was easier to see [40].

Techniques for membrane filtration offer numerous benefits over heat processing. They meet the customer's desire for wholesome, natural foods with a long shelf life and no preservatives [39]. Comparing membrane filtering to traditional heat processing, energy savings are also significant. Moreover, it protects the environment by reducing trash production [41]. These benefits have led to the widespread usage of membrane filtering systems in the production of fruit juice. Membrane fouling (rapid decrease of permeate flow) and cleaning are the primary drawbacks of membrane filtration systems, which ultimately result in high expenses for membrane replacement and make the filtration system relatively costly in terms of operating costs and maintenance [42].

Pulsed electric field: PEF pasteurization is a method based on the transmission of millisecond-long pulses of high electric field strength (5-55 kV cm^{1}) to food [31]. It may be used to produce safe, shelf-stable goods like fruit juice that have great nutritional contents and "fresh-like" qualities. It has been shown that PEF, with substantially less phenolic degradation, may achieve an equal level of microbial inactivation effectiveness as heat pasteurization. Table 2 provides examples of how PEF pasteurization affects the microbial inactivation of fruit juice.

PEF is a method of continuous processing used to inactivate vegetative organisms like *E. coli* and yeast. For the inactivation of bacterial spores, it is ineffective enough, albeit [31]. Although studies on outbreaks have linked fruit juices to the presence of harmful microorganisms such as *E. coli* O157: H7 [43], PEF could be considered an appropriate treatment strategy for fruit juice preservation. The mechanism of membrane structural or functional damage in microorganism inactivation by high-voltage PEF is similar [31]. When PEF is applied, the buildup of molecules with opposing charges surrounding the membrane may raise the transmembrane potential of cells. The cell membrane becomes thinner when the transmembrane potential is surpassed, leading to reversible or irreversible electroporation [44].

Electric field intensity, treatment duration, temperature, and product composition are just a few of the variables that might determine how effective PEF therapy is at inactivating microorganisms.

Electric field strength and microbial inactivation effectiveness were shown to be significantly correlated [45-47]. With increasing temperature, *Escherichia coli* inactivation in apple juice rose from 2 to 3.3 log. The range of the electric field from 16 kV to 20 kV at 35°C [23]. Higher electric field application, nevertheless, may potentially have negative impacts on food quality [48].

Microbial inactivation is influenced by treatment duration as well. As the number of pulses delivered and the pulse width determine the treatment duration, increasing the number of pulses lengthens the treatment period and enhances microbial inactivation. Also, it was hypothesized that the first 10-20 pulses were when the therapy was most effective [47].

Inactivation of microorganisms and phenolic degradation are both significantly influenced by treatment temperature. PEF application at a cool temperature has been recommended as a way to increase the preservation method's potency. When the inlet temperature increases from 10°C to 50°C, microorganism inactivation rates will rise [45]. The phenolics in apple juice, however, may be thermally degraded at higher temperatures. PEF works better on juices with straightforward compositions than on more intricate multi-juice products. For instance, adding more and more carrot juice to orange juice decreased the PEF's ability to kill *E. coli*, which was likely due to the multicomponent product's more complex matrix [49]. Because of their different cell structures, it was considered that Gram-positive bacteria were usually more resistant to PEF than Gram-negative bacteria [50]. For instance, a tropical fruit smoothie with PEF treatment at 34 kV/cm for 150 s resulted in a 5.4-log reduction of *E. coli* [30]. However, despite orange juice being a less viscous and complex food system, *Staphylococcus aureus* still needed to be treated with PEF under harsher circumstances (40 kV cm^{1} for 150 s) to be reduced by 5.5 logs [51].

Type of juice	Conditions	Microbial inactivation (log_{10})	References
Longan	32 kV cm^{-1},90s	2	[32]
Orange	35 kV cm^{-1}, 1000 µs	25	[34]
Strawberry	35 kV cm^{-1}, 1700 µs	N/A	[35]
Apple	40 kV cm^{-1}, 100 µs	5.4	[29]
Apple	35 kV cm^{-1}, 4800 µs	*L. brevis* 6.3	[52]
Apple	35 kV cm^{-1},4800 µs	*S. cerevisiae* 4.2	[52]
Water melon	35 kV cm^{-1},50 µs	N/A	[53]
Fruit smoothie	34 kV cm^{-1}, 150 µs	*E.coli* 5.4	[54]
Orange juice	40 kV cm^{-1}, 150 µs	*S. aureus* 5.5	[22]

Note: N/A, not reported.

Table 2: Examples of fruit juice microbial elimination using PEF pasteurization.

Ultraviolet exposure: Broadly acting as an antimicrobial, UV-C light effectively renders viruses, vegetative bacteria, bacterial spores, conidia, yeasts, and parasites inactive. Many studies have shown the capability of UV-C light to destroy bacteria, viruses, and molds. Some of these studies are included in Table 3.

UV-C radiation's effects on microorganisms, however, varies depending on the species, medium, strain, density, and even the size of the organisms. Additionally, UV-C radiation's ability to prevent bacteria from replicating is due to the dimerization of their thymine bases in DNA strands [55], which is only possible when UV-C radiation can pass through liquid food. Fruit juices absorb 90% of UV-C light within a millimeter of the surface [56]. Researchers have also noted that different UV-C light source-to-product distances, power levels, process times, and product thickness were used to achieve different levels of pathogen inactivation, which had a variety of effects on the juice quality. Highly reactive hydroxyl radicals are produced as a result of UV-C light acting as an oxidizing agent [57]. Temperature has a positive impact on this radical production and the cellular components' subsequent response [58]. The four constituent bases of DNA (Deoxyribonucleic Acid) are adenine, guanine, pyrimidines, and purines (thymine and cytosine). A double-stranded helix connects them all. The pyrimidine bases' ability to absorb UV-C radiation allows for a special photochemical reaction that results in the dimerization of nearby pyrimidines (formation of a chemical bond between the pyrimidines). Thymines are the most common nucleotide to dimerize, but cytosine dimers and thymine-cytosine heterodimers can also form. When the cell goes through mitosis, this structural error in the DNA prevents it from replicating [59]. The capsid proteins can be impacted by UV-C light at higher doses (>1000 mJ/cm2). It is believed that nucleic acids and the size/type of the virion work together to affect how sensitive or resistant viruses are to UV-C [60]. The unique fruit juice's absorption coefficient and travel length determine UV-C fluency. Two key variables might affect these parameters: (1) the properties of the liquid food, such as turbidity, particle size, viscosity, total soluble solids, suspended particles, and-in certain cases-pH.

These characteristics are crucial in determining how much UV-C light will be absorbed.
Liquid foods differ from water in a variety of optical, physical, and chemical characteristics [61]; in contrast, factor (2) pertains to the UV-C reactor was used to make the juice sensitive to light, which will ultimately affect UV-C light transmittance, momentum transfer, dose delivery, and-therefore-microbial inactivation [62]. In turn, these elements will affect how much photo-oxidation occurs in the treated juice. In order to produce effective UV-C pasteurization, it is important to know how UV-C affects the relationship between the absorption coefficient of liquid food, particle interference, and soluble and suspended solids.

Guerrero-Beltrén, et al. [63], and Koutchma, et al. [64], where it was discovered that the absorption coefficient and the efficiency of UV-C inactivation are strongly influenced by the product composition, solid contents, color, and overall chemistry of the food product. Different fruit juices with various levels of turbidity, total soluble solids, pH, and viscosity make a big difference in how to successfully treat them with UV-C light. In addition to reducing the UV-C dose through light scattering, suspended solids may also act as a site for bacterial aggregation on particle surfaces [64]. Therefore, it is important to consider the variations and combinations of the juice's physical characteristics, such as turbidity and particle size. Juice composition has a significant impact on its absorption coefficient. Shah, et al. [65], found in her study that juice's absorption coefficient is related to its turbidity and total soluble solids, which also have an impact on the juice's particle size distribution. Unless they have high porosity, the soluble and suspended solids in the juice are small enough to absorb a lot of

light. Porosity, however, may protect microorganisms, allowing them to endure or even be partially harmed by UV-C processing. Although the amount of suspended solids in juice (or juice matter and pulp) determines its turbidity, this factor also has a significant impact on the juice's viscosity characteristics. The juice's increased flowability or viscosity will subsequently enhance its rate of flow within the UV-C reactor. Increased flow rates led to more effective mixing and irradiation of the juice. Juice turbidity is negatively correlated with UV-C inactivation efficiency, hence lowering it will increase inactivation rate.

Juices	Microflora	UV-C Dosage	Log Reduction	References
Mango nectar	Aerobic plate count	45 J cm^{-2}	2.7	[63]
Pineapple juice	Aerobic plate count	10.76 mJ cm^{-2}	1.9	[66]
	Yeast and mold	10.76 mJ cm^{-2}	1.4	
	S. Typhinrurium	0.000154 L s^{-1}	3	[67]
	Aerobic plate count	1607 J L^{-1}	<1-0	[33]
	Yeast and mold	1607 J L^{-1}	<1-0	
Pummela (*Citrus grandis L.* Osbeck) Juice	*S. Typhinrurium*	15.45-27.63 mJ cm^{-2}	5.23-9.10	[65]
Starfruit juice	Aerobic plate count	NA	Total inactivation	[68]
Lemon -melon juice mix	*E. coli* K12	0.44-2.86 mJ cm^{-2}	0.06-6 log	[69]
Apple cider	*E. coli* 0157:H7	4.45, 6.67, 13-34 mJ cm^{-2}	2.85-4.76	[70]
	Aerobic plate count	14 mJ cm^{-2}	1.8	[71]
	Yeast and mold	14 mJ cm^{-2}	1.4	
	E. coli 0157:H7	8.77-35.11 mJ cm^{-2}	>5.0	[72]
	E. coli K12	19.4 mJ cm^{-2}	<2.0	[73]
Apple juice	*L.innocua*	2.7 J cm-2	4.8-5.8	[36]
	E.coli	7.7 KJ L^{-1}	6	[74]
	S. cerevisiae	9.6 KJ L^{-1}	4	
	L.plantarium	3.9 KJ L^{-1}	>5.0 (total inactivation)	
	A.acidoterrestries	9.6 KJ L^{-1}	4	
	E.coli K12	24.9 mJ cm^{-2}	>5.0	[73]
Apple and cranberry juice	*P.fermentans*	5.3 J cm^{-2}	<2.0	[75]
	E.coli	5.3 J cm^{-2}	6	
Grape juice	*S.cerevisisae*	138 mJ cm^{-2}, 9 min	5	[76]
	Yeasts	280 mJ cm^{-2},24 min	3	
	Lactic acid bacteria	280 mJ cm^{-2},24 min	04-Mar	
Grape juice (White)	*E.coli* K12	0.90 mL s^{-1}	5.2	[77]

	A.acidoterrestris	0.38-1.31 mW cm^{-2}	5.8	[78]
	B.bruxellensis	1377.0 J L^{-1}	>5.0	[79]
	S.cerevisiae	3672.0 J L^{-1}	>5.0	
Grape fruit juice	*E.coli*	19.0 mJ cm^{-2}	5.1	[80]
	S.cerevisiae	14.0 mJ cm^{-2}	6	
Grape juice (Red)	*B.bruxellensis*	3672.0 J L^{-1}	2	[79]
	S.cerevisiae	3672.0 J L^{-1}	>5.0	
	L.plantarum	3672.0 J L^{-1}	>5.0	
Pomegranate juice	*E.coli*	62.4 J mL^{-1}	6.2	[81]
	Aerobic Plate count	62.4 J mL^{-1}	1.8	
	Yeast and Mold	62.4 J mL^{-1}	1.5	
Watermelon juice	Aerobic palte count	2.7-37.5 J mL^{-1}	1.5	[82]
Passion fruit	Aerobic plate count	NA	0.53	[83]
	Yeast and mold	NA	Total inactivation	

Table 3: Effect of UV-C light to destroy microorganisms in fruit juice.

But, according to Müller, et al. [74], they found blood orange juice with the maximum turbidity (9986 NTU), viscosity (2.74 mPa.s), and linear correlation to an absorption coefficient of 194.3 cm-1 had a higher rate of *L.plantarum* inactivation than naturally murky apple juice with an absorption value of 48.4 cm-1. In a separate investigation, Koutchma, et al [84] found that using a coiled UV-C module, the absorption coefficient of juices seems to have a substantial effect on the inactivation of *E. coli* K12. Nevertheless, it was observed that the inactivation had a decrease of less than 1 log10 with only one run through the UV-C reactor at values of the absorption coefficient greater than 48 cm-1. If the passes are increased, the log decrease may be raised, exposing the juice to more UV-C light energy and killing the microorganisms. This observation was supported by *E. coli* K12 inactivation in apple cider (turbidity=1383 NTU, α=57 cm-1,), after six reactor runs at a flow rate of 75 L/min, there has been a 1 log10 decrease. UV-C lethality against microorganisms may be enhanced depending on the pass duration and the quantity of UV-C absorbed by the fruit juice.

Combination of PEF and UV: When used as pasteurization techniques, PEF and UV both have drawbacks. Bacterial spores cannot be inactivated using PEF technology, and fruit juices' reduced medium transparency makes UV radiation less effective. On the other hand, employing PEF in conjunction with UV exposure may have synergistic benefits since the microbial inactivation processes of PEF and UV radiation are distinct [29,31,48]. It was found that PEF, followed by UV exposure, had the highest effectiveness in maintaining the quality of blended juice while also reducing microorganisms. But in a different study, Gachovska, et al. [48], no differences in microbial inactivation (5.3 log) between various orders of combined treatment were found.

Table 4 provides a summary of these findings. Overall, phenolic degradation is less affected by hurdle technology than microbial inactivation. According to some reports, PEF followed by UV exposure is preferable to PEF followed by PEF [29,85].

Type juice	Microbial inactivation (log10)					References
	Treatment[a]	PEF	UV	PEF+UV	UV+PEF	
Apple	1	5.4	2.2	6.2	7.1	[29]
Apple	2	58	2.2	N/A	8.3	[54]

Apple	3	4.87	3.46	5.35	5.3	[48]
Apple/cranberry	4	4.5	1.6	N/A	6	[75]
Apple/cranberry	5	N/A	N/A	N/A	N/A	[85]

Note: N/A, not reported. [a]Treatment 1-PEF: 40 Kv cm-1 , 100µs; UV: 254 nm, 30 min, 30 W. Treatment 2-PEF: 36 kV cm-1 , 100 µs; W: 254 nm, 30 W, 30 min. Treatment 3-PEF: 60 Kv min-1 flow rate, 40 µs; UV: 253.7 nm, 2.9 s, 25 W. Treatment 4-PEF: 34 kV cm-1 , 93 µs; UV: 254 nm, 30 s, 35 W. Treatment 5-PEE: 34 kV cm-1 , 93 µs; UV: 254 nm, 30s, 35 W.

Table 4: Effect of PEF and UV pasteurization combined on fruit juice's microbial inactivation.

Sonication Treatment (US): US is one of the non-thermal pasteurization methods used in the processing of liquid foods, particularly juices, purees, and smoothies. In its simplest form, ultrasound is sound pressure waves over 20 kHz [86]. Ultrasonic devices generally run at 20 kHz-10 MHz. Powerful ultrasound, which runs between 20 and 100 kHz, may generate cavitation to kill germs [87]. Yet, the ultrasonic procedure kills germs through cavitation caused by pressure changes from ultrasonic vibrations.

In article of Kernou, et al. [19], the impact of ultrasound on microorganisms is very well described. Numerous studies have demonstrated that ultrasound can render pathogenic and spoilage microorganisms in fruit juice inactive (Table 5).

Sample	Experimental parameters	Effect of ultrasound	References
Inactivation of *Escherichia coli* and *Saccharomyces cerevisiae* in pomegranate juice	20 kHz, amplitude levels of 50, 75 and 100%; 0, 3, 6, 9, 12 and 15 min , 25 ±1°C	15 minutes at 100% amplitude level lowered levels by 3.47 log CFU/mL and 1.86 log CFU/mL, respectively.	[88]
Fusarium oxysporum in orange juice	20kHz, 130 W, amplitude 40-100%, pulse (2 and 10 s), 2-10 min.	Citrus extract and benzoate controlled the growth of *F. oxysporum* in orange juice and to achieve a decrease of 5 log CFU/mL for at least 14 days.	[89]
Saccharomyces cerevisiae, Pichia membranificans, Wickerhamomyces anomalus, Aygosaccharomyces bailii, ygosaccharomyces rouxii, Candida norvegica in strawberry, orange, apple, pineapple and red-fruits juice.	20 kHz , 130 W amplitude 20-60%, pulse (2 and 6 s), 2-10 min.	Reductions of spoilage organisms	[90, 91]
Escherichia coli in cactus pear juice	20 kHz, 1500W (60%, 70%, 80%, and 90% amplitude), 1, 3 and 5min	In both fruit juices, total inactivation was shown after 5 minutes of ultrasonic treatment at the majority of amplitude values, as measured over a 5-day period.	[92]
Inactivation of *Alicyclobacillus acidoterrestris spores* in orange juice	24 kHz, 460 W cm^{-2}, 33 W and 105 W cm-2, 162W.	Thermosonication requied at least 8°C lower temperature than thermal treatments to achieve the same spore inactivation. (D75°C-value of 49min for 20.2W/mL vs. 217 min for 0.33W/mL). (D85°C -value decreased from 69 to 29min)	[93]
Inactivation of *Alicyclobacillus acidoterrestris spores* and *Saccharomyces cerevisiae* in natural squeezed apple juices	20 kHa, 600 W and 95.2 µm wave amplitude; 10 or 30 min at 20, 30, or 44 1°C and pulsed light (PL) (Xenon 1 and 3 pulpses/s; 0.1 m distances ; 2.4-71.6J cm^{-2}; initial temperature 20, 30, 40 1°C	For *S. cerevisiae*, there were 3.0 log cycles of spore reduction in commercial apple juice and 2 log cycles in natural juice. Reduction cycles of 6.4 and 5.8 log were obtained.	[94, 95]

Escherichia coli ATCC 35218, *Salmonella enteridis* MA44 and *Saccharomyces cerevisiae* KE 162 and indigenous flora in commercial (CAJ) and freshly pressed (NAJ) apple juice	20 kHz, 600 W and 95.2 µm wave amplitude; pulsed light 0.73 J cm^{-2}, 155 mL/min	3.7-6.3 log reductions of inoculates microorganisms. Browning development during storage was prevented.	[95]
The inactivation of *Listeria monocytogenes* and *Escherichia coli* suspended in apple and orange juices	35°C, 110 µm, 200 kPa	Increase of 116 W increased the inactivation rate approximately 10-folsin both juices	[96]
Escherichia coli 0157: H7 and *Salmonella enteridis* in mango juice	25 kHz, 200 W, 50 and 60°C for 10 and 7 min respectively	Inactivation rate was different for both pathogens	[97]
Escherichia coli in apple cider	20 kHz, 100 kPa, 59°C, 4 min	5- log reduction was achieved	[98]
Escherichia coli and *Saccharomyces cerevisiae* in pomegranate juice	20 kHz amplitude (50, 75 and 100%) and times : 0, 6, 12, 18, 24 and 30 min	More than a 5 log inactivation of *E.coli* and 1.36 log inactivation of *S.cerevisiae*	[99]
Candida parapsilosis and *Rhodotorula glutinis* in cloudy apple juice	24 kHz, 400 W, amplitude 100%, 35°C, 360 s/100mL.	Shelf life of sonication juices around 21 days with flavour maintained	[100]

Table 5: The impact of ultrasound on sterilization and its parameters.

DISCUSSION

In terms of total soluble solids, pH, and titratable acidity, the survival and development of *Escherichia coli* in cactus pear juice were assessed over a period of five days [92]. After 5 minutes of ultrasonic treatment at 20 kHz, 1500 W, the majority of amplitude levels (60%, 70%, 80%, and 90%) showed complete inactivation. In cloudy apple juice, the microbiological shelf life of the yeasts, *Candida parapsilosis* and *Rhodotorula glutinis* was also investigated [100]. Acoustic waves reduced aerobic mesophilic counts and psychrophilic bacteria in samples by around 3 and 5 log CFU/mL, respectively. Ultrasonic baths may sometimes have little to no impact on the inactivation of bacteria. The survival rate decrease of *E. coli* contained in orange juice on average (1.3 log for 60 min of sonication) is not significantly affected by ultrasonic treatment (42 kHz) [17].

CONCLUSION

Fruit juice has traditionally been preserved by a process known as thermal pasteurization, which has been shown to be highly effective. However, the heat that is applied can result in unwelcome phenolic degradation in addition to other chemical changes in the constituents of the juice. There is hope for the long-term storage of fruit juice in non-thermal methods such as membrane filtration, photoelectric and ultraviolet (UV) irradiation, and sonication.

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