

Pulsed Electric Field Technology in Food Processing Industry-A Review

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Abstract: Pulsed electric field (PEF) processing is a non-thermal method of food preservation. The basic principle of the PEF technology is the application of short pulses of high electric fields with duration of micro seconds micro- to milliseconds and intensity in the order of 10- 80 kV/cm. In this paper application of PEF in different food processing industries and the effect of PEF on microorganisms, enzymes, proteins, fats and emulsions, pigments are reviewed.

Keywords: Pulsed electric field, Electroporation, Electro permeabilization, Compression chamber.

1. Introduction

Thermal processing is a major technology that has been commonly used in the food industry to increase shelf life and maintain food safety with low processing costs. Compared with thermal pasteurization, non-thermal processing offers an advantage of low process temperatures which results in a better retention of flavors and nutrients (Vega-Mercado et al., 1996). In recent years, several technologies have been investigated that have the capability of inactivating microorganisms at lower temperatures than typically used in conventional heat treatments. The increasing consumer interest for high nutritious fresh-like food products, together with the search for environmentally friendly processing technologies, has aided in the development of emerging non-thermal technologies such as pulsed electric fields. Among all emerging nonthermal technologies, high intensity pulsed electric fields (PEF) is one of the most appealing technologies due to its short treatment times and reduced heating effects with respect to other technologies. PEF is commonly understood as a non-thermal food preservation technology that involves the discharge of high voltage electric pulses (up to 70 kV/cm) into the food product, which is placed between two electrodes for a few microseconds (Angersbach et al., 2000). High intensity pulsed electric field (PEF) processing involves the application of pulses of high voltage (typically

20 - 80 kV/cm) to foods placed between 2 electrodes. PEF treatment is conducted at ambient, sub-ambient, or slightly above ambient temperature for less than 1 s, and energy loss due to heating of foods is minimized. For food quality attributes, PEF technology is considered superior to traditional heat treatment of foods because it avoids or greatly reduces the detrimental changes of the sensory and physical properties of foods.

2. Applications of PEF

2.1 Inactivation of Microbes:

2.1.1 How does PEF inactivate microorganisms?

PEF treatment has lethal effects on various vegetative bacteria, mold, and yeast. Efficacy of spore inactivation by PEF in combination with heat or other hurdles is a subject of current research. A series of short, high-voltage pulses breaks the cell membranes of vegetative microorganisms in liquid media by expanding existing pores (electroporation) or creating new ones. Pore formation is reversible or irreversible depending on factors such as the electric field intensity, the pulse duration, and number of pulses Fig 1. The membranes of PEF-treated cells become permeable to small molecules; permeation causes swelling and eventual rupture of the cell membrane.

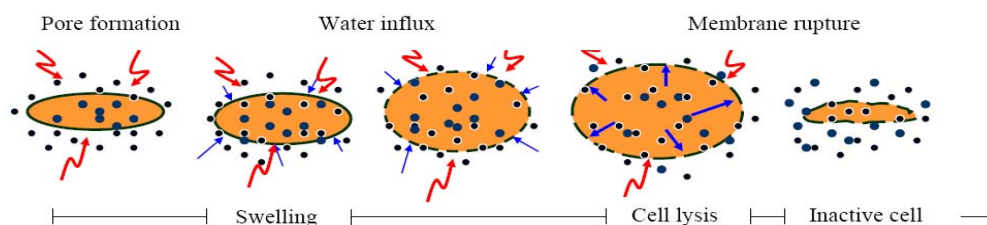


Figure 1: Stages of electroporation in a cell membrane through osmosis. The red arrows show the field intensity and blue dots are water molecules.

Table 1: Inactivation of microorganisms and enzymes by pulsed electric fields (PEF)

Source	Microorganisms	Suspension media	Log reduction (max)	Treatment Vessel ^a	Process conditions ^b
Fernandez-Molina and others (1999)	<i>Listeria innocua</i>	Raw skim milk (0.2% milkfat)	2.6	coaxial, 29 ml, d = 0.63,	15 to 28°C, 0.5 l/min 100 pulses, 50 kV/cm, 0.5 µF, 2 µsec, 3.5 Hz Exponential decay
Reina and others (1998)	<i>Listeria monocytogenes</i> (scott A)	Pasteurized whole milk (3.5% milkfat) 2% milk (2% milkfat), skim milk (0.2%)	3.0-4.0	C, cofield flow, 20 ml,	10 to 50°C, 0.07l/s, 30 kV/cm, 1.5 µsec, 1,700 Hz, bipolar pulses, t = 600 µsec
Dunn and Pearlman (1987)	<i>Lactobacillus brevis</i>	Yogurt	2	B, parallel plates	50°C, 1.8 V/µm
Vega-Mercado and others (1996a)	<i>B. subtilis</i> spores ATCC 9372	Pea soup	5.3	C., coaxial, 0.51 / min	<5.5°C, 3.3 V/µm, 2 µsec, 0.5 µF, 4.3 Hz, 30 pulses, exponential decay

2.2 Juice Processing

Juice extraction from Chardonnay white grape using pulsed electric field with two pressure conditions was studied. A PEF treatment of 400 V/cm was applied. The PEF pretreatment increased the juice yield by 67 - 75% compared to the control sample without any treatment (Grimi, 2009).

2.3 Laboratory device for the combined pressing and PEF treatment

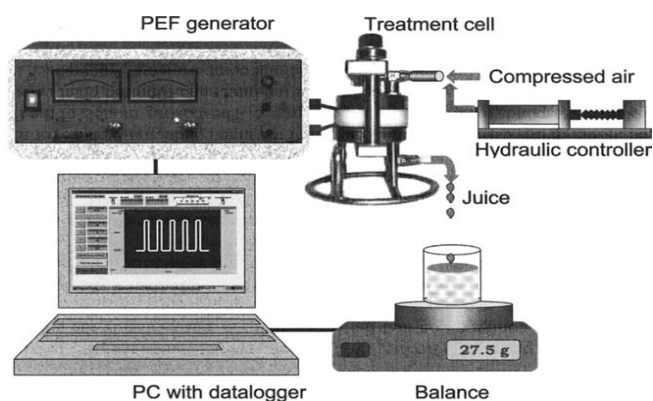


Figure 2: Compression chamber.

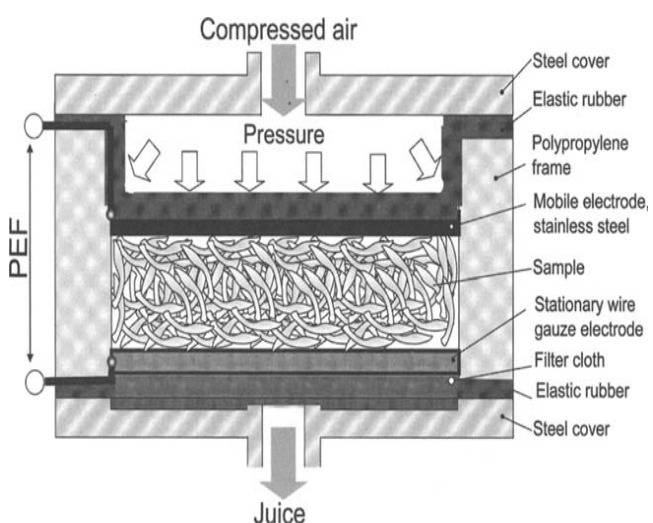


Figure 3: Conductivity of selected liquids

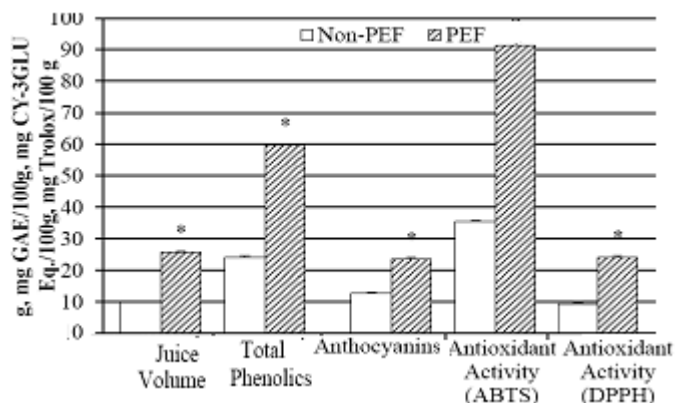
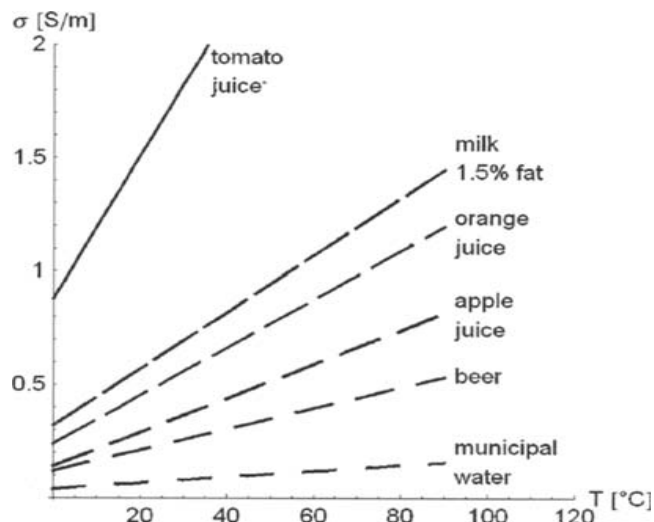
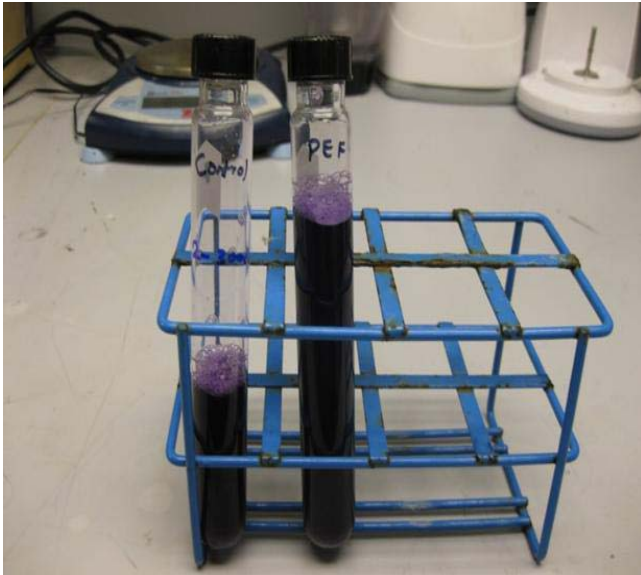
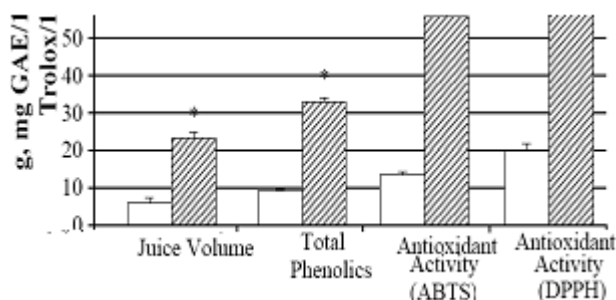


Figure 4: juice volume of PEF treated



The juice volume, total phenolics, betacyanins, betaxanthins concentrations and antioxidant activity were increased ($p < 0.01$) for the juice from PEF treated compared to non-PEF treated beetroot. Whole beetroots were treated with a 1.5 kV/cm electric field, 0.66 μF capacitance and 20 pulses (Valli Kannan, 2011).



2.4 Pef Treatment of Microalgae, Seaweed, and Other Aquatic Species:

Microalgae are a promising source of lipids and biopolymers. In most cases algal lipids are stored intracellular. During the extraction of intracellular products from cells the cell wall and the cell membrane are natural barriers, preserving the cell content. Pulsed Electric Field (PEF) treatment results in the electroporation (EP) or the electro permeabilization of the cell membrane. The

formation of pores across the membrane often leads to an enhanced extraction process since solvents can penetrate the biomass matrix more efficiently. In this study the influence of PEF treatment on the extraction of lipids from the microalgae *Auxano chlorella protothecoides*. was investigated. Microalgae suspensions with a cell density of 50-100 g/l (dry mass) and a lipid content of the algae of 15-20% (by weight) were treated in a flow cell connected to a transmission line pulse generator. Pulses of 1 μs were applied at a constant specific energy input. After PEF-treatment the microalgae were removed immediately from the suspension by centrifugation. The algae-pellet was dried before a solid liquid extraction was performed using ethanol as organic solvent. In order to investigate the spontaneous release of intracellular compounds the supernatant was analyzed using High-Performance Liquid Chromatography (HPLC). Compared to the control samples the Dissolved Organic Carbon Content (DOC) of the supernatant was up to 4 times higher after PEF-treatment. However the HPLC-analysis revealed that hardly any high molecular weight compounds and no hydrophobic substances, e.g. lipids, did leak out of the cells. The increase in DOC primarily was due to low molecular weight compounds, presumably monosaccharides and amino acids. The solid-liquid extraction experiments showed that the lipid-recovery from PEF treated microalgae was considerably higher compared to untreated cells. Although the EP did not lead to a spontaneous release of intracellular lipids into the surrounding liquid, it resulted in an improved lipid extraction from dehydrated microalgae.

a) Aid in air drying:

PEF pre-treated samples showed a reduction of approximately 25 % of drying time compared with control samples. The total specific energy consumption was 3.0kJ/kg and the temperature increase due to PEF treatment was less than 1°C.

b) Effect of Pef on Osmotic Dehydration:

Rastogi et al. (1999) investigated the effect of PEF on the osmotic dehydration of carrot. Carrot discs (2 cm of diameter, 1 cm of thickness) were pre-treated by PEF at different level with exponential pulses, 5 pulses and a total specific energy input in the range of 0,04 to 2,25 kJ/kg. The electric field strength was in the range between 0, 22 to 16 kV/cm and pulse duration between 378 up and 405 μs . Both PEF-treated and untreated samples were osmotically dehydrated (immersion in 50° B sucrose solution at 40 °C for 5 h). PEF pre-treated samples showed decreased moisture content as well as an increased solid content during osmotic dehydration.

c) Plant oil extraction:

Yield and quality of oils from plant origin has been studied by Guderjan et al. (2005) and a modified processing scheme for production of maize germ oil with an increased amount of phytosterols and high oil yield was developed. Wet milled com, steeped for 48 h at 30, 40, and 50°C in water, was treated at field strength of 3.0kV/cm, 120 pulses. Subsequently, oil was separated by hexane extraction, pressing, and supercritical CO₂ extraction. At an electrical field strength of 3.0kV/cm and a steeping water temperature of 50°C the oil yield could be increased by 27.8% for hexane

extraction, 25.2% for pressing, and by 14.9% for supercritical CO₂ extraction. Different fractions of maize germ hulls have been analyzed regarding their phytosterol content and it was shown that fine hull fractions can be used to improve the physiological value of maize germ oil. Oil recovery from olives was improved by 7.4% after a PEF treatment at 1.3 kV/cm in comparison to the control sample.

d) Meat and fish treatment:

The electro-permeabilization of cell membranes, leading to a drastic increase in mass transfer rates, can be utilized to enhance drying rates of cellular tissue. An increase in mass transfer rates, resulting in faster water transport to the product surface and therefore reduction of drying time after a pretreatment will lead to drastic saving of energy and better utilization of production capacities during convective air drying. Taking into account the low energy input required for a PEF treatment of plant or animal tissue (2-20 kJ/kg), it is evident that there is a potential to reduce the total energy input for product drying.

e) Processing of eggs

Qin *et al.* (1996) reported that liquid whole egg with 0.15% citric acid processed at 35 kV/cm for 20 us and at a maximum temperature of 45°C was preferred over a commercial brand in an acceptance test. Also, scrambled eggs prepared with PEF-treated were not distinguished from a control in a triangle test and did not detect significant changes in the viscosity, °Brix, and color parameters between untreated liquid whole egg controls and samples treated by PEF (25 kV/cm, 250 us) plus a following heat treatment at 55°C for 3.5 min. These treatment conditions were chosen to obtain a product with a long shelf life in refrigeration temperatures (more than 60 days) since PEF alone resulted insufficient.

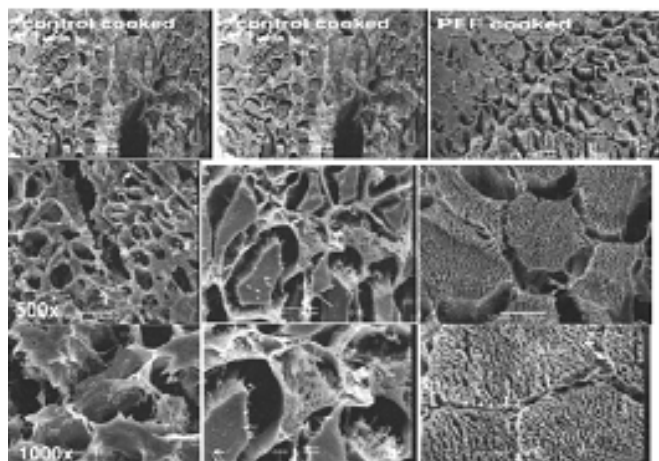


Figure 4: Electron Micrographs of pork meat untreated (left column), after cooking (centre column) and after PEF-treatment and cooking (right column). To all samples an injection of 20% brine containing 10% of pickling salt was applied. Cooking was prormed at 75°C, 90% humidity until a core temperature of 64°C

f) Other food

Pulsed electric field (PEF) processing is a non-thermal method of food preservation that uses short bursts of electricity for microbial inactivation and causes minimal or

no detrimental effect on food quality attributes. PEF can be used for processing liquid and semi-liquid food products.

The maintenance of the immunoactivity of bovine IgG in soymilk subjected to PEF and thermal treatments was studied by Li *et al.* (2003). PEF treatments (41 kV/cm, 54us) resulted in no significant loss of antigen-binding activity, whereas thermal treatment yielded 86% decrease. It is noteworthy that both procedures (PEF and thermal treatment) were equivalent in terms of natural flora destruction (5.1-5.3 logs). No changes in color parameters (L, a, and b), electric conductivity, °Brix, or viscosity were detected in PEF-treated milk at various electric field strengths from 26.0 to 38.4 kV/cm, with respect to the untreated controls. This opens the possibility of producing functional foods processed by PEF with better characteristics than those of heat-pasteurized ones.

g) Sugar processing

The juice yield of HELP pretreated samples was higher (74.5% at 5kV, 20 pulses) than heat treated (73.2%) and untreated sugar cane (65.5%). The energy consumption for HELP disintegration of sugar cane (17 kJ/ kg at 5kV and 20 pulses) was 10 times less when compared to heat treatment (171 kJ/ kg). Additionally the cell disintegration using HELP occurred faster (less than 2 min with 1Hz pulses frequency and 80 pulses) than thermal disintegration (20 min at 70° C) (Jarupan Kuldiloke *et al.*, 2008). PEF was used as an intermediate in the cold juice extraction from sugar beet cossettes using a pilot scale multi-plate and frame pressing equipment and a pulse generator. A yield of about 80% in juice per initial mass of cossettes was achieved before washing. Purity of juices was higher following PEF treatment compared to those juices without to PEF treatment (96-98% and 90-93% respectively (Jemai and Vorobiev, 2006).

h) Increase in Shelf Life

Simpson *et al.* (1995) reported that apple juice from concentrate treated with PEF at 50 kV/cm, 10 pulses, and pulse width of 2 μs and maximum processing temperature of 45°C had a shelf-life of 28 d compared to a shelf-life of 21 d of fresh-squeezed apple juice. There were no physical or chemical changes in ascorbic acid or sugars in the PEF-treated apple juice and a sensory panel found no significant differences between untreated and electric field treated juices. Milk with 2% fat content was processed by PEF, aseptically filled into packaging bags, and stored at 4°C. Its physical and chemical properties were not influenced by the PEF treatment and its microbial shelf life was 2 weeks. A sensory panel found no differences between heat-pasteurized milk and PEF pasteurized milk (Qin *et al.*, 1996).

i) Treatment of waste sludge

In PEF, a series of short, high voltage pulses breaks the cell wall, by expanding existing pores in the cell until they burst. This bursting of the cell wall has three main effects. It kills living cells, such as bacteria, making it an alternative to pasteurization for liquid foods, such as fruit juices and beer. It releases the contents of the burst cell to the surrounding liquid, which can aid in the extraction of sugars and starches from plant cells, such as sugar beets. Finally, the burst cells are much more susceptible to other biological and chemical

processes, such as anaerobic digestion, which can significantly reduce the solid content (sludge) in wastewater treatment facilities. PEF processing is currently being demonstrated for all three of these applications, and is beginning to emerge as a viable commercial process (Gaudreau et al., 2005).

j) Extraction of bioactive compounds

Increase of total polyphenolic (TP) content in fresh pressed grape juice of 13% was reached in comparison to referent sample simultaneously with 24% increase of TP content in

grape residue. 28% increase of TP content in fresh pressed grape juice was reached simultaneously with 14% higher TP content in grape residue, in comparison to referent sample. When treatment conditions of 0.5 kV/cm, 50 pulses, 0.1kJ/kg 2.4 kV/cm, 50 pulses 2.3 kJ/kg (Balasa et al., 2006). Higher juice yield (75%) of PEF-treated vine grapes in comparison to referent sample (70%). Total anthocyanin content was almost 3 times higher than of untreated grapes when treated with 3 kV/cm, 50 pulses (Tedjo et al., 2002).

Table 2: Effect of pef on enzymes:

Enzyme	Media	Treatment conditions	Effects	Reference
Alkaline phosphatase	SMUF Skim milk (SM) 2% fat milk (SSM) Whole milk (WM)	18.8 and 22 kV/cm, up to 70 pulses	SMUF and SM: 65% inactivation WM and SSM: 59% inactivation	Castro et al., 2001
Peroxidase	Raw milk	13–19 kV/cm, up to 200 pulses	>3% inactivation (process at room T) 2–13% inactivation (process at 44–52_C)	Van Loey et al., 2002
Glucose oxidase	glucose oxidase obtained from <i>Aspergillus niger</i> .	60 IJ.S at 50 kVfcm	reduction of enzyme activity to the 25% of the original	Ho et al. (1997)
Lysozyme	Egg	60 us at 87 kV/cm	increased activity	Ho et al. (1997)
Lipase	raw milk	60 /l-S at 87 kV/cm,	reduction to a 15%	Ho et al. (1997)

There are also some reports on the effect of PEF treatments on egg white. Jeantet *et al.* (2004) measured the surface hydrophobicity of egg white proteins and did not find any increase after PEF treatment, suggesting that no protein denaturation occurs. Fernandez-Diaz *et al.* (2000) also found that PEF treatments did not induce significant changes in the gelling properties of dialyzed egg white.

k) Proteins:

Fernandez-Diaz *et al.* (2000) studied the effect of exponential decay pulses (180 us at 31.5 kV/cm) on ovoalbumin solutions. Their first observation was that ovoalbumin solutions (2% protein content) submitted to PEF treatments showed an increased reactivity of sulphhydryl groups. Nevertheless, this was a transient change because if

ovoalbumin PEF-treated solutions were kept at 4°C during 30 min, thiol groups became less reactive again. According to this observation, PEF treatments would not induce permanent modifications in ovoalbumin.

l) Fats and Emulsions

The only noticeable effect caused by PEF treatments was the rupture of fat globules aggregates into smaller droplets, in a similar way as anionic detergents such as SDS do. However, the extent of this droplet dispersion effect was very small. These conclusions were obtained in model oil in-water emulsions stabilized by lactoglobulin, and further confirmed in food emulsions, specifically pasteurized half skimmed milk, pasteurized whole milk, and dairy cream (35% fat).

Table 4: Pigments:

Isoflavonoids	Soybeans	1.3 kV/cm, 50 pulses, 1.857 kJ/kg 1.3 kV/cm, 20 pulses, 0.743 kJ/kg	Amount of isoflavonoid diadzein increased by 20% in comparison to the referent sample. A rise of 21% of isoflavonoid genistein in comparison to the reference was reached	Guderjan et al. (2005)
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Lycopene is a carotenoid pigment responsible for the red color in tomato. PEF treatment did not cause any decrease in the lycopene concentration of tomato samples. Also, the color (Hunter lab color parameters) of a nutraceutical beverage, containing annatto and turmeric as sole colorings, was not modified by a treatment of 28 kVfcm for 200 us (Sharma *et al.*, 1998).

3. Conclusion

The PEF method is not suitable for most of the solid food products containing air bubbles when placed in the treatment chamber. Homogeneous liquids with low electric conductivity and maximum particle size provide ideal conditions for continuous treatment with the PEF method.

PEF have been shown to be an interesting technology to process acidic products such as fruit juices or even low acidic commodities, if properly combined with other processing techniques. Hence, high-quality, safe and shelf stable liquid foods can be obtained without significant depletion of their fresh bioactive potential. In-depth research is needed in order to study the factors involved in the generation/destruction of these compounds, as well as to elucidate the mechanistic insight of the changes.

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