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Innovative Food Processing on Food Chemistry, Food Bioactive Composition and Public Health Nutrition

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Abstract

In this review context, innovative food processing including high presure processing (HHP) and pulsed electrical fields (PEF) effects on food chemical properties and bioactives has been dealed. Innovative food processing technologies can influence the quality and quantity of food quality. Innovative non-thermal technologies (e.g. high-hydrostatic pressure-HHP and pulsed electrical fields (PEF) can preserve the treated foods without decomposing the chemical constituents and sensorial properties which are normally affected during heat treatment and these innovative products are stabil and safety for public nutrition.

Introduction

Consumers around the world are better educated and more demanding in their identification and purchase of quality health-promoting foods. The food industry and regulatory agencies are searching for innovative technologies to provide safe and stable foods for their clientele. Thermal pasteurization and commercial sterilization of foods provide safe and nutritious foods that, unfortunately, are often heated beyond a safety factor that results in unacceptable quality and nutrient retention.

Nonthermal processing technologies offer unprecedented opportunities and challenges for the food industry to market safe, high-quality health-promoting foods. The development of nonthermal processing technologies for food processing is providing an excellent balance between safety and minimal processing, between acceptable economic constraints and superior quality, and between unique approaches and traditional processing resources (Zhang et al., 2011).

Nonthermal food processing is often perceived as an alternative to thermal food processing; yet, there are many nonthermal preparatory unit operations as well as food processing and preservation opportunities and challenges that require further investigation by the food industry. Nonthermal technologies are useful not only for inactivation of microorganisms and enzymes, but also to improve yield and development of ingredients and marketable foods with novel quality and nutritional characteristics (Bermudez-Aguirre and Barbosa-Canovas, 2011). Innovative nonthermal processing is effectively combined with thermal processing to provide improved food safety and quality. Nonthermal processing facilitates the development of innovative food products not previously envisioned. Niche markets for food products and processes will receive greater attention in future years.

Nonthermal technologies successfully decontaminate, pasteurize, and potentially pursue commercial sterilization of selected foods while retaining fresh-like quality and excellent nutrient retention. The quest for technologies to meet consumer expectations with optimum quality-safe processed foods is the most important priority for future food science research.

HHP,ultra-high pressure (UHP), and ultra-high-pressure processing (HPP) *are different names and acronyms for equivalent nonthermal processes employing pressures in the range of 200–1000 MPa with only small increases in processing temperature. The UHPs inactivate microbial cells by disrupting membrane systems, retaining the biological activity of quality, sensory, and nutrient cell constituents, thus extending the shelf lives of foods. High pressures inactivate enzymes by altering the secondary and tertiary structures of proteins, changing functional integrity, biological activity, and susceptibility to proteolysis.*

HHP processing of dairy proteins reduces the size of casein micelles, denatures whey proteins, increases calcium solubility, and induces color changes (Morris et al., 2007). The use of HHP to increase the yield of cheese curd from milk and accelerate the proteolytic ripening of Cheddar cheeses are promising improvements to the economics for the dairy food industry. The most widely available commercial applications of HHP include pasteurization of guacamole, tomato salsas, oysters, deli-sliced meats, and yogurts. The provision of HHP processing to provide a preservation method for thermally labile tropical fruits is very promising. It is stated that HHP provides pathogen inactivation, shelf-life extension, unwanted enzyme inactivation, gives innovative fresh products, reduced sodium products and clean-labelling.

PEF processing exposes fluid foods to microsecond bursts of high-intensity electric fields, 10–100 kV/cm, inactivating selected microorganisms by electroporation, a disruption of cell membranes. PEF processing reliably results in five-log reduction in selected pathogenic microorganisms, resulting in minimal detrimental alterations in physical and sensory properties of the fluid foods. PEF adequately pasteurizes acid (pH $<$ 4.5) fruit juices and research is continuing on uniform adequate pasteurization of milk and liquid eggs. The commercial application of PEF to improve the extraction yield of fruit juices and bioactive components of plant materials is in progress. PEF inactivation of enzymes is inconsistent and nonuniform, resulting in plant products subject to short shelf lives at ambient temperatures. It is expressed that PEF provides pathogen inactivation, shelf-life extension of liquid foods, unwanted enzyme inactivation, improves functionality and texture of foods, gives innovative fresh liquid foods and reduced solid volume (sludge) of wastewater. Although PEF is identified as a nonthermal process, temperature increases during PEF processing result in fluid foods at 35–50°C, requiring cooling prior to packaging. The presence of particulates or bubbles in fluid foods subjected to PEF will result in dielectric breakdown, arcing, and scorching of the food. Homogenization and vacuum degassing are necessary to minimize the hazards associated with PEF processing of fluid foods. Technical issues that must be addressed to commercialize PEF for approval as an adequate food pasteurization technology include: (1) consistent and uniform generation of high-intensity electric fields; (2) identification of critical electric field intensities for uniform microbial inactivation; (3) identification of homogenization and vacuum-degassing techniques to assure the absence of particulates and air cells that promote arcing; and (4) identification of flow rates, temperature control, cooling, and aseptic packaging parameters to obtain processing uniformity and safe handling practices (Morris et al., 2007).

High Pressure Processing (HHP)

Phenolic compounds including flavonoids play some important roles in fruits such as visual appearance, taste, and aroma. In addition to these, phenolic compounds have health-promoting benefits. These bioactive compounds have been found to be important in the quality of plant-derived foods (Thomas-Barberan and Espin, 2001). Anthocyanins are a type *of phenolic compounds classified under flavonoids group of phenolic compounds, which are water-soluble glycosides of anthocyanidins(Tokuşoğlu and Hall,2011).*

The flavonoid (Figure 1) composition in fruits is affected by some intrinsic factors, such as using different genus, species, or cultivars, and extrinsic factors, such as the time of the collection of fruits, location, environmental factors, and storage. In addition to these intrinsic and extrinsic factors, some food-processing technologies can also affect the composition of plant phenolics (Tokuşoğlu,2001).

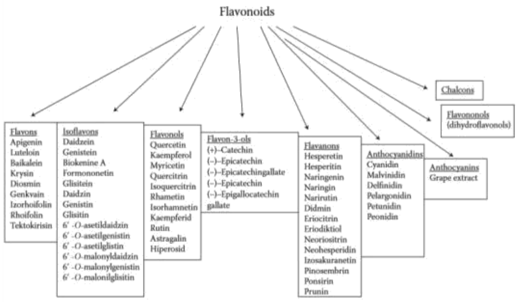

Figure 1. *Flavonoid family in food plants. (Adapted from Tokusoglu Ö. 2001. The Determination of the Major Phenolic Compounds (Flavanols, Flavonols, Tannins and Aroma Properties of Black Teas. PhD thesis. Department of Food Engineering, Bornova, Izmir, Turkey: Ege University; Tokusoglu Ö., and Hall, C. 2011. Fruit and Cereal Bioactives: Sources, Chemistry and Applications. Boca Raton, FL, USA: CRC Press, Taylor & Francis Group, 459pp. ISBN: 9781439806654; ISBN-10:1439806659.)*

Phenolic compounds in fruits and vegetables decrease by conventional and traditional heat-treatment processes. These thermal treatments are the most used methods to extend the shelf life of foods by the microorganism and enzyme inactivation, while heat causes irreversible losses of nutritional compounds, undesirable alterations in physicochemical properties, and changes of their antioxidant properties (Plaza et al., 2006; Wang and Xu, 2007). Many factors including temperature, pH, oxygen, enzymes in the presence of copigments, metallic ions, ascorbic acid (AA), sulfur dioxide, as well as sugars may affect the stability of the anthocyanins. During pasteurization and storage, several red-fruit derivatives lose their bright-red colors and become dull-red colors.

Similarly, the polyphenol content decreases in several liquid, semisolid, or solid foodstuffs by heat treatments (Ferrari et al., 2011). Many food manufacturers have investigated alternative techniques to thermal pasteurization to facilitate the preservation of unstable nutrients and bioactives in foods and beverages. Nonthermal technologies have been reported to be a good option for obtaining food and beverages with a fresh-like appearance while preserving their nutritional quality (Odriozola-Serrano et al., 2009). At that point, the potential use of these emerging technologies, such as "High Hydrostatic Pressure (HHP)" or "Pulsed Electrical Fields (PEF)," are important because they inactivate microorganisms and undesirable enzymes to a certain extent and can avoid the negative effects of heat pasteurization (Toepfl et al., 2006).

HPP can be used to obtain a high-quality food/beverage and increases its shelf life while maintaining its physicochemical, nutritional characteristics, and bioactive profiles (Tokusoglu, 2011; Tokusoglu and Doona, 2011a,b; Tokusoglu et al., 2010).

The technology is especially beneficial for heat-sensitive products (BarbosaCánovas et al., 2005; Tokusoglu and Doona, 2011). HPP can be conducted at ambient or moderate temperatures, thereby eliminating thermally induced cooked off- flavors. Compared to thermal processing, the HPP of foods results in products with a fresher taste, better appearance, and texture. Foods are *processed in batch (for solid products) or continuous and semicontinuous systems (for liquid products) in a pressure range of 50–1000 MPa; process temperature during pressure treatment can be from below 0°C to above 100°C, while exposure time usually ranges from seconds to 20 min (Bevilacqua et al., 2010; Corbo et al., 2009). HPP technology has been successfully applied in several industrial sectors such as meat, seafood, dairy food, fruit juices, fruit, and vegetable products. HPP has been found to inactivate several microorganisms and enzymes. However, it has less effect on lowmolecular-weight food components such as vitamins, pigments, flavoring agents, and other nutritional compounds. HPP conditions in the range of 300–700 MPa at moderate initial temperatures (around ambient) are generally sufficient to inactivate vegetative pathogens for pasteurization processes, some enzymes, or spoilage organisms to extend shelf life. HPP can also increase the extraction capacity of phenolic constituents, and higher levels of bioactive compounds and phytochemicals are preserved in HPP-treated samples (Oms-Oliu et.al., 2012; Tokusoglu and Doona, 2011ab).*

The extraction capacity of phenolic constituents has been increased by HHP and HPP-treated samples that retain higher levels of bioactive compounds (Tokusoglu et al., 2010; Tokusoglu and Doona, 2011ab; Zhang et al., 2005). Studies on HPP effects on total phenolics determined that these compounds were either unaffected or actually increased in concentration and/or extractability, following treatment with HPP.

It has been reported that the anthocyanins of different liquid foods (red-fruit juices) are stable to HHP treatment at moderate temperatures. The nutraceutical and sensorial properties are strictly related to the anthocyanin and polyphenol content in pomegranate juice at room temperature. It was reported that the stability or preservation of bioactive compounds of red-fruit juices is contradictory. The concentration of red-fruit-based bioactives decreases with the intensity of the treatment in terms of pressure level and processing time (Ferrari et al., 2010). It was found that HPP treatment at moderate temperatures promoted the extractability of colored pigments and increased the polyphenol levels of fruits (Ferrari et al., 2010).

Although thermal treatments, enzymatic treatments, and other conventional methods have generally been used for eliminating food allergenicity, some treatments result in a degradation of the processing food characteristics, as well as a deterioration in the flavor and taste; for instance, the development of bitterness or an unpleasant odor (Tokuşoğlu and Bozoğlu,2015). Besides, the ezymatic treatment applications to foods give a high level of protein; this situation is not practicable, especially for meats. High-pressure (HP) processing treatments are novel-processing techniques that have the potential to alleviate the need for thermal processing of foods. High-pressure (400–700 MPa) processing is combined with temperatures around room temperature (5–40°C). It is stated that treatments offer an alternative to high-temperature pasteurization, or chemical preservation and fresh-like properties of foods are preserved. It is known that the current recommended strategy for allergy sufferers is avoidance of allergen foods and also the recommended strategy for manufacturers is the necessity of labeling regarding potential changes in food manufacturing and/or information of ingredient/additive used in food preparation (Tokuşoğlu and Bozoğlu,2015).

Pulsed electric field processing (PEF) applies short bursts of high-voltage electricity for microbial inactivation and causes no or minimum effect on food-quality attributes. Briefly, the foods being treated by PEF are placed between two *electrodes, usually at room temperature. The applied high voltage results in an electric field that causes microbial inactivation. The applied high voltage is usually in the order of 20–80 kV for microseconds. The common types of electrical field waveform applied include exponentially decaying and square wave (Amiali and Ngadi, 2012; Barbosa-Cánovas et al., 1999). The principles of PEF processing have been explained by several theories including the transmembrane potential theory, electromechanical compression theory, and the osmotic imbalance theory. One of the most accepted theories is associated with the electroporation of cell membranes. It is generally believed that electric fields induce structural and functional changes in the membranes of microbial cells based on generation of pores in the cell membrane, consequently leading to microbial destruction and inactivation. Compared with thermal processing, PEF processing has many advantages. It can preserve the original sensory and nutritional characteristics of foods due to the relatively short processing time and low processing temperatures. Energy savings for PEF processing are also important compared with conventional thermal processing. Moreover, it is environmentally friendly with no waste generated (Amiali and Ngadi, 2012).*

PEFs can cause electroporation of cell membranes that, depending on the field intensity, may induce irreversible cell damage. It is stated that PEF can be applied as an alternative method for cell disintegration. Biological tissues exposed to high electric field pulses develop pores in the cell membrane and these actions result in increased membrane permeability and loss of the cell content (Knorr et al., 2001; Tokuşoğlu et.al..2015). It is stated that the novel nonthermal technology PEF for pasteurization or sterilization can inactivate microorganisms and enzymes with minor increasing in temperature, providing fresh-like products with improved flavor and color properties as well as highly preserved nutritive value (Aguilar-Rosas et al., 2007).

Spesific Study on Citrus Juices By HHP and PEF

It was stated that the greater the electric field strength, higher the temperature, or longer the treatment time, the greater the microbial inactivation (Wouters et al., 2001). It is accepted that the pertinent pathogen in citrus juices is generally regarded as Salmonella while critical and relatively PEF-resistant microorganisms in orange juice are lactic acid bacteria and pathogenic E. coli (Buckow et al., 2013; Parish, 1998).

Hartyáni et al. (2011) stated the physical-chemical and sensory properties of PEF and HHP-treated citrus juices. In the study described by Hartyáni et al. (2011), the physicochemical quality properties (pH, Brix°, electric conductivity, and color), the aroma content of most consumed citrus juices (100% orange, grapefruit, and tangerine juice) were examined (Hartyáni et al., 2011).

The applied technology was pulsed electric field (PEF) treatment with the parameters of 28 kV/cm with 50 pulses; respectively high hydrostatic pressure (HHP) technology with the parameter of 600 MPa pressure for 10 min treatment time. Table 1 shows the physical–chemical properties and total color difference of fruit juices in the case of control, PEF-treated and HHP-treated samples (Hartyáni et al., 2011). Table 2 shows the organic acid content of the fruit juices in the case of control, PEF-treated and HHP-treated juice. In the study reported by Hartyáni et al. (2011), malic and citric acid content did not decrease significantly after the treatments (Table 2). Respectively, in ascorbic acid content, there was a slight difference, but as an advantage of the treatment the vitamin C content was still quite stable (Hartyáni *et al., 2011). It was established that the electronic nose and tongue were able to differentiate each treatment type from the control samples.*

Timmermans et al. (2011) reported that the mild heat pasteurization, HP processing, and PEF processing of freshly squeezed orange juice were comparatively evaluated, examining their impact on microbial load and quality parameters immediately after processing and during 2 months of storage. It was found that microbial counts for treated juices were reduced beyond detectable levels immediately after processing and up to 2 months of refrigerated storage. Quality parameters such as pH, dry-matter content, and Brix were not significantly different when comparing orange juices immediately after treatment and were, for all treatments, constant during storage time (Timmermans et al., 2011). It was stated that the quality parameters related to PME inactivation, such as cloud stability and viscosity, were dependent on the specific treatments that were applied. It was found that mild heat pasteurization was effective and was obtained as the most stable orange juices (Timmermans et al., 2011). On the basis of the data obtained by Timmermans et al. (2011), residual enzyme activity was clearly responsible for changes in viscosity and cloud stability during storage for PEF. Figure 2 shows the overview of the production, handling, and analysis of orange juice samples (Figure 2).

It was found that mild heat-pasteurized orange juice was significantly lighter than HP and untreated orange juice, having less red color and more yellowness. It was reported that PEF-treated samples showed the opposite: significantly darker in color than untreated, HP and heat, with significantly more red and less yellow tints (Timmermans et al., 2011). It was shown that DE values, indicated in Figure 3, are the sum of L, a*, and b* values, which are more closely associated to consumer perception than singular L* a*, or b* values, since consumers do not judge each particular attribute, but the combination of them (Cserhalmi et al., 2006). According to DE data obtained by Timmermans et al. (2011), it was found that all types of orange juice showed a noticeable (DE 0.5–1.5) difference in color compared to its color on day 1 and there were no noticeable color differences between the different treatments (Figure 3) (Timmermans et al., 2011).*

In the study described by Timmermans et al. (2011), PEF-treated orange juice gave a slightly lower Brix° after processing. It was reported that the effect of mild heat treatments on the pH of orange juice was determined and no significant differences were found between untreated and different types of treated juices. It was found that there was no variation during storage time, except for the untreated orange juice, in which the pH decreases significantly over the first 9 days (Timmermans et al., 2011).

As it is known, cloud loss is considered as a quality defect in shelf-stable citrus juices derived from the concentrate and it is one of the main reasons for the level of heating in heat pasteurization, where 90–100% of PME is inactivated (Goodner et al., 1999). It was reported the observed sedimentation and cloud loss of untreated, mild heat-pasteurized, high-pressure-pasteurized (HPP), and PEF-processed orange juice bottles during the first 115 days of storage at 4°C (Timmermans et al., 2011). It was stated that cloud stability was measured evaluating the degree and rate of sedimentation, by recording the height of the interface of the sediment and cloud. On the basis of the data obtained by Timmermans et al. (2011), sedimentation of 0% corresponded to a completely stable orange juice, having no cloud loss.

Conclusion

The requirement of fortificated bioactive compounds such as polyphenolic *antioxidants and minor component vitamins has been accelerated the development of innovations in the food industry, generating the so-called* **''functional foods''** *and* **''nutraceuticals'** *Innovative food processing technologies can influenced the quality and quantity of food quality. Innovative non-thermal technologies (e.g. high-hydrostatic pressure-HHP and pulsed electrical fields (PEF) can preserve the treated foods without decomposing the chemical constituents and sensorial properties which are normally affected during heat treatment. Also by using of novel technologies, the bioactive chemical contituents have been obtained from food waste recovery and it can be utilized as food by product based powders for public nutrition.*

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Table 1. *Physical–Chemical Properties and Total Colour Difference of Fruit Juices in Case of Control, PEF Treated, and HHP Treated Samples*

Sample	Treatment	Brix (%)	pH	Conductivity (mS)	Total Color Difference (ΔE)	
Orange	Control	10.60 ± 0.01	3.65 ± 0.01	3.33 ± 0.01	Reference	
	PEF-treated	10.60 ± 0.05	3.65 ± 0.01	3.33 ± 0.01	4.8 ± 0.05	Visible
	HHP-treated	10.50 ± 0.05	3.63 ± 0.01	Not measured	9.3 ± 0.01	Big differences
Grapefruit	Control	8.90 ± 0.05	2.96 ± 0.01	3.72 ± 0.01	Reference	
	PEF-treated	8.90 ± 0.01	2.96 ± 0.01	3.78 ± 0.01	2.8 ± 0.06	Noticeable
	HHP-treated	8.70 ± 0.01	2.92 ± 0.03	Not measured	2.1 ± 0.05	Noticeable
Tangerine	Control	10.20 ± 0.05	2.95 ± 0.01	3.50 ± 0.01	Reference	
	PEF-treated	10.20 ± 0.01	3.00 ± 0.01	3.60 ± 0.01	3.9 ± 0.05	Visible
	HHP-treated	10.20 ± 0.01	2.90 ± 0.01	Not measured	2.6 ± 0.05	Noticeable

Source: Adapted from Hartyáni P. et al. 2011. *Innovative Food Science and Emerging Technologies*, 12, 255–260.

Note: Values were mean ± SD of three measurements, n = 4; different letters represent a significant difference within the same column ($p < 0.05$).

Table 2. *Organic Acid Content of the Fruit Juices in Case of Control, PEF Treated, and HHP Treated Samples*

Sample	Treatment	Malic Acid (mg/l)	Citric Acid (mg/l)	Ascorbic Acid (mg/l)
Orange	Control	847.50 ± 70.06^{a}	5290.73 ± 207.48^{a}	511.59 ± 2.04^{a}
	PEF-treated	826.24 ± 0.09^{a}	5222.57 ± 63.59^{a}	520.64 ± 12.93^{a}
	HHP-treated	755.77 ± 53.83^{a}	5207.17 ± 254.89^{a}	526.29 ± 17.64^{a}
Grapefruit	Control	537.42 ± 49.00^{a}	9923.92 ± 80.86^{a}	421.18 ± 0.79^{a}
	PEF-treated	494.71 ± 5.09^{ab}	9933.22 ± 59.90^{a}	411.38 ± 6.96^{ab}
	HHP-treated	452.75 ± 49.87^{b}	9751.39 ± 111.82^{a}	405.42 ± 5.56^{b}
Tangerine	Control	903.08 ± 112.20^{a}	341.41 ± 1.41^{a}	6318.03 ± 175.56^{a}
	PEF-treated	944.02 ± 3.55^{a}	346.45 ± 1.15^{a}	6557.13 ± 7.03^{a}
	HHP-treated	1191.20 ± 105.92^{b}	386.49 ± 12.33^{b}	7596.88 ± 171.62^{b}

Source: Adapted from Hartyáni P. et al. 2011. *Innovative Food Science and Emerging Technologies*, 12, 255–260.

Note: Values were mean ± SD of three measurements, n = 4; different letters represent a significant difference within the same column ($p < 0.05$).

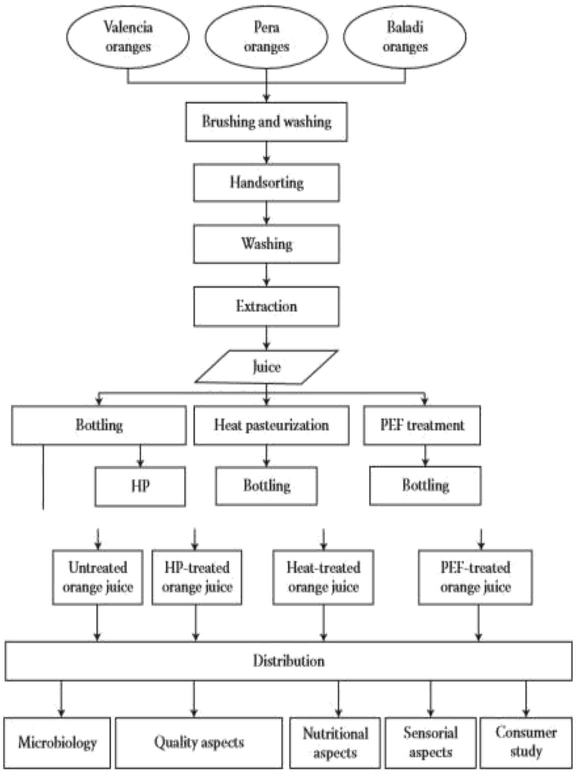

Figure 3. *The total color difference (DE value) for untreated (), mild heat-pasteurized (▲), HP-processed (•), and PEF-(■) processed orange juice. (Adapted from Timmermans R.A.H. et al. 2011. Innovative Food Science and Emerging Technologies, 12, 235–243.)*