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Impact of innovative technologies on fruit and vegetable quality

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Food processing operations have a major impact on the stability of the nutrients and generally damage antioxidants in fruit and vegetables, and their products. Domestic, conventional, industrial and even non-thermal processing is reported to degrade the level of phytochemicals in processed food products. Recent concerns in non-thermal technologies are not only to obtain high quality food with "fresh-like" properties, but also to provide food with better functionalities. However, some researchers reported that results obtained from non-thermal processes might not be different from the thermal treatments. The main focus of this review is to clarify the dependence of non-thermal technologies such as high hydrostatic pressure (HHP), pulsed electric field (PEF) and ultrasound (US) processing on key nutrients of fruits and vegetables.

Key words: *Non-thermal food processing, high hydrostatic pressure processing, pulsed electric field, ultrasound, fruit and vegetables, phytochemicals*.

INTRODUCTION

The optimization of food processing and storage conditions is an essential step to reduce the degradation of phytochemicals for potential health benefits [1]. The effect of several non-thermal techniques such as high pressure processing (HPP), pulsed electric field (PEF), and ultrasound/sonication (US) techniques on the fruit and vegetables, and their products have been investigated [2].

High hydrostatic pressure (HHP processing could preserve nutrients and the organoleptic properties of fruits and vegetables due to its restricted effect on the covalent bonds of low molecular mass compounds and vitamins. HHP treatment may enhance the antioxidant activity of juices comparing to the untreated one [3]. While most researchers have reported that HPP helps retaining the antioxidant activity of the individual fruits, Keenan et al.[4] found out that the retention of ascorbic acid (AA), antioxidant and polyphenols contents in HHP processed smoothies was not better than that of thermally processed samples.

PEF has proved to be a validated technology for the production of safe beverage products as shown by the positive influence on the texture of solid plant foods, leading to increased yields of extraction of metabolites, as well as enhanced juice yields [5]. However, Morales-de la Peña et al. [6] determined PEF treatment to cause a reduction in vitamin C content and antioxidant capacity which might decline over time compared to conventional thermal treatment.

US treatment of fruit juices is reported to have a minimal effect on the AA content during processing and results in improved stability during storage when compared to thermal treatment [7]. Moreover, Rostagno et al.[8] used the US-assisted extraction for isoflavone extraction from soy beverages blended with fruit juices and determined that total and individual isoflavone concentration obtained with the optimized method were not significantly different from that of the conventional methods.

In order to retain the nutraceutical and pharmacological properties of phytochemicals in processed fruit and vegetable products, the food processor must optimize relevant processing steps in order to restrict the loss of phytochemicals [9]. Furthermore, positive effects of these new technologies arise from all process parameters consistency. Generally, new technologies are presenting great solutions about keeping nutrients but in some situations, parameters may affect the nutritional values of the processed product in a negative way. For example, longer PEF treatment times may induce reduction in the product retention of vitamin C due to product heating. Besides, some researchers reported that results obtained from non-thermal processes might not be different from the thermal treatments [10]. Thus for obtaining processed products in good qualities and sufficient nutritional values and having positive results after the treatments, these new technologies had to be studied thoroughly.

This review considers the impact of processing on both key nutrients and antioxidants, taking an example of fruit and vegetables as a case study to

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demonstrate how the nutritional quality of fruits and vegetables may be affected during processing.

High hydrostatic pressure processing

HHP processing is an established non-thermal food processing and preservation technique with reduced effects on nutritional and quality parameters compared to conventional thermal processing. In HHP processing, the products are treated under pressure above 100 MPa. The great advantage of HHP treatment is that pressure at a given position and time is the same in all directions, transmitted uniformly, immediately through the pressure transferring medium and independent of geometry. Literature data indicate that HPP preserves the nutritional value of HPP processed food and food products. HPP treatment at ambient temperature is reported to have minimal effect on the bioactive content of various fruits and vegetables [11].

Yen and Lin [12] investigated the effects of HHP and thermal pasteurization on AA content of guava puree during storage at 4 °C. After treatment under pressure of 600 MPa, at temperature 25 °C and 15 min treatment time, the product exhibited no change in AA content as compared to the fresh samples. The authors concluded that samples retained good quality similar to the freshly extracted puree after storage at 4 °C for 40 days. It is suggested that further AA degradation after HHP processing could take place during storage and it could be eliminated by lowering storage temperature. The AA content of untreated and pressurized (400 MPa/room temperature/15 min) guava puree started to decline after 10 and 20 days, whereas it remained constant in thermal (88–90 °C/24 s) and in higher pressure (600 MPa/ room temperature/15 min) treated guava puree during 30 and 40 days, respectively. The latter could be caused by inactivation of endogenous pro-oxidative enzyme during treatment at high pressure level[12]. Isaacs [13] - reported that at elevated temperatures, pressure treatment could degrade vitamin C to a large extent for long treatment time, e.g., pressurization up to 600 MPa/75 °C/40 min resulting in 70 % and 50 % losses of vitamin C, respectively in pineapple and grapefruit juices. In addition, at constant pressure (600 MPa/40 min), increasing temperature enhanced the vitamin C degradation of pineapple juice as a decrease of 20–25 % at 40 °C; 45–50 % at 60 °C, and 60–70 % at 75 °C respectively was observed.

Ferrari et al. [14] investigated the effects of HHP (400–600 MPa) at 25, 45 and 50 °C for 5 or 10 min on anthocyanin and polyphenol contents of pomegranate juice. Their experimental results indicated that anthocyanin content was mainly influenced by pressure and temperature levels. At room temperature, the concentration of these molecules decreased with the intensity of the treatment in terms of pressure level and processing time. The authors also indicated that high pressure treatments modified the mechanism of anthocyanin degradation by affecting the molecules involved in the kinetics of reaction, such as enzymes. The residual activity of the enzymes along with a small concentration of dissolved oxygen could cause the degradation of the anthocyanins during the storage of the processed juice, as widely supported [15].

Distinct from the application of HPP for preservation purposes, high pressure treatments have been extensively used in the extraction process of secondary plant metabolites from fruits and vegetables. For example, De Ancos et al.[16] successfully employed HHP processing (50–400 MPa/25 °C/15 min) for extraction of carotene from persimmon fruit purees. As a result, different pressure levels at constant temperature gave different release of various carotenes depending on their chemical properties and chromoplast location.
The extraction of bioactive compounds can be described as a mass transport phenomenon where solids contained in plant structures migrate into the solvent, up to their equilibrium concentration. Additionally, mass transport can be increased by some factors like heating, changes in concentration gradients, and the influence of new technologies such as ultrasound, high pressure, and pulsed electric field [17]. HHP enhances the mass transfer rates, which increase cell permeability as well as secondary metabolite diffusion [18,19]. Prasad et al.[20] extracted long an fruit pericarp in 50 % ethanol applying both HHP (500 MPa) and conventional methods. Their results demonstrated that HHP extraction showed excellent antioxidant and anticancer activities and were found to be higher than conventional extraction. Three phenolic compounds, gallic acid, corilagin and ellagic acid were identified and quantified. Compared with conventional extraction, HHP extraction exhibited higher extraction effectiveness in terms of higher extraction yield, phenolic content and antioxidant and anticancer activity with shorter extraction time. Increased extraction yields caused by high pressure were probably related to its aptitude to deprotonate charged groups and to disrupt salt bridges and hydrophobic bonds in cellular membranes, which may lead to higher permeability [19].

Pulsed electric field

PEF is a technology that has been extensively investigated in recent years for its applications in food processing. By the mechanism of electropermeabilization, PEF has been proven as a valid technology for the production of safe beverage products showing positive influence on the texture of solid plant foods, leading to enhanced yields of extraction of metabolites, as well as increased juice yields. One of the principal differences in the use of PEF consists of the intensity of field which were classified as high intensity field (15–40 kV/cm/5–100 pulses/40-700 μs/1.1-100 Hz) that are more effective towards microbial inactivation and low and medium intensity field (0.6–2.6 V/cm/5–100 pulses/ short treatment time within 10^{-4}–10^{-2} s; 1 Hz) which have been successfully used for enhancing mass transfer in solid foods [17,21]. With the increasing interest in availability of bioactive compounds from fresh to processed foods, the effects of this technology have been reviewed comprehensively [22]. Morales-de la Peña et al.[6,10] investigated the effect of PEF on vitamin C in exotic fruit based drinks immediately after the treatment and concluded that levels were not different from the thermally processed juices such as orange/kiwi/pineapple and soymilk based drinks. However, the beneficial effect of the PEF was noticeable over 31 days storage period, (800 μs/35 kV/cm) showed significantly greater vitamin C retention than both a 1400 μs and a thermal treatment. Generally, longer treatment times may induce reduction in the retention of vitamin C of the juice related with product heating. Longer exposure time may also generate free radicals which may speed up vitamin C degradation. Watermelon juice, product with a low initial vitamin C concentration, was PEF treated (25 kV/cm/50 μs/50 Hz), and it exhibited the highest vitamin C retention (96.4–99.9 %). On the other hand, vitamin C loss was higher than 50 % when HIPEF (high-intensity PEF) treatment parameters were risen (35 kV/cm/2050 μs/250 Hz). However, this treatment found to be appropriate for product safety [22].

In cases where PEF has caused a loss of anthocyanins, this probably might come from the direct impact of the treatment on these compounds and the partial inactivation of enzymes (β-glucosidase, peroxidase and polyphenoloxidase) which were induced. Aguiló-Aguayo et al.[23] reported an increase of β-glucosidase activity in strawberry juice, which could explain the corresponding degradation of anthocyanin following PEF treatment (35 kV/cm, 1000 μs, 50 Hz). In another research, the total phenolic content of a blend of orange/kiwi/pineapple juice and soymilk was not affected by PEF treatments (35 kV/cm, 4 μs bipolar pulses, 200 Hz) for a total treatment time of 800 μs and 1400 μs [10].

The effect of PEF processing on the bioactive compounds in watermelon juice was extensively studied by Oms-Oliu et al.[22]. While severe PEF strength proved to increase the rate of vitamin C loss in the juice, the lycopene retention in HIPEF processed changed it from 87.6 % to 121.2 % over the range of processing parameters (25–35 kV/cm, 1–7 μs or 50–2050 μs, 50–250 Hz). Enhancement of lycopene content might be related to PEF-induced cell permeabilization and the release of intracellular pigments (lycopene) from watermelon. Consequently, it was determined that such an increase at these electric field intensities could have been a stress induction for cells and subsequent production of lycopene as secondary metabolite stimulating metabolic activity [24]. These results were similar to those observed by Odriozola-Serrano et al.[25] in strawberry juice processed by PEF. Keeping constant 35 kV/cm electric field strength, and the treatment time of 1000 μs, the treatments were set at frequencies from 50 to 250 Hz, pulse width from 1 to 7 μs. The authors determined that the presence of health-related compounds (vitamin C, anthocyanins and antioxidant capacity) were maximal at a treatment frequency of 232 Hz and a pulse width of 1 μs. Under all experimental conditions, the relative retention of anthocyanins ranged between 87 % and 102 %.

Main causes of degradation in antioxidants during thermal processing could be attributed to oxidation and isomerization [26]. According to Morales-de la Peña et al.[6,10], the antioxidant capacity of a mix kiwi/orange/pineapple juice and soy milk was not affected by the PEF. Moreover, antioxidant capacity of this product - decreased to a greater degree in thermally treated (90ºC, 60 s) sample than in PEF-treated one after storage period of 60 days [6,10]. Conversely, Aguiló-Aguayo et al.[23] reported that total antioxidant capacity of watermelon juice was affected by the treatment conditions. In the process with 35 kV/cm, 2050 μs, 250 Hz did not seem to affect the antioxidant capacity of the juice when treated with a 7 μs pulse width, though it was significantly reduced when the pulse width was applied as 1 μs and the frequency was reduced to 50 Hz.

The application of this technology as a treatment for enhancing yield extraction has been reported for several plant foods (apple, sugar beet, grapes, carrot) [17,27-29]. Ade-Omowaye et al.[30] applied successfully the PEF technology, as a pre-processing step in coconut milk processing, with an increase in milk yield but the bioactive compounds contents were not reported. However, to date there are limited reports focusing on the application of similar methods for extraction of juice and/or on the effect of such processing technology on bioactive metabolites from exotic fruit sources. Although the existing data, other plant foods may provide a solid base for studies on bioactive compounds and further investigations are required.

Ultrasound processing

Ultrasound with frequencies in the range 20-100 kHz has been a subject of research and development for many years in the food industry. Such processing requires the presence of a liquid medium for power transmission. It causes chemical and physical changes in the biological structures due to intracellular cavitation. Ultrasound processing on its own or in combination with heat and/or pressure is an effective processing tool for microbial inactivation and phytochemical retention. Advantages of ultrasound include reduced processing time, higher throughput at lower energy consumption [31].

Salleh-Mack and Roberts [32] investigated the effects of temperature, sugar concentration (8, 12, and 16 g/100 ml), organic acids (citric and malic acids) and pH (2.5 and 4.0) on ultrasound pasteurization in fruit juices. For this aim, *Escherichia coli* ATCC 25922 was used as a model organism and US treatment times were chosen to achieve a 5 log (base 10) reduction. Temperature was set at 30 °C and below in order to eliminate the thermal inactivation effects. Consequently, US increased the sensitivity of *E. coli* to thermal inactivation. The presence of soluble solids had a protective effect where the sonication time requirement increased. Similar to heat sensitivity, the lower pH environment resulted in *E. coli* having less resistance to sonication and the type of organic acid had the least significant effect on US inactivation. Additionally, it was reported that US could negatively modify some food properties including flavor, color or nutritional value.

US treatment of fruit juices is reported to have a minimal effect on the AA content during processing and results in improved stability during storage when compared to thermal treatment. This positive effect of US is attributed to the effective removal of occluded oxygen from the juice as this is a critical parameter influencing the retention of AA [33]. With regard to exotic fruits, Cheng et al.[34] reported a significant increase in the AA content of guava juice during sonication from 110 ± 0.5 mg/100mL (fresh) to 119 ± 0.8 mg/100 mL (sonication) and to 125 ± 1.1 mg/100 mL (combined sonication and carbonation). The authors also observed that during carbonation, sample temperature decreased substantially which could have disfavoured AA degradation.

Rawson et al. [35] determined that sonication temperature played a significant role in preservation of bioactive compounds. Freshly squeezed watermelon juice was subjected to thermosonication treatments with processing variables of temperature (25-45°C), amplitude level (24.1-60 μm) and processing time (2-10 min) at a constant frequency of 20 kHz and pulse durations of 5 s and pulse repetition time and 5 s. The authors observed a higher retention of AA and lycopene at low amplitude level and temperature. They determined a decrease in the phenolic content of sonicated watermelon juice with temperature rise from 25 to 45 °C. Temperature effect was more pronounced at higher processing times (10 min) [35]. Additionally, in another study US processing was reported to enhance extraction yield of bioactive compounds like polyphenols and carotenoids in both aqueous and solvent extraction systems about 6 % and 35 % depending on the processing conditions [36].

Ultrasonic extraction is a well-known commercial method for increasing mass transfer rate by cavitation forces. Bubbles in the liquid-solid extraction using ultrasonic extraction can explosively collapse and produce localized pressure while improving the interaction between the intracellular substances and the solvent to facilitate the extraction of the phytochemicals. The extraction of lycopene from tomato using ultrasonic assisted extraction (UAE) and ultrasound/microwave assisted extraction (UMAE) was reported in Lianfu and Zelong's [37] research. They showed that the optimal conditions for UMAE were 98 W microwave power together with 40 KHz ultrasonic processing, the ratio of solvents to tomato paste was 10.6:1 (V/W) and the extracting time should be 367 s; whereas for UAE, the extracting temperature was 86.4°C, the ratio of the solvents to tomato paste was 8.0:1 (V/W) and the extracting time should be 29.1 min. Additionally, the percentage of lycopene yield was determined 97.4 % and 89.4 % for UMAE and UAE, respectively. The comparison of these two methods showed that UMAE overcomes theshortcomings of UAE and would be a more attractive extract method in the future.

CONCLUSION

Ensuring food safety and at the same time meeting the demands of conscious consumers for good quality and nutritious foods has resulted in increased interest in non-thermal preservation technologies. In parallel with the processing conditions, innovative technologies such as HPP, PEF and ultrasound might have a positive or negative effect on nutrients and phytochemicals of fruits and vegetables. However, some researchers determined that nutritional values were not significantly affected by the non-thermal processing parameters. Therefore, to properly evaluate the impact of these technologies further researches on this topic is still required.

REFERENCES

1. U. Tiwari, E. Cummins, *Cereal Chem*., **86**, 290 (2009).
2. B. K. Tiwari, C. P. O'Donnell, P. J. Cullen, *Trends Food Sci. Tech*., **20**, 137 (2009).
3. J. A. Guerrero-Beltrán, G.V. Barbosa-Cánovas, B. G. Swanson, *Food Rev. Int*., **21**, 411 (2005).
4. D. F. Keenan, N. P. Brunton, T. R. Gormley, F. Butler, B. K. Tiwari, A. Patras, *Innovative Food Sci. Emerg.Technol.*, **11**, 551 (2010).
5. H. W. Yeom, C. B. Streaker, Q. H. Zhang, D. B. Min, *J. Agr. Food Chem*., **48**, 4597 (2000).
6. M. Morales-de la Peña, L. Salvia-Trujillo, M. A. Rojas-Graü, O. Martín-Belloso, *Innov. Food Sci. Emerg. Technol.*, **43**, 872 (2010).
7. F. Chemat, Z. Huma, M. K. Khan, *Ultrason. Sonochem*., **18**, 813 (2011).
8. M. A. Rostagno, M. Palma, C. G. Barroso, Anal. Chim. Acta, **597**, 265 (2007).
9. H. Q. Zhang, G. V. Barbosa-Canovas, V. M. Balasubramaniam, C. P. Dunne, D. F. Farkas, J. T. C. Yuan, Non thermal Processing Technologies for Food, Wiley Blackwell, 2011.
10. M. Morales-de la Peña, L. Salvia-Trujillo, M. A. Rojas-Graü, O. Martín-Belloso, *LWT Food Sci. Technol.*, **43**, 872 (2010).
11. I. Oey, I. V. Plancken, A. V. Loey, M. Hendrickx, *Trends Food Sci. Tech*., **19**, 300 (2008).
12. G. C. Yen, H. T. Lin, *Int. J. Food Sci. Tech*., **31**, 205 (1996).
13. N. S. Isaacs, High Pressure Food Science, Bioscience and Chemistry, The Royal Society of Chemistry, Cambridge, 1998.
14. G. Ferrari, P. Maresca, R. Ciccarone, J. Food Eng., **100**, 245 (2010).
15. W. Suthanthangjai, P. Kajda, I. Zabetakis, *Food Chem.*, **90**, 193 (2005).
16. B. De Ancos, E. Gonzalez, M. Pilar Cano, *J. Agr. Food Chem*., **48**, 3542 (2000).
17. M. Corrales, S. Toepfl, P. Butz, D. Knorr, B. Tauscher, *Innov. Food Sci. Emerg.Technol*., **9**, 85 (2008).
18. S. Zhang, Z. Junjie, W. Changzhen, *Int. J. Pharm*., **278**, 471 (2004).
19. H. Dornenburg, D. Knoor, *Food Biotechnol*., **7**, 35 (1993).
20. K. N. Prasad, J. Hao, J. Shi, T. Liu, J. Li, X. Y. Wei, *Innov. Food Sci. Emerg.Technol*., **10**, 413 (2010).
21. A. Zulueta, M. J. Esteve, A. Frígola, *Innov. Food Sci. Emerg.*, **11**, 84 (2010).
22. G. Oms-Oliu, I. Odriozola-Serrano, R. Soliva-Fortuny, O. Martín-Belloso, *Food Chem*., **11**5, 1312 (2009).
23. L. Aguiló-Aguayo, A. Sobrino-Lopez, R. Soliva-Fortuny, O. Martın-Belloso, *Innov. Food Sci. Emerg.*, **9**, 455 (2008).
24. M. Guderjan, S. Toepfl, A. Angersbach, D. Knorr, *J. Food Eng*., **67**, 281 (2005).
25. I. Odriozola-Serrano, R. Soliva-Fortuny, O. Martín-Belloso, *LWT Food Sci. Technol*., **42**, 93 (2009).
26. J. Shi, M. Le Maguer, *Crit. Rev. Food Sci. Nutr*., **40**, 1 (2000).
27. K. El-Belghiti, Z. Rabhi, E. Vorobiev, *Food Bioprod. Process*., **85**, 24 (2007).
28. K. El-Belghiti, E. Vorobiev, *Food Bioprod. Process*., **82**, 226 (2004).
29. N. Lopez, E. Puertolas, S. Condon, J. Raso, I. Alvarez, *J. Food Eng*., **90**, 60 (2009).
30. B. I. O. Ade-Omowaye, A. Angersbach, N. M. Eshtiaghi, D. Knorr, *Innov. Food Sci. Emerg. Technol.*, **1**, 203 (2001).
31. M. Zenker, V. Heinz, D. Knorr, *J. Food Prot*., **66,** 1642 (2003).
32. S.Z. Salleh-Mack, J.S. Roberts, *Ultrason. Sonochem*., **14**, 323 (2007).
33. D. Knorr, D. Zenker, V. M. Heinz, D. Lee, *Trends Food Sci. Technol.*, **15**, 261 (2004).
34. L.H. Cheng, C.Y. Soh, S.C. Liew, F.F. Teh, *Food Chem*., **104**, 1396 (2007).
35. A. Rawson, B. K. Tiwari, A. Patras, N. Brunton, C. Brennan, P.J. Cullen, C.O. Donnell, *Food Res. Int*., **44**, 1168 (2010).
36. K. Vilkhu, R. Mawson, L. Simons, D. Bates, *Innov. Food Sci. Emerg. Technol*., **9**, 161 (2008).
37. Z. Lianfu, L. Zelong, *Ultrason. Sonochem*., **15**, 731 (2008).

ВЛИЯНИЕ НА ИНОВАТИВНИТЕ ТЕХНОЛОГИИ ВЪРХУ КАЧЕСТВОТО НА ПЛОДОВЕТЕ И ЗЕЛЕНЧУЦИТЕ

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(Резюме)

Процесите, свързани с преработката на храните, оказват значително въздействие върху стабилността на хранителните вещества и като цяло увреждат антиоксидантите в плодовете, зеленчуците техните продукти. Домашните, конвенционалните, индустриалните и дори нетермичните обработки намаляват нивото на фитохимикали в преработените хранителни продукти. Най-новите тенденции в нетермичните технологии са не само да се получи високо качествени продукти със запазени свойства, но също така да се осигури по-добра функционалност на храната. Въпреки това, някои изследователи съобщават, че резултатите от не-термични процеси, не могат да бъдат различени от тези, получени при термични обработки. Главният фокус на настоящото ревю е да изясни влиянието на не-термични технологии, като високо хидростатично налягане (ВХН), импулсно електрично поле (ИЕП) и ултразвук (УЗ) върху ключови хранителни вещества в плодовете и зеленчуците.