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EC NUTRITION
Review Article

Impact of Nonthermal Treatments on Quantity and Bioaccessibility of Phenolic Compounds in Food Matrix

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Received: October 13, 2017; **Published:** November 30, 2017

Abstract

Novel emerging nonthermal techniques that are alternatives to the traditional heat treatments are topical for a long time in food industry. Phenolic compounds are bioactive compounds have several health promoting effects and have been reported to exhibit antioxidative, anticarcinogenic, anti-inflammatory, antiaggregatory and vasodilating effects. Bioaccessibility, which is defined as the relative amounts of nutrients or phytochemicals released from a complex food matrix in the lumen of the gastrointestinal tract and therefore available for absorption into the body, is the first step for bioavailability. Nonthermal treatments affect the amount of phenolic compounds and bioaccessibility of phenolic compounds in food matrix. There are limited studies investigating effects of nonthermal treatments on quantity and especially bioaccessibility of phenolic compounds. Studies showed that HPP increased bioaccessibility of total flavonoids and some phenolic compounds such as hesperidin, rutin, etc. HPP generally increased bioaccessibility of phenolics, but there also some studies that HPP did not change or decreased bioaccessibility of phenolics. Ultrasound mostly increased bioaccessibility of phenolic compounds, excluding one study that bioaccessibility of phenolic compounds did not change. PEF and HIPEF have different impacts on bioaccessibility of phenolics depending on process conditions and food matrix. As nonthermal treatments can induce significant changes in food structure, it can influence the bioaccessibility of phenolic compounds that are intracellularly located. Consequently, bioaccessibility of phenolic compounds is highly dependent on composition of food matrix, food structure, type of nonthermal technique, processing conditions. This study aims to review the effects of nonthermal treatments such as HPP, ultrasound, PEF, HIPEF and HVED on both the amount and bioaccessibility of phenolic compounds in different food matrices.

Keywords: *Nonthermal; Phenolic Compounds; Bioaccessibility; Food Matrix; HHP; PEF*

Introduction

Nonthermal treatments have been developed as an alternative to thermal treatments, they provides required safety and shelf life and generally minimizes the effects on nutritional and quality characteristics of foods [1]. Nonthermal processing methods are high pressure processing (HPP), high hydrostatic pressure (HHP), high pressure homogenization processing (HPHP), ultrasound, pulsed electric field (PEF), high intensity pulsed electric field (HIPEF), pulsed light, high voltage electrical discharges (HVED) and microvawe. Each nonthermal process has specific applications in terms of the type of food processed. For instance, high hydrostatic pressure and pulsed light are useful in processing both solid and liquid foods, whereas pulsed electric field (PEF) is suitable for liquid foods [2]. Nonthermal processes has many advantages. These treaments provide inactivation of pathogen microorganisms and unwanted enzymes, as good as thermal treatments. Taste, flavour, odour, texture, nutritional and non-nutritional elements of nonthermal treated food can be preserved better than thermal treated food [3,4].

Phenolic compounds are bioactive non-nutrients in fruits, vegetables, grains and other plant foods with several health benefits [5,6]. These compounds exhibit antioxidant properties. It has been showed that a diet rich in fruits and vegetables, containing various classes of polyphenols, decreases the risk of premature mortality, cardiovascular disorders, age-induced oxidative stress, inflammatory responses and diverse degenerative diseases [7-9]. The fraction of phenolic compounds released from the food matrix following digestion that is solubilised into the gut for intestinal uptake is known as the bioaccessible fraction of the phenolic compounds [10,11]. The concentration of phenolic compounds reaching bioaccesible fraction is much more important than the concentration of these compounds in the food. Because bioavailable fraction can reach the systemic circulation and exert promoting effects on people's health, and bioaccessibility is the first step for bioavailability. Food matrix and processing modify bioaccessibility of phenolic compounds in foods.

Nonthermal treatments have several impacts on quantity and bioaccessibility of phenolic compounds in food matrix. While the effects of nonthermal technologies on the concentration of phenolic compounds has previously been evaluated [11-24], information about the impact of these technologies on the bioaccessibility of phenolic compounds is limited [11,12,17,18]. These review aims to compile the effects of some nonthermal treatments such as HPP, ultrasound, PEF, HIPEF and HVED on both the quantity and bioaccessibility of phenolic compounds.

Impact of nonthermal treatments on quantity and bioaccesibility of phenolic compounds

High Pressure Processing (HPP)

High pressure processing (HPP) has been developed as an alternative to thermal treatments in order to provide nutritious, healthy and safe products with a fresh apperance [2,11]. Destruction of microorganisms and inactivation of enzymes at low or moderate temperatures without changing organoleptic and nutritional properties shows that high-pressure processsing has the potential to be used in the development of value added foods [25]. In addition to cold pasteurization, high pressure processing also can be used for several aims such as blanching, homogenization, which is called high pressure homogenization [12,15,26].

As shown in table 1, total phenolic content (TPC) of foods usually do not change by HPP or increase. Total flavonoid content (TFC) of milk-fruit juice beverage and soymik-fruit juice beverage increased by 400 MPa/<40°C/5 min HHP, while TF of water-fruit juice beverage decreased [11]. Total anthocyanin content of strawberry and blackberry purees didn't change in all studied HHP process conditions [14]. Caffeic acid content in all studied beverages increased by HHP [11].

Food	Process Conditions	TA	TFC	TPC	Reference
Water-Fruit Juice Beverage	400 MPa/<40°C/5 min		D	D	[11]
Milk-Fruit Juice Beverage	400 MPa/<40°C/5 min		I	NC	[11]
Soymik-Fruit Juice Beverage	400 MPa/<40°C/5 min		I	D	[11]
Apple Juice	250 MPa/10 min			D	[12]
Grape Juice	250 MPa/10 min			I	[12]
Orange Juice	250 MPa/10 min			I	[12]
Strawberry Purees	400 MPa/15 min	NC		NC	[14]
Blackberry Purees	400 MPa/15 min	NC		NC	[14]
Strawberry Purees	500 MPa/15 min	NC		NC	[14]
Blackberry Purees	500 MPa/15 min	NC		I	[14]
Strawberry Purees	600 MPa/15 min	NC		I	[14]
Blackberry Purees	600 MPa/15 min	NC		I	[14]
White Cabbage	200 MPa/5 min/20 °C			NC	[15]
White Cabbage	200 MPa/5 min/40 °C			NC	[15]
White Cabbage	400 MPa/5 min/20 °C			NC	[15]
White Cabbage	400 MPa/5 min/40 °C			NC	[15]
White Cabbage	600 MPa/5 min/20 °C			NC	[15]
White Cabbage	600 MPa/5 min/40 °C			NC	[15]
Apple Juice	100 MPa/4°C			NC	[16]
Apple Juice	200 MPa/4°C			NC	[16]
Apple Juice	300 MPa/4°C			NC	[16]
Apple Juice	100 MPa/20°C			NC	[16]
Apple Juice	200 MPa/20°C			NC	[16]
Apple Juice	300 MPa/20°C			I	[16]

Table 1: *Changes of phenolics in foods after HPP.*

(TA: Total Anthocyanins; TFC: Total Flavonoid Content; TPC: Total Phenolic Content; I: Increase; D: Decrease; NC: No Change)

There are limited studies researching HHP effect on bioaccessibility of phenolic compounds. As shown in table 2, bioaccessibility of phenolics generally increased by HPP [11,12]. TFC of all studied beverages increased by 400 MPa/<40˚C/5 min [11]. These studies showed that HPP conditions and food matrix modulated the bioaccessibility of phenolic compounds. Therefore, phenolic compound type, food matrix and processing conditions should be considered when functional foods are developed in order to avoid undesirable interactions that could decrease the bioaccessibility and bioavailability of these compounds [11,12]. Additional studies must be performed in order to understand the behavior of phenolic compounds types in different food matrixes and process conditions.

Food	Process Conditions	CA	CHA	FA	*p*-CA	*p*-HA	H	N	Q	R	TFC	TPC	Reference
Water-Fruit Juice Beverage	400 MPa/<40˚C/5 min	I	NC	D	I	NC	I	NC	I	I	I	D	[11]
Milk-Fruit Juice Beverage	400 MPa/<40˚C/5 min	I	I	I	I	NC	I	NC	I	I	I	NC	[11]
Soymik-Fruit Juice Beverage	400 MPa/<40˚C/5 min	NC	NC	NC	NC	I	I	I	NC	I	I	I	[11]
Apple Juice	250 Mpa/10 min		D				D					D	[12]
Grape Juice	250 Mpa/10 min											NC	[12]
Orange Juice	250 Mpa/10 min											NC	[12]

Table 2: *Bioaccessibility changes of phenolics in foods after HPP.*

(CA: Caffeic Acid; CHA: Chlorogenic Acid; FA: Ferulic Acid; p-CA: p-Coumaric Acid; p-HA: p-Hydroxybenzoic Acid; H: Hesperidin; N: Naringenin; Q: Quercetin; R: Rutin; TFC: Total Flavonoid Content; TPC: Total Phenolic Content; I: Increase; D: Decrease; NC: No Change)

Ultrasound

Ultrasound is a very effective innovative technology of food processing, being applicable to many processes for example in the emulsification, crystallization, homogenization, cutting, hydrolysis, extraction and microbial inactivation. The technology is based on the transmission of sound through liquid media at a frequency beyond the human audible range [27,28].

As shown in table 3, ultrasound treatment usually increased or did not change quantity of phenolic compounds. Phenolic compounds are present in the vacuole in soluble form or bound to the cell wall such as pectin, cellulose, hemicelluluose or lignin traces. Ultrasound treatment enhances the disruption of cell wall, and facilitates the release of phenolic compounds [20,29,30].

Food	Process Conditions	TA	TFC	TPC	Reference
Exotic Fruit Juice	32 kj:kg/20 s	NC		NC	[17]
Exotic Fruit Juice	256 kj:kg/160 s	NC		NC	[17]
Cashew Apple Bagasse Puree	75 $W:cm^2$/2 min			I	[18]
Cashew Apple Bagasse Puree	75 $W:cm^2$/2 min			I	[18]
Pear Juice	750 W/20 kHz/25°C		I	I	[19]
Pear Juice	750 W/20 kHz/45°C		D	D	[19]
Pear Juice	750 W/20 kHz/65°C		D	D	[19]
Purple Cactus Pear Juice	1500 W/20 kHz/A:40%/10 min			I	[20]
Purple Cactus Pear Juice	1500 W/20 kHz/A:60%/10 min			I	[20]
Purple Cactus Pear Juice	1500 W/20 kHz/A:80%/10 min			NC	[20]
Purple Cactus Pear Juice	1500 W/20 kHz/A:40%/25 min			NC	[20]
Purple Cactus Pear Juice	1500 W/20 kHz/A:60%/25 min			NC	[20]
Purple Cactus Pear Juice	1500 W/20 kHz/A:80%/25 min			I	[20]
Longan Flower Honey	130 W/20 kHz/A:40/30 min			NC	[21]
Longan Flower Honey	130 W/20 kHz/A:80/30 min			NC	[21]
Lychee Flower Honey	130 W/20 kHz/A:40/30 min			I	[21]
Lychee Flower Honey	130 W/20 kHz/A:80/30 min			NC	[21]
Wildflower Honey	130 W/20 kHz/A:40/30 min			NC	[21]
Wildflower Honey	130 W/20 kHz/A:80/30 min			NC	[21]

Table 3: *Changes of phenolics in foods after ultrasound treatment.*

(TA: Total Anthocyanins; TFC: Total Flavonoid Content; TPC: Total Phenolic Content; I: Increase; D: Decrease; NC: No Change)

There are limited studies searching the inflluence of ultrasound treatments on phenolic compounds, especially studies are scarce on bioaccessibility of phenolic compounds [17-21]. Bioaccessibility changes of phenolics after ultrasound treatment are presented in table 4. In a study [17], ultrasound was used for preservation of exotic fruit juice blend sweetened with *Stevia rebaudiana* and this treatment increased bioaccessibility of total phenolics and did not change bioaccessibility of total anthocyanins. In another study, ultrasound was used as a pre-treatment on air-drying of cashew apple bagasse puree and this treatment increased bioaccessibility of total phenolics [18]. In these two studies, ultrasound treatment had positive effects on bioaccessibility of phenolics, but more studies are needed to clarify the effects of ultrasound technology on different phenolic compound types and food matrices.

Food	Process Conditions	TA	TPC	Reference
Exotic Fruit Juice	32 kj/kg	NC	I	[17]
Exotic Fruit Juice	256 kj/kg	NC	I	[17]
Cashew Apple Bagasse Puree			I	[18]
Cashew Apple Bagasse Puree			I	[18]

Table 4: *Bioaccessibility changes of phenolics in foods after ultrasound treatment.*

(TA: Total Anthocyanins; TPC: Total Phenolic Content; I: Increase; NC: No Change)

Pulsed Electric Field (PEF) and High Intensity Pulsed Electric Field (HIPEF)

Pulsed electric field (PEF) and high intensity pulsed electric field (HIPEF) are nonthermal technologies that inactivate microorganisms and enzymes with preserving sensory and nutritional quality of food [8,11,22,31].

Changes of phenolics in foods after PEF and HIPEF are presented in table 5. Caffeic acid, p-coumaric acid, p-hydroxybenzoic acid, hesperidin, quercetin, total flavonoids are usually increased by PEF and HIPEF treatments. Total phenolic content was not generally affected by PEF and HIPEF treatments [11,17,22-24]. There are limited studies on bioaccessibility of phenolics affected by PEF and HIPEF, these studies are showed in table 6. Bioaccessibility of caffeic acid, p-coumaric acid, hesperidin, quercetin, rutin, total flavonoids were mostly increased by PEF and HIPEF treatments. Bioaccessibility of total phenolic content was depended on food matrix and process conditions. While bioaccessibility of total phenolic content in milk-fruit juice bevarage increased, it decreased in water-fruit juice bevarage by the same HIPEF treatment [11,17].

Food	Process Conditions	TA	TPA	TFC	TPC	Reference
Water-Fruit Juice Beverage	35 kV:cm/4-μs/200 Hz/1800 μs/<35°C			D	I	[11]
Milk-Fruit Juice Beverage	35 kV:cm/4-μs/200 Hz/1800 μs/<35°C			I	NC	[11]
Soymik-Fruit Juice Beverage	35 kV:cm/4-μs/200 Hz/1800 μs/<35°C			I	NC	[11]
Exotic Fruit Juice	25 kV:cm/32 kj:kg/<35°C	NC			NC	[17]
Exotic Fruit Juice	25 kV:cm/256 kJ:kg/<35°C	NC			NC	[17]
Orange Juice	13.82 kV:cm/10.89 J/1033.9 μs/ 31.88°C				NC	[22]
Orange Juice	25.26 kV:cm/51.32 J/1206.2 μs/ 42.60°C				NC	[22]
Fruit Juice-Soy Milk Beverage	35 kV:cm/4-μs/200 Hz/800 μs		I	I		[23]
Fruit Juice-Soy Milk Beverage	35 kV:cm/4-μs/200 Hz/1400 μs		I	I		[23]
Apple Juice	25 kV:cm/0.2 μs/75 μs/16-21°C				NC	[24]
Apple Juice	35 kV:cm/0.2 μs/75 μs/16-21°C				NC	[24]

Table 5: *Changes of phenolics in foods after PEF and HIPEF.*

(TA: Total Anthocyanins; TPA: Total Phenolic Acids; TFC: Total Flavonoid Content; TPC: Total Phenolic Content; I: Increase; D: Decrease; NC: No Change)

Food	Process Conditions	CA	CHA	FA	*p*-CA	*p*-HA	H	N	Q	R	TA	TFC	TPC	Reference
Water-Fruit Juice Beverage	35 kV:cm/4-µs/200 Hz/1800 µs/<35°C	I	D	D	I	D	I	NC	I	I		I	D	[11]
Milk-Fruit Juice Beverage	35 kV:cm/4-µs/200 Hz/1800 µs/<35°C	I	I	I	I	NC	I	NC	I	I		I	I	[11]
Soymik-Fruit Juice Beverage	35 kV:cm/4-µs/200 Hz/1800 µs/<35°C	NC	NC	NC	D	NC	I	NC	I	I		I	NC	[11]
Exotic Fruit Juice	25 kV:cm/32 kj:kg/<35°C										NC		NC	[17]
Exotic Fruit Juice	25 kV:cm/256 kJ:kg/<35°C										NC		I	[17]

Table 6: *Bioaccesibility changes of phenolics in foods after PEF and HIPEF.*

(CA: Caffeic Acid; CHA: Chlorogenic Acid; FA: Ferulic Acid; p-CA: p-Coumaric Acid; p-HA: p-Hydroxybenzoic Acid; H: Hesperidin; N: Naringenin; Q: Quercetin; R: Rutin; TA: Total Anthocyanins; TFC: Total Flavonoid Content; TPC: Total Phenolic Content; I: Increase; D: Decrease; NC: No Change)

High Voltage Electrical Discharges (HVED)

High voltage electrical discharge is a process by which a current flows from an electrode with a high potential into a neutral fluid, by ionizing that fluid a region of plasma around the electrode is being created. Its application is involved in many areas of food processing such as drying, thawing and increasing fruits and vegetables shelf-life. It can comply well with high product quality and low energy consumption during processing [32,33]. Changes and bioaccessibility changes of phenolics in foods after HVED are shown in table 7 and table 8, respectively.

Food	Process Conditions	TA	TPC	Reference
Exotic fruit juice	32 kJ:kg/<35°C	NC	NC	[17]
Exotic fruit juice	256 kJ:kg/<35°C	NC	I	[17]

Table 7: *Changes of phenolics in foods after HVED.*

(TA: Total Anthocyanins; TPC: Total Phenolic Content; I: Increase; NC: No Change)

Food	Process Conditions	TA	TPC	Reference
Exotic fruit juice	32 kJ:kg/<35°C	I	I	[17]
Exotic fruit juice	256 kJ:kg/<35°C	NC	D	[17]

Table 8: *Bioaccesibility changes of phenolics in foods after HVED.*

(TA: Total Anthocyanins; TPC: Total Phenolic Content; I: Increase; NC: No Change)

Conclusion

It is important to analyse whether the digestion process affects phenolic compounds and their stability, as this, in turn, will affect their bioavailability and their possible health effects. Bioaccessibility is the first step of bioavailability.

Nonthermal technologies generally affected positively the quantity and bioaccessibility of phenolic compounds. The bioaccessibility of phenolics is dependent on type of phenolic compounds, food matrix and process conditions. As nonthermal treatments can induce significant changes in the food structure, it can affect the phenolic compounds that are intracellularly located. Nonthermal treatments may enhance the extractability of phenolic compounds, and this result may favor their bioaccessibility. However, additional studies must be performed in order to clarify the overall effects of nonthermal treatments on quantity and especially bioaccessibility of phenolic compounds.

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Volume 12 Issue 1 November 2017
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