Improving Food Quality with Novel Food Processing Technologies

EDITED BY
Özlem Tokuşoğlu • Barry G. Swanson

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To my mother, Özden Tokuşoğlu, a retired teacher and to my father, Armağan Tokuşoğlu, a retired senior colonel, for their great emotional support and cordial encouragements.

Özlem Tokuşoğlu

Contents

Editors

Özlem Tokuşoğlu, PhD, is an associate professor and faculty member of the Department of Food Engineering at Celal Bayar University, Manisa, Turkey. She earned a bachelor's degree (1992) and master's degree (1996) from Ege University, Izmir, Turkey in the Department of Chemistry and a PhD from Ege University in the Department of Food Engineering (2001). She worked as a researcher at Ege University from 1993 to 2001, and was a research associate in the Food Science and Nutrition Department at the University of Florida–Gainesville from 1999–2000. Dr. Tokuşoğlu was an assistant professor at Celal Bayar University, Manisa, Turkey, during 2002–2007.

Dr. Tokuşoğlu was a visiting professor in the Food Science and Nutrition Department at the University of Florida, Gainesville during 1999–2000 and at the School of Food Science, Washington State University, Pullman during April–May 2010. Her study focuses on food quality control, food chemistry, food safety and toxicology, shelf-life of foods, and innovative food processing technologies in foods, beverages, and functional products. Her specific study areas are phenolics, phytochemicals, bioactive antioxidative components, food additives, bioactive lipids, their determination by instrumental techniques, their effects on the quality of food and beverages, oil-fats and functional food technologies, and the novel food processing effects on food bioactives, food toxicants, and shelf-life of foods and beverages.

Tokuşoğlu has conducted academic research studies, delivered keynote addresses, and made academic presentations at Geneva, Switzerland in 1997; Gainesville, Florida, in 1999; Anaheim–Los Angeles, California, in 2002; Sarawak, Malaysia in 2002; Chicago, Illinois, in 2003; Szczyrk, Katowice, Poland in 2005; Ghent, Belgium in 2005; Madrid, Spain in 2006; New Orleans, Louisiana, in 2008; Athens, Greece in 2008; Anaheim–Los Angeles, California, in 2009; Skopje/Üsküp, the Republic of Macedonia in 2009, Chicago, Illinois, in 2010; Munich, Germany in 2010; Jamshoro, Sindh-Hyderabad, Pakistan in 2011; New Orleans, Louisana, in 2011; Boston, Massachusetts, in 2011; Natick, Massachusetts, in 2011; Damghan, Tehran, Iran in 2011; Osnabrück, Germany in 2011, Otsu, Kyoto, Japan in 2012; Chicago, Illinois, in 2013; Philadelphia, Pennsylvania, in 2013; Las Vegas, Nevada, in 2014; and San Francisco-Albany, California, in 2014. She has professional affiliations with the Institute of Food Technologists (IFT) and American Oil Chemists' Society (AOCS) in the United States and has a professional responsibility with the Turkey National Olive and Olive Oil Council (UZZK) as a research and consultative board member.

As conference chair, Professor Tokuşoğlu organized and directed the International Congress titled *ANPFT2012* (Advanced Nonthermal Processing in Food Technology: Effects on Quality and Shelf-Life of Food and Beverages) in May 7–10, 2012 at Kusadasi-Aegean, Turkey. She served as an organizing committee member at the 2nd International Conference and Exhibition on Nutritional Science & Therapy Conference in July 2013 in Philadelphia, USA and cochair at the *Food*

Technology 2014 conference (3rd International Conference and Exhibition on Food Processing and Technology) in July 2014 in Las Vegas, USA. She is currently chair of the Food Technology 2015 conference in August 10–12 in London, UK. Dr. Tokuşoğlu is an editorial board member of the *International Journal of Food Science and Technology* (*IJFST*) and the *Polish Journal of Food and Nutrition Sciences (PJFNS).* Dr. Tokuşoğlu has several editorial and reviewer assignments in the Science Citation Index (SCI) and international index covered journals. She has published a scientific edited book titled *Fruit and Cereal Bioactives: Chemistry, Sources and Applications* by CRC Press, Taylor & Francis Group, and another book titled *Food By-Product Based Functional Food Powders* by CRC Press, Taylor & Francis Group, is in progress. She has published many research papers in peer-reviewed international journals, international book chapters, and international presentations (as oral and posters) presented at international congresses and other organizations. She was the principal administrator and advisor for the theses of four master's students, and currently one doctorate student and one master's student are under her supervision.

Barry G. Swanson, PhD, is Emeritus Regents Professor of the School of Food Science at Washington State University and the University of Idaho. Dr. Swanson's research interests range from studies of legume protein digestibility and storage quality in collaboration with the Institute for Nutrition in Central America and Panama (INCAP) supported by the USAID Collaborative Research Support Program (CRSP), to initial studies with sucrose fatty acid polyesters, syntheses of fat substitutes, alternative fat replacers and methods to improve the quality of reduced fat cheeses. More recent research interests focused on the implementation of ultra-high pressure to improve cheese yield and the hydrophobic functional properties of whey proteins. Dr. Swanson has coauthored more than 200 research manuscripts and 35 book chapters. He takes pride in having mentored 47 MS and 24 PhD students who now are successfully pursuing professional careers across the United States and around the world. Dr. Swanson received a College of Agricultural, Human, and Natural Resource Sciences (CAHNRS) Faculty Excellence in Research Award in 2001 and was invited to Michigan State University as a prestigious G. Malcolm Trout Visiting Scholar in 2004. In July 2005, he was recognized as one of ISI Thomson Citation Index's Most Highly Cited Researchers and is ranked 22nd among international authors in agricultural sciences, 1996–2006, by *Science Watch* 17(4), Thomson Scientific.

Dr. Swanson was elected a Fellow of IFT (Institute of Food Technologists) in 2002, and a Fellow of IUFoST (International Union of Food Science and Technology) in 2006. He is a retired editor of the *Journal of Food Processing and Preservation*. Dr. Swanson served for 6 years as executive secretary to the Washington State University (WSU) Faculty Senate, and served as interim director of the merged WSU and University of Idaho (UI) School of Food Science. He was promoted to the prestigious rank of Regents Professor at WSU and elected to the IFT Board of Directors in 2009. The professor retired in May 2011 and is currently serving on the IFT Education Advisory Panel and 2013 AMFE Food Chemistry Program Sub-Panel.

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Part I

Introduction

1 Introduction to Improving Food Quality by Novel Food Processing

Özlem Tokuşoğlu and Barry G. Swanson

CONTENTS

1.1 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).

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. Zhang et al. (2011) listed the relevant factors to consider when conducting research into novel nonthermal and thermal technologies such as: (1) target microorganisms to provide safety; (2) target enzymes to extend quality shelf life; (3) maximization of potential synergistic effects; (4) alteration of quality attributes; (5) engineering aspects; (6) conservation of energy and water; (7) potential for convenient scale-up of pilot-scale processes; (8) reliability and economics of technologies; and (9) consumer perception of the technologies. "The search for new approaches to processing foods should be driven, above all, to maximize safety, quality, convenience, costs, and consumer wellness" (Zhang et al., 2011).

Morris et al. (2007) conclude that nonthermal unit operations in food processing interest food scientists, manufacturers, and consumers because the technologies expose fresh foods to minimal impact on nutritional and sensory qualities, yet presumably provide safe shelf-stable foods by inactivating pathogenic microorganisms and spoilage enzymes. The presumption that nonthermal processing is energy efficient and environmentally friendly adds to contemporary popularity. Additional benefits to the food industry include the provision of food safety, value-added heat-labile foods, and new market opportunities.

Nonthermal food-processing technologies are extensive with high hydrostatic pressure (HHP), pulsed electric fields (PEFs), ultrasonics, ultraviolet light, ionizing irradiation (electron beams), and hurdle technologies leading the way. In addition, pulsed x-rays, pulsed high-intensity light, high-voltage arc discharge, magnetic fields, dense-phase carbon dioxide, plasma, ozone, chlorine dioxide, and electrolyzed water are receiving attention individually and as a hurdle in minimal processing protocols (Morris et al., 2007; Sun, 2005; Tokuşoğlu, 2012).

The authors in this book devote attention to improving food functionality with HHP and PEFs. The focus on improving the quality and retaining bioactive constituents of fruits and vegetables and improving the quality of dairy, egg, meat, and seafood products with HHP is evident in many chapters. The inclusion of modeling reviews and simulations of HHP inactivation of microorganisms and the relative effects of HHP processing on food allergies and intolerances broaden the scope of the information provided. Improving food functionality with PEF processes is focused on dairy and egg products, fruit juices, and wine. A chapter attending to industrial applications of HHP and PEF systems and potential commercial quality and shelf life of food products concludes this discussion.

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 (Figure 1.1a).

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

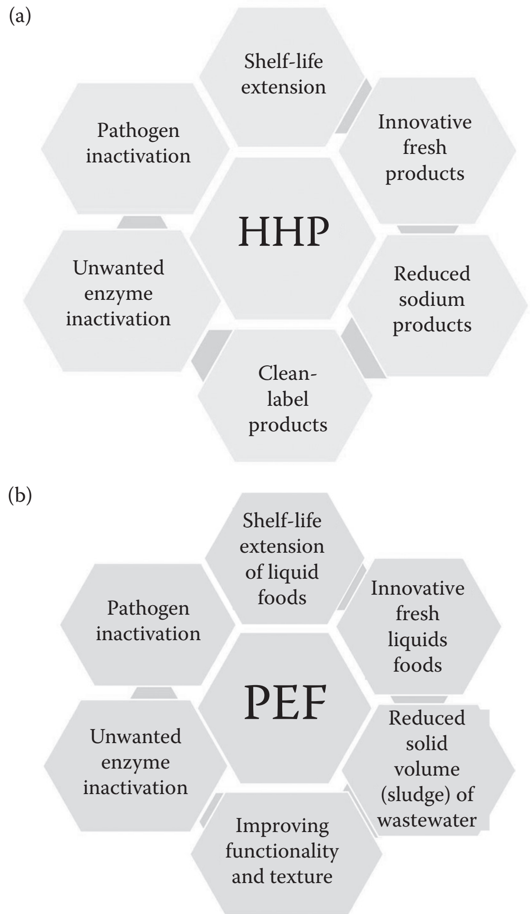

FIGURE 1.1 The usage area of HHP and PEF.

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 (Figure 1.1b). 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).

HHP and PEFs processing of foods continues with a focus on heat-labile acid fruits, vegetables, and dairy foods that meet consumer expectations for a minimally process, safety, fresh-like quality, and convenience. Nonthermal preservation extends shelf life without the addition of preservatives while retaining expected fresh-like appearance, sensory, and nutrient quality. It will be necessary to combine nonthermal and thermal preservation technologies to inactivate heat-resistant spores, potentially contaminating low-acid foods. Commercial nonthermal processing success stories such as pasteurized guacamole, oysters, salsa, yogurt, refrigerated meats, and improved yields of fruit juices, and bioactive compounds from herbs and other plant materials will demonstrate the efficacy and economic success of the technologies in niche markets. Successful research and identification of economic benefits, including energy and water conservation as well as demonstrated safety and fresh-like quality attributes will improve consumer perception of nonthermal technologies and result in further development by the food industry around the world.

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Part II

Improving Food Quality with High-Pressure Processing

2 High-Pressure Processing of Bioactive Components of Foods

Özlem Tokuşoğlu

CONTENTS

2.1 INTRODUCTION

Phenolic compounds are naturally derived bioactive substances that have health-promoting, and/or nutraceutical and medicinal properties. Phenolics occur as plant secondary metabolites that are widely distributed in the plant kingdom and represent an abundant antioxidant component of the human diet.

Recently, there is a great demand for high-quality and convenient products with natural flavor and taste, and a greater appreciation for the fresh appearance of minimally processed food. High-pressure processing (HPP) is a nonthermal processing method that holds promise for retaining wholesomeness and freshness of the processed food products. HPP is an emerging technology that can be used instead of thermal process for pasteurization and sterilization. Recent work provides studies to illustrate the ability of this nonthermal food preservation technology, regarding the preservation of the phenolic bioactives of plant foods and health-related compounds.

2.2 PHENOLICS AS BIOACTIVE COMPOUNDS

Phenolic compounds occur as plant secondary metabolites. Their ubiquitous presence in plants and plant foods, favors animal consumption and accumulation in tissues. Polyphenols are widely distributed in the plant kingdom and represent an abundant antioxidant component of the human diet. Interest in the possible health benefits of polyphenols has increased due to the corresponding antioxidant capacities.

Recent evidence shows that there is a great interest to anticarcinogenic effects of polyphenolic compounds, as well as the potential to prevent cardiovascular and cerebrovascular diseases. As the name suggests, phytochemicals working together with chemical nutrients found in fruits, cereals, and nuts may help slow the aging process and reduce the risk of many diseases, including cancer, heart disease, stroke, high blood pressure, cataracts, osteoporosis, and urinary tract infections (Cheynier, 2005; Meskin et al., 2003; Tokuşoğlu and Hall, 2011).

Polyphenols divide into several subgroups including flavonoids, hydroxybenzoic and hydroxycinnamic acids, lignans, stilbenes, tannins, and coumarins that have specific physiological and biological effects (Andersen and Markham, 2006; Meskin et al., 2003; Tokuşoğlu, 2001; Figure 2.1).

Flavonoids are a major group of polyphenols (Figure 2.2) that include flavan-3-ols, flavonols, flavones, flavanones, isoflavones, anthocyanidins, anthocyanins, flavononols, and chalcons as subgroups (Figure 2.3), which are distributed in plants and foods of plant origin (Crozier et al., 2006; Tokuşoğlu and Hall, 2011).

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 (Thomas-Barberan and Espin, 2001). 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 (Kong et al., 2003; Tokuşoğlu and Yldrm, 2012).

Phenolic contents of the fruits obviously vary from fruit to fruit. This difference may depend on the methods used both for the extraction of the phenolic compounds and methods for analysis. Also, the phenolic compound composition in fruits is

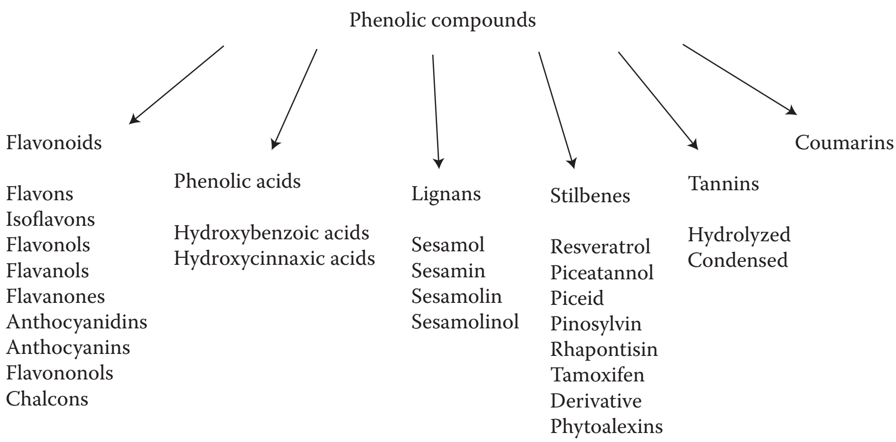

FIGURE 2.1 Family of phenolic compounds. (Adapted from Andersen, Q. M., and Markham, K. R. 2006. *Flavonoids. Chemistry, Biochemistry, and Applications,* CRC Press, Taylor & Francis, Boca Raton, FL; Tokuşoğlu, O., and Hall, C. 2011. *Fruit and Cereal Bioactives, Chemistry, Sources and Applications*, CRC Press, Taylor & Francis, Boca Raton, FL.)

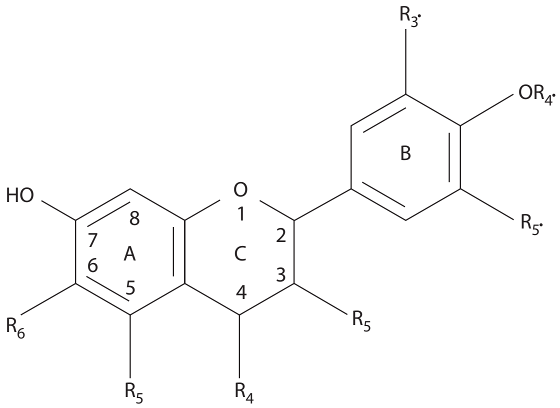

FIGURE 2.2 General chemical structure and numbering pattern for common food flavonoids. Attached R groups: H or OH substituents.

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).

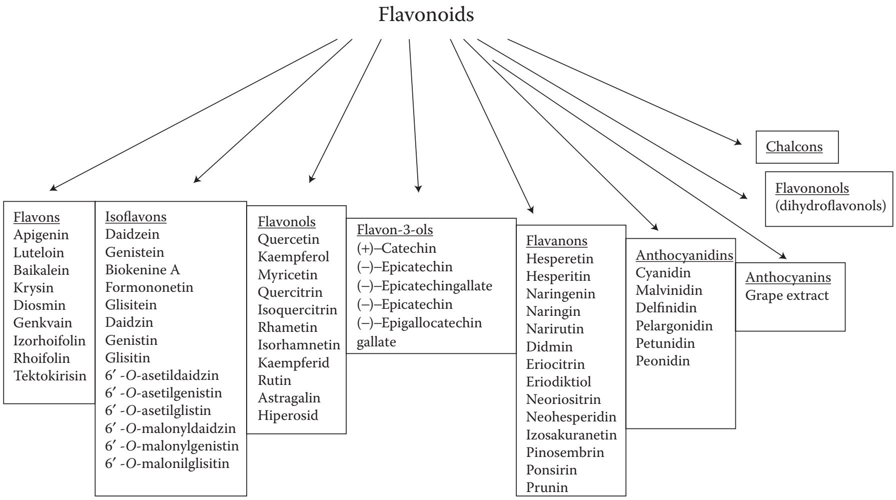

FIGURE 2.3 Flavonoid family in food plants. (Adapted from Tokuşoğlu, Ö. 2001. *The Determination of the Major Phenolic Compounds (Flavanols, Flavonols, Tannins and Aroma Properties of Black Teas*. PhD thesis. Department of Food Engineering, Bornova, Izmir, Turkey: Ege University; Merken, H. M., and Beecher, G. R. 2000. *Journal of Agriculture Food Chemistry*, 48(3), 579–595; Tokuşoğlu, 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.)

2.3 HIGH-PRESSURE PROCESSING AND ITS PREFERENCES AND ADVANTAGES

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; Zabetakis et al., 2000). 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).

Recently, there has been an increasing interest for nonthermal technologies as HPP to preserve fruits, vegetables, daily foods, and beverages (Barbosa-Cánovas et al., 1998). Great technological and research efforts have been made to obtain foods and beverages by HPP without the quality and nutritional damage caused by heat treatments. HHP or ultra-HPP or HPP is one technology that has begun to fulfill its potential to satisfy both consumer and scientific requirements, and is a leading alternative in replacing thermal processing in some food applications in the drive to meet increasing consumer demand for foods featuring improved organoleptic qualities and higher acceptance (Patterson et al., 2008; Bevilacqua et al., 2010; Tokuşoğlu and Doona, 2011a).

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 (Tokuşoğlu, 2011; Tokuşoğlu, 2012a,b; Tokuşoğlu and Doona, 2011a,b; Tokuşoğlu et al., 2010).

The technology is especially beneficial for heat-sensitive products (Barbosa-Cánovas 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; Patterson et al., 2008). HPP technology has been successfully applied in several industrial sectors such as meat, seafood, dairy food, fruit juices, fruit, and vegetable products (Figure 2.4). HPP has been found to inactivate several microorganisms and enzymes. However, it has less effect on low-molecular-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., 2012b; Tokusoglu and Doona, 2011).

Consumer perception of food quality depends not only on microbial quality but also on other food factors such as biochemical and enzymatic reactions and structural changes. In this context, HPP can have an effect on food yield and on sensory qualities such as food color and texture. High pressures (HPs) can also be used to enhance extraction of compounds from foods. Recent studies have shown that high-pressure extraction (HPE) can shorten processing times, and provide higher extraction yields while having less negative effects on the structure and antioxidant activity of bioactive constituents. The use of HPE enhances mass transfer rates, increases cell permeability, and increases diffusion of secondary metabolites (Cheftel, 1995; Dornenburg and Knoor, 1993; Tokusoglu and Doona, 2011).

HHP increases the dissolution rate of the bioactives. A rapid permeation is observed under HPE owing to the large differential pressure between the cell interior and the exterior of cell membranes (Zhang et al., 2005). This situation increases the solvent penetration through the broken membranes into cells or increases the mass transfer rate due to increased permeability (Shouqin et al., 2005). This means the higher the hydrostatic pressure is, the more solvent can enter into the cell. More compounds can permeate the cell membrane that could cause the higher yield of extraction (Shouqin et al., 2005; Zhang et al., 2005).

In other words, 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, 2011; Zhang et al., 2005). Studies on HPP effects on total phenolics determined that these compounds were either

FIGURE 2.4 HHP. (Centre for Nonthermal Processing of Food (CNPF), Washington State University (WSU), Pullman, WA, USA.) (Photo: Tokuşoğlu by Frank Younce, 2010.)

unaffected or actually increased in concentration and/or extractability, following treatment with HP.

2.4 HHP APPLICATIONS ON PHENOLIC AND ANTIOXIDANT BIOACTIVES OF VEGETABLES

In one study given by Vázquez-Gutiérrez et al. (2013), HHP (100–600 MPa/1–3 min/25°C) affected the microstructure and antioxidant properties of onions (cv. Doux). Owing to the fact that onions have antioxidant properties and are an important source of bioactive compounds such as phenols, HHP also affected the extractability of potential health-related compounds of studied onions (Vázquez-Gutiérrez et al., 2013). In this study, it is shown that vitamin C (AA) did not show significant alterations, while the extracted phenolic content and antioxidant activity increased at pressures of 300 or 600 MPa of HHP. Vázquez-Gutiérrez et al. (2013) concluded that HHP produced changes in membrane permeability and disruption of cell walls, favoring the phenolic compounds releasing from the tissue and, in consequence, improving their extractability (Vázquez-Gutiérrez et al., 2013).

Jung et al. (2013) stated the potential effectiveness of HHP on the alterations in quality-related properties of carrot and spinach. In the study described by Jung et al. (2013), better retention of AA and carotenoids was observed as the carrots and spinaches were treated at 100, 300, and 500 MPa for 20 min compared to the thermal processing (Jung et al., 2013). It was shown that the flavonoid amounts were increased with increasing pressure levels, leading to the enhanced antioxidant activity and also, it was determined that the residual polyphenoloxidase (PPO) activities were decreased in carrot and spinach as 6.9–15.1% and 21.3–31.1%, respectively. Jung et al. (2013) reported that HHP could be used as an alternative technology for improving quality of vegetables (Jung et al., 2013).

HHP (400 MPa/10 min, 500 MPa/5 min, and 600 MPa/2.5 min) and high-temperature short time (HTST) (110°C/8.6 s) processing of purple sweet potato nectar was reported by Wang et al. (2012). The quality-related aspects including the microorganism level, total phenolics, anthocyanins, antioxidant capacity, color, and shelf-life prediction during 12 weeks of storage at 4°C and 25°C were determined. It was reported that the purple sweet potato nectar samples stored at 4°C showed better quality and longer shelf life when compared with those stored at 25°C and longer shelf life was observed in HHP-treated samples compared to HTST-treated samples (Wang et al., 2012). The shelf life, estimated in accordance with the zero-order reaction, was 29.256, 35.862, 32.821, and 32.499 weeks for HTST, 400 MPa/10 min, 500 MPa/5 min, and 600 MPa/2.5 min treated purple sweet potato nectar at 4°C, respectively. By comparison, it was 6.343, 7.256, 8.466, and 7.951 weeks for HTST, 400 MPa/10 min, 500 MPa/5 min, and 600 MPa/2.5 min treated purple sweet potato nectar at 25°C, respectively, by Wang et al. (2012).

Figure 2.5 shows the changes of antioxidant capacity (DPPH) in purple sweet potato nectar during 12 weeks of storage at 4°C (a) and 25°C (b). It was determined that the DPPH antioxidant capacity decreased by 23.76–26.97% and 28.27–41.62% in purple sweet potato nectar at 4°C and 25°C after the 12-week storage.

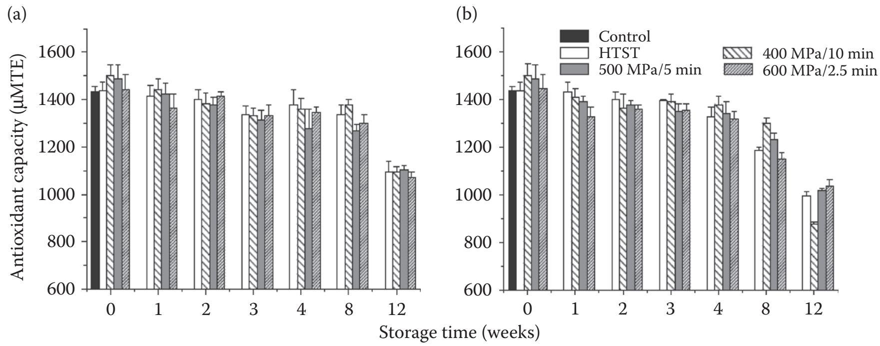

FIGURE 2.5 The antioxidant capacity (DPPH) changes in purple sweet potato nectar during 12 weeks of storage at 4°C (a) and 25°C (b). (Adapted from Wang, Y. et al. 2012. *Innovative Food Science and Emerging Technologies,* 16, 326–334.)

The DPPH antioxidant capacity in HTST-treated samples was higher than that in 400 MPa/10 min treated samples, while lower than 600 MPa/2.5 min, and 500 MPa/5 min treated samples at 25°C (Wang et al., 2012). It was also shown that sweet potato nectar samples stored at 4°C had higher DPPH antioxidant capacity than those stored at 25°C by Wang et al. (2012).

Low-pressure treatments (100–200 MPa for 10–20 min) on green peppers caused a decrease of 10–15% of the initial vitamin C, while in red peppers, these treatments resulted in a 10–15% increase in vitamin C (Barrett and Lloyd, 2011).

Van Eylen et al. (2007) studied the HP (600–800 MPa) and temperature (30–60°C) stabilities of sulforaphane and phenylethyl isothiocyanate in broccoli juice. It was concluded that isothiocyanates are relatively thermolabile and pressure stable. Van Eylen et al. (2007) also stated that myrosinase activity was stabilized by using mild pressure treatments, and thus leading to products with increased isothiocyanate content.

2.5 HHP APPLICATIONS ON PHENOLIC AND ANTIOXIDANT BIOACTIVES OF FRUITS

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).

Ferrari et al. (2010) stated the effects of HHP on the polyphenol contents and anthocyanin levels of several red-fruit-based products (strawberry and wild strawberry mousses, pomegranate juice). 500 MPa/50°C/10 min and 400 MPa/25°C/5 min of HHP conditions were applied for mousse samples (strawberry and wild

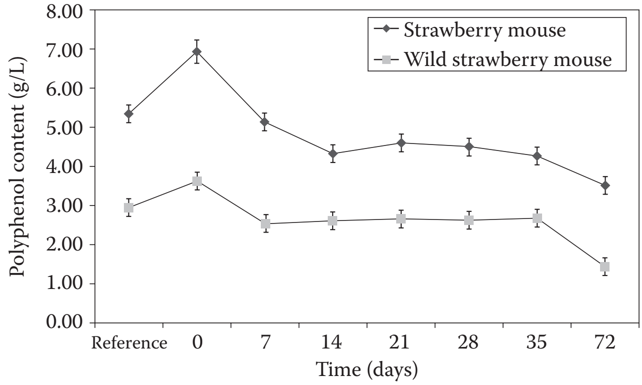

FIGURE 2.6 The polyphenol level of HP-treated strawberry mousse and wild strawberry mousse evaluated at fixed storage times under refrigerated conditions (4°C). (Adapted from Ferrari, G., Maresca, P., and Ciccarone, R. 2010. *Journal of Food Engineering,* 100 (2), 245–253.)

strawberry mousses) and pomegranate juice samples, respectively. 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). Figure 2.6 shows that polyphenol level of HP-treated strawberry mousse and wild strawberry mousse evaluated at fixed storage times under refrigerated conditions (4°C) whereas Figure 2.7 shows the polyphenol content of HP-treated samples of pomegranate juice evaluated at fixed storage times under refrigerated conditions (4°C) (Ferrari et al., 2010). The results by Ferrari et al. (2010) showed the potentiality of

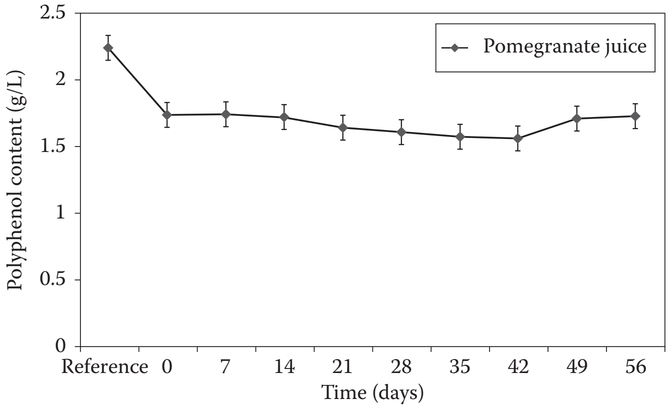

FIGURE 2.7 The polyphenol content of HP-treated samples of pomegranate juice evaluated at fixed storage times under refrigerated conditions (4°C). (Adapted from Ferrari, G., Maresca, P., and Ciccarone, R. 2010. *Journal of Food Engineering,* 100 (2), 245–253.)

the HP processing for the treatment of products rich in thermolabile nutraceutical constituents.

Barba et al. (2012) reported quality changes of blueberry juice during 56 days of refrigerated storage at 4°C after HPP and PEF processing. The study as described by Barba et al. (2012), shows blueberry juice was processed by HP (600 MPa/42°C/5 min). It was determined that it was decreasing lower than 5% in AA content compared with the untreated blueberry juices. At the end of refrigerated storage, unprocessed blueberry juices and similarly PEF-treated juices showed 50% of AA losses whereas they showed 31% losses of AA for HPP-treated blueberry juices (Barba et al., 2012).

Figure 2.8 shows AA remaining levels in untreated, HP- and PEF-treated blueberry juices stored in refrigeration at 4°C. It was found that the AA of HPP-treated blueberry juices maintained more stability during storage time and HPP preserved antioxidant activity (21% losses) more than unprocessed (30%) juices and PEF-treated (48%) juices after 56 days at 4°C (Barba et al., 2012). It was concluded that the second conservation treatment such as refrigerated storage must join to nonthermal technologies and HPP can be a potentially useful unit operation for preserving bioactive compounds in blueberry juices during refrigerated storage (Barba et al., 2012).

Varela-Santos et al. (2012) stated the HHP processing (350–550 MPa for 30, 90, and 150 s) effects on microbial, physicochemical quality, and bioactives of pomegranate juices during 35 days of storage at 4°C. The applied HHP treatment at or over 350 MPa for 150 s resulted in about 4.0 log-cycles reduction of microbial load and these treatments were able to extend the microbiological shelf life of pomegranate juice stored in the above-mentioned conditions. In the study reported by

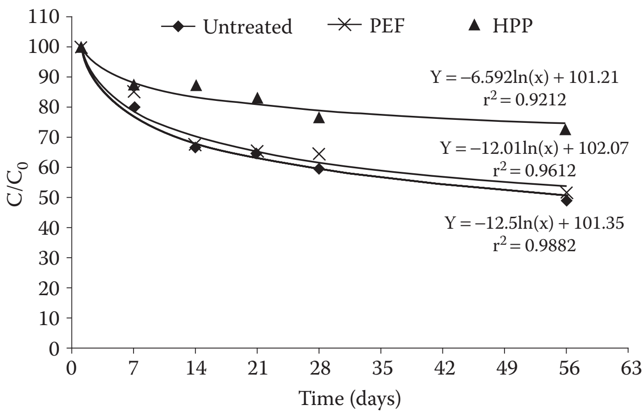

FIGURE 2.8 AA remaining levels in untreated, HP-, and PEF-processed blueberry juices stored in refrigeration at 4°C. The lines interpolating the experimental data points show the fit of a 1.4th-order reaction model. (Adapted from Barba, F. J. et al. 2012. *Innovative Food Science and Emerging Technologies*, 14, 18–24.)

Varela-Santos et al. (2012), the phenolic levels of pomegranate juices showed an increase in the first 3 days and started to decrease after 5 days. It was shown that the phenolic of pomegranate juices reached a steady-state level after 10 days, remaining constant for those treated samples stored at 4°C, until the end of the study (Varela-Santos et al., 2012). It was revealed that HHP has a remarkable effect on the antioxidant activities, IC50, with much lower values when pressure increases; therefore, a smaller IC50 value was obtained at 500 MPa that corresponds to a higher antioxidant activity. The DPPH scavenging activities of the pomegranate juice expressed as an IC50 value were 11– 20 mg/mL at starting point. At 450 and 550 MPa, it exhibited the strongest antioxidant capacity (11–13 mg/mL), followed by the control sample (14 mg/mL). Pérez-Vicente et al. (2004) put forward that the increasing antioxidant activity in pomegranate juices could be due to the extraction of some of the hydrolyzable tannins, present in the fruit rind, and/or related to the increase in ellagic acid, ellagic structures polymerized into ellagitannins, and/or anthocyanin polymers formed during the storage period of fruit (Pérez-Vicente et al., 2004).

Vázquez-Gutiérrez et al. (2011) showed the effects of HHP (for 200/400 MPa treatment during 1/3/6 min) on the microstructure of persimmon fruit cv. "Rojo Brillante" during two different ripening stages including with and without deastringency treatment (95–98% CO_2), and on some bioactive compounds levels. Vázquez-Gutiérrez et al. (2011) reported that HHP treatment produced a significant effect on the persimmon structure by affecting the integrity of cell walls and membranes. Vázquez-Gutiérrez et al. (2011) stated that much of the soluble tannins spread outside vacuoles, carotenoid substances were released from the chromoplasts, cell walls were degraded, and extractability was affected. It was put forward that the HHP application has been induced with the precipitation of soluble tannins in "*Rojo Brillante*" persimmons, which could be related to the loss of astringency (Vázquez-Gutiérrez et al., 2011).

Food matrix and processing parameters are effective on retaining of phenolic compounds. The combination with other emerging methods (ultrasound, γ-irradiation, carbon dioxide, and antimicrobial agents) can also help to retain nutritional and health-related characteristics of these compounds. HHP process condition parameters (pressure, temperature, and time) are important for phenolic quality and quantity (Tokusoglu and Doona, 2011; Tokusoglu et al., 2010).

Qiu et al. (2006) revealed that the highest stability of lycopene (Figure 2.9) in tomato purée was found when pressurized at 500 MPa and stored at 4 ± 1°C

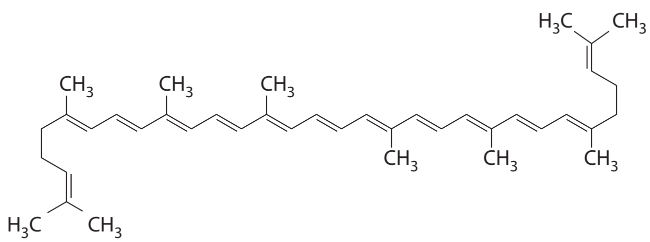

FIGURE 2.9 Lycopene.

in the study, which retained most of the total lycopene content in tomato purée (6.25 ± 0.23 mg/100 g) (Qiu et al., 2006). Table 2.1, parts (a) and (b) show total lycopene losses in lycopene standard (as percentage) and total lycopene content in tomato purée (as mg/100 g), respectively, as a function of storage time at 4 ± 1°C, at six different HHP conditions (Qiu et al., 2006).

It was found that 500 and 600 MPa of pressure led to the highest reduction of lycopene, while 400 MPa could retain the maximal stability of lycopene (Qiu et al., 2006). The highest stability of lycopene in tomato purée was found when pressurized at 500 MPa and stored at 4 ± 1°C. It was established that HHP is an alternative preservation method for producing ambient-stable tomato products in terms of lycopene conservation (Qiu et al., 2006).

The caffeic acid increasing in tomato juices after 28 days of storage could be directly associated with residual hydroxylase activities, which convert coumaric acid into caffeic acid. It was stated that total phenolics in tomato-based beverages and tomato purées appeared to be relatively resistant to the effect of HP (Patras et al., 2009; Barba et al. 2010).

After HPP treatment of tomato purée for 400 MPa/25°C/15 min, the AA and total AA contents decreased as 40% and 30%, respectively (Sánchez-Moreno et al., 2006). Individual carotenoids including β-carotene, β-cryptoxanthin, zeaxanthin, and lutein with antioxidant activity in tomato-based soup appeared to be resistant to a HPP treatment of 400 MPa at 40°C for 1 min, thus resulting into a better preservation of the antioxidant activity in comparison with the thermally pasteurized activity (Sánchez-Moreno et al., 2005).

It was reported that key antioxidants (cyanidin-3-glycoside, pelargonidin-3-glucoside, and AA) in strawberry and blackberry purées (Figure 2.10) and the antioxidant activity of these purées were quantified after various HPP treatments (400, 500, and 600 MPa/15 min/10–30°C) and thermal treatments (70°C/2 min) (Patras et al., 2009).

400, 500, and 600 MPa/15 min/10–30°C and thermal treatment (70°C/2 min) applications of strawberry and blackberry purées were performed by Patras et al. (2009) (Table 2.2). Table 2.2 shows the antioxidant indices of HPP-treated and thermally processed strawberry and blackberry purées. It was found that the three different pressure treatments did not cause any significant changes in AA levels. Following thermal processing ($P_{70} \geq 2$ min), the AA content degraded by 21% compared to the unprocessed purée (Patras et al., 2009). Similarly, no significant alterations in anthocyanin compounds were observed in HPP-treated and HPP-unprocessed purées, while conventional thermal treatments significantly reduced the anthocyanin levels. Antioxidant activity of HPP-treated strawberry and blackberry purées was significantly higher than in thermally processed purées (Patras et al., 2009)

It was stated that dry-weight content of vitamin C in strawberry and blackberry purées was significantly higher in HPP-treated samples (Barrett and Lloyd, 2011). It was reported that the level of retention of AA in guava purée proceeded according to the following decreasing order: (400 MPa for 15 min) > (88–90°C for 24 s) > (600 MPa for 15 min) (Yen and Lin, 1999).

After HPP processing (400 MPa, 40°C, and 1 min), orange juice presented a significant increase on the extractability of each individual flavanone with regard to untreated juice and hence on total flavanone content (15.46%) (Plaza et al.,

TABLE 2.1
Total Lycopene Losses in Lycopene Standard (a) (as Percentage) and Total Lycopene Content in Tomato Purée (b) (as mg/100 g) as a Function of Storage Time at 4 ± 1°C, at Six Different HHP Conditions

		Pressure Applied (MPa)					
Storage Time (Days)	**Untreated (0 MPa)**	**100**	**200**	**300**	**400**	**500**	**600**
a. Lycopene							
0	2.10 ± 0.02	2.10 ± 0.02	2.11 ± 0.02	2.11 ± 0.02	2.13 ± 0.02	20.8 ± 1.12	56.3 ± 3.02
2	3.05 ± 0.23	2.10 ± 0.02	2.11 ± 0.02	2.11 ± 0.02	2.13 ± 0.02	20.8 ± 1.12	56.3 ± 3.02
4	5.22 ± 0.34	2.40 ± 0.05	2.52 ± 0.09	2.34 ± 0.07	2.29 ± 0.09	21.7 ± 1.19	57.4 ± 3.34
8	6.13 ± 0.40	2.49 ± 0.07	2.63 ± 0.09	2.45 ± 0.09	2.39 ± 0.11	22.7 ± 1.21	57.4 ± 3.34
16	7.89 ± 0.44	4.21 ± 0.23	3.29 ± 0.28	3.78 ± 0.22	2.70 ± 0.28	25.7 ± 1.41	60.4 ± 3.76
b. Tomato Purée							
0	5.16 ± 0.12	5.33 ± 0.13	5.39 ± 0.11	5.48 ± 0.12	5.55 ± 0.12	6.25 ± 0.23	5.10 ± 0.10
2	5.18 ± 0.13	5.39 ± 0.12	5.42 ± 0.12	5.50 ± 0.13	5.50 ± 0.13	6.20 ± 0.21	5.11 ± 0.11
4	5.18 ± 0.13	5.37 ± 0.12	5.43 ± 0.12	5.51 ± 0.13	5.50 ± 0.13	6.21 ± 0.20	5.10 ± 0.12
8	5.17 ± 0.13	5.37 ± 0.13	5.40 ± 0.15	5.51 ± 0.13	5.48 ± 0.14	6.19 ± 0.22	5.08 ± 0.10
16	4.37 ± 0.10	5.17 ± 0.12	5.22 ± 0.16	5.26 ± 0.12	5.18 ± 0.13	6.11 ± 0.23	4.88 ± 0.12

Source: Adapted from Qiu, W. et al. 2006. *Food Chemistry*, 97, 516–523.
Note: Values reported are means of triplicate determinations ($n = 3$) ± SD.

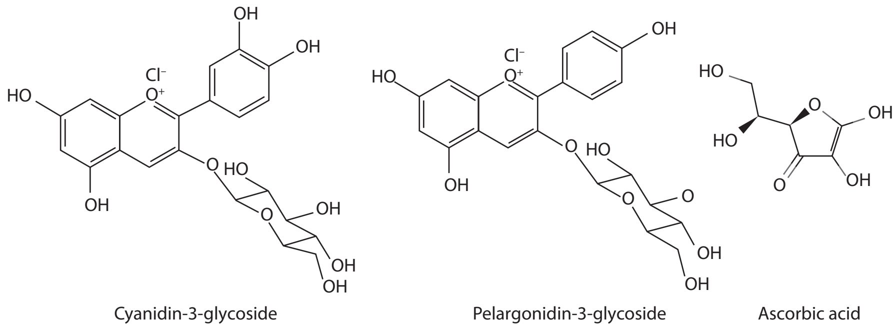

FIGURE 2.10 Key antioxidants of strawberry and blackberry purées.

2011). Regarding the main flavanones identified in orange juice, HP treatments (400 MPa/40°C/1 min) increased the content of naringenin by 20% and by 40% the content of hesperetin in comparison with an untreated orange juice (Oms-Oliu et al., 2012). These data are in accordance with those obtained by other authors showing higher extraction of phenolic compounds due to HPP and the levels of phenols increased significantly in HP-treated (600 MPa, 20°C, and 15 min) strawberry and blackberry purées (9.8% and 5.0%, respectively).

The litchi is the sole member of the genus *Litchi* in the soapberry family Sapindaceae and it is a tropical fruit tree. The litchi (*Litchi chinensis* Sonn.) is a fragranced fruit with a sweet taste. After 30 min of HPE of litchi fruit pericarp (LFP), the extract yield, total phenolic level, 1,1-diphenyl-2-picrylhydrazyl radical scavenging activity (DPPH), and superoxide anion scavenging ability were carried out (Prasad et al., 2009a). The extraction yield by treatments of 400 MPa HPE for 30 min was 30%, while that by conventional extraction (CE, control) was 1.83%. There was no significant difference in the total phenolic content (as mg/g DW) among the two extraction methods (HPE and CE). It was found that the DPPH radical scavenging activity obtained by HPE (400 MPa) was the highest (74%) level (Prasad et al., 2009a) (Table 2.3).

Epicatechin (EC) and epicatechingallate (ECG) were identified and quantified as the major flavonoids of litchi, while catechin (C) and procyanidin B_2 (Pro B_2) (Figure 2.11) were identified as the minor litchi phenolic compounds (Prasad et al., 2009a). The total flavonoid content of litchi was 0.65, 0.75, 0.29, and 0.07 mg/g dry weight by HPE at 200 and 400 MPs, ultraextraction (UE), and CE, respectively. It was reported that the yield of flavonoid extraction increased 2.6 times in comparison with UE, and up to 10 times compared with CE (Prasad et al., 2009a) (Table 2.3).

The longan fruit ("dragon eyes") (*Dimpcarpus longan* Lour.) is edible, extremely sweet, juicy, and succulent in superior agricultural varieties, and apart from ingested fresh, is also often used in East Asian soups, snacks, desserts, and sweet-and-sour foods, either fresh or dried, sometimes canned with syrup in supermarkets. Prasad et al. (2009b) indicated the extraction of longan fruit pericarp by various pressures of HPP (200 – 500 MPa/2.5 – 30 min of duration at 30 – 70°C) and by different solvent concentration (25 – 100%, v/v) and solid-to-liquid ratio (1:25–1:100, w/v) (Prasad et al., 2009b).

TABLE 2.2
Antioxidant Indices of HPP-Treated and Thermally Processed Strawberry and Blackberry Purées

	Antiradical Power $(g/L)^{-1}$		Total Phenols (mg GAE/100 g DW)^{e}		Anthocyanin (mg/100 g DW)		Ascorbic Acid (mg/100 g DW)	
Treatment	**Strawberry**	**Blackberry**	**Strawberry**	**Blackberry**	**Strawberry**	**Blackberry**	**Strawberry**	**Blackberry**
Unprocessed	1.55 ± 0.07^{a}	2.86 ± 0.23^{a}	855.02 ± 6.52^{a}	1694.19 ± 3.0^{a}	202.27 ± 0.50^{a}	1004.90 ± 8.60^{a}	633.10 ± 9.31^{a}	nd
Thermal	1.16 ± 0.01^{b}	2.78 ± 0.26^{a}	817.01 ± 5.26^{b}	1633.62 ± 8.4^{a}	145.82 ± 6.40^{b}	975.28 ± 7.90^{b}	496.11 ± 0.04^{b}	nd
HPP (400 MPa)	1.25 ± 0.05^{b}	3.87 ± 1.11^{a}	859.03 ± 6.56^{a}	1546.26 ± 8.0^{a}	173.34 ± 6.51^{ab}	1039.21 ± 4.51^{a}	574.30 ± 3.93^{c}	nd
HPP (500 MPa)	1.30 ± 0.02^{ab}	3.70 ± 0.57^{a}	926.00 ± 5.93^{a}	1724.65 ± 0.7^{b}	202.53 ± 5.40^{a}	1014.21 ± 0.10^{a}	577.10 ± 6.52^{c}	nd
HPP (600 MPa)	1.33 ± 0.02^{a}	4.80 ± 1.79^{b}	939.01 ± 0.99^{c}	1778.44 ± 6.0^{b}	204.30 ± 1.60^{a}	1014.47 ± 1.00^{a}	599.11 ± 0.60^{c}	nd

Source: Adapted from Patras, A. et al. 2009. Effect of thermal and high pressure processing on antioxidant activity and instrumental colour of tomato and carrot purées. *Innovative Food Science Emerging Technology*, 10, 16–22.

Note: Values are mean ± standard deviation, $n = 3$, and mean values in a column with different letters are significantly different at $p < 0.05$; nd = not detected.

[a] Dry weight.

[b] Expressed as mg/100 g DW pelargonidin-3-glucoside.

[c] Expressed as mg/100 g DW cyanidin-3-glucoside.

TABLE 2.3
HPP, UE, and CE Effects on Litchi Phenolics

	Extraction Methods			
Flavonoids (mg/g DW)[a]	**CE**	**UE**	**HPE at 200 MPa**	**HPE at 400 MPa**
Epicatechin	0.0414 ± 0.001	0.16 ± 0.04	0.32 ± 0.002	0.348 ± 0.06
Epicatechin gallate	0.0121 ± 0.003	0.06 ± 0.01	0.019 ± 0.04	0.2527 ± 0.04
Catechin	0.0002 ± 0.0	0.0020 ± 0.0005	0.0016 ± 0.001	0.0160 ± 0.07
Procyanidin B2	0.0175 ± 0.0003	0.0731 ± 0.0011	0.14 ± 0.03	0.1346 ± 0.03

Source: Adapted from Prasad, K. N. et al. 2009a. *Journal of Food Process Engineering*, 32(6), 828–843.

Note: Values reported are means of triplicate determinations (n = 3) ± SD; DW[a], dry weight; CE, conventional extraction; UE, ultrasonic extraction; HPE, high-pressure extraction.

The extraction yield, total phenolics, and scavenging activities of superoxide anion radical and DPPH radical by HPE were determined and compared with those from a CE for longan fruit pericarp. The HPE provided a higher extraction yield and required a shorter extraction time compared to CE. In addition, the total phenolics and the antioxidant activities of HPE were higher than those produced by CE (Table 2.4) (Prasad et al., 2009b).

Corrales et al. (2008) examined the extraction capacity of anthocyanins that could be used as natural antioxidants or colorants from grape by-products by HPP and other emerging techniques (Figure 2.12). The HPP at 600 MPa showed feasibility and selectivity for extraction purposes. The heat-treatment effect at 70°C combined with the effect of different emerging novel technologies such as ultrasonics (35 KHz), HHP (600 MPa), and PEF (3 kV cm^{-1}) showed a great feasibility and selectivity for extraction purposes. By 1 h of extraction, the total phenolic levels of grape by-products subjected to HHP technology were 50% higher than in the control samples (Figure 2.12). Using novel technology applications, the antioxidant activity of the pomace extracts increased with PEF as fourfold, with HHP

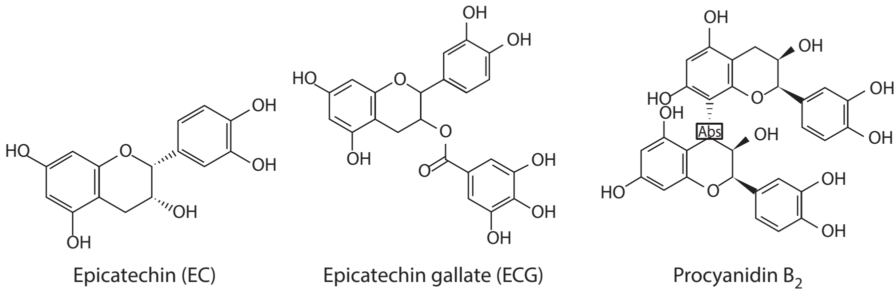

FIGURE 2.11 Major phenolics in litchi (*Litchi chinensis* Sonn.) fruit, EC, ECG, and Pro B_2.

TABLE 2.4
DPPH Scavenging Activity for Longan Fruit

	DPPH Scavenging Activity (%)	
	50 μg/mL	**100 μg/mL**
CE extract	50.1 ± 0.2c	76.6 ± 0.5b
HPE extract	75 ± 0.2b	77.7 ± 0.2a
Ascorbic acid	80 ± 2a	80.4 ± 0.6a
BHT™	77.4 ± 2a	80 ± 1a

Source: Adapted from Prasad, K. N. et al. 2009b. *Innovative Food Science and Emerging Technologies*, 10, 155–159.

Note: Conventional extraction (CE): 50% ethanol, 1:50 (w/v) solid/liquid ratio, and 12 h of extraction time at 30°C and high-pressure extraction (HPE): 50% ethanol, 1:50 (w/v) solid/liquid ratio, 500 MPa pressure, and 2.5 min of extraction time at 30°C. For each treatment means within a column followed by different letters were significantly different at the 5% level.

as threefold, and with ultrasonics as twofold higher than the control extraction (Corrales et al., 2008).

Anthocyanins have been reported to be stable to HP treatments in different fruit juices such as strawberry juice, blackcurrant juice, and raspberry juice (Oms-Oliu et al., 2012). Combined pressure and temperature application of blueberry-pasteurized juice led to a slightly faster degradation of total anthocyanins during storage

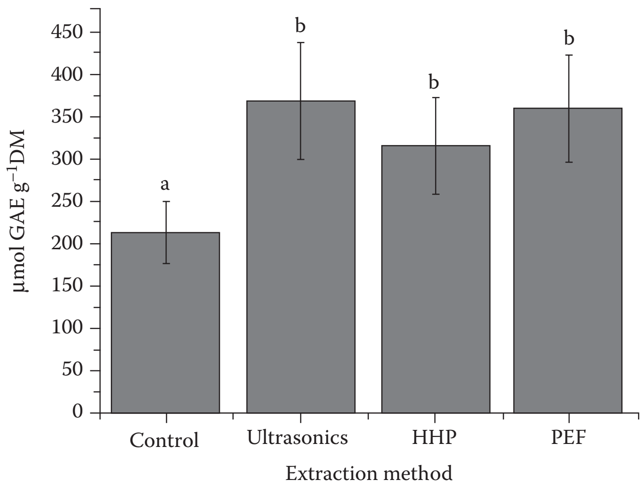

FIGURE 2.12 Total phenolic content (μmol GAE g^{-1} DM) from grape by-products extracted by ultrasonics, HHP, and PEF. (Adapted from Corrales, M. et al. 2008. *Innovative Food Science Emerging Technology*, 9, 85–91.)

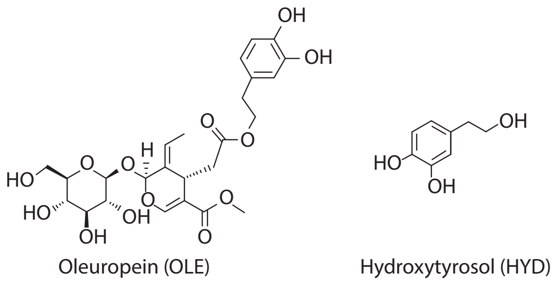

FIGURE 2.13 The major phenolics of table olives.

compared to conventional heat treatments (Buckow et al., 2010). Pressure seems to accelerate anthocyanin degradation at elevated temperatures. This can be related to condensation reactions, involving covalent association of anthocyanins with other flavanols present in fruit juices.

Tokuşoğlu et al. (2010) reported that the total phenolics of table olives increased (2.1–2.5)-fold after HPP (as mg gallic acid equivalent/100 g). Phenolic hydroxytyrosol (Figure 2.13) in olives increased as average (0.8–2.0)-fold, whereas phenolic oleuropein (Figure 2.13) decreased as average (1–1.2)-fold after HPP (as mg/kg DW). Antioxidant activity values varied from 17.238 to 29.344 mmol Fe^{2+}/100 g for control samples, and 18.579 to 32.998 mmol Fe^{2+}/100 g for HPP-treated samples (Tokuşoğlu et al., 2010).

HP causes a significant reduction in the activity of the enzymes although apparent enzymatic activation of PPO in some HP-treated strawberry samples (300 MPa/60°C/30 s) may be caused by the release of membrane- bound enzymes due to pressurization (Terefe et al., 2009). The vitamin A content of persimmon purée increased by 45% with HP processing. It was found that the total carotenoid content was significantly higher in all carrot purées treated with HP. Following the 600 MPa/20°C/15 min treatment, total carotenoids increased by 58% as compared to raw carrots. de Ancos etal. (2000) stated that pressure treatments at 50 and 300 MPa/15 min/25°C for Spain originated Rojo Brillante persimmon fruit purees and at 50 and 400 MPa/15 min/25°C for Sharon persimmon fruit purees increased the amount of extractable carotenoids (9–27%), which are related with the increase of vitamin A value (75–87 RE/100 g) (de Ancos et.al., 2000). Butz et al. (2002) studied the effects of both HP (600 MPa/25°C) and thermal processing (118°C/20 min) and found that neither preservation method resulted in a significant change in total carotenoids in fruit and vegetable juices, or pieces of apple, peach, and tomato.

HPP is an excellent food-processing technology that has the potential to retain the bioactive constituents with health properties in plant foods. HPP-treated foods retain more of their fresh-like features and can be marketed at a premium over their thermally processed counterparts.

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