Chapter 2
Overview on the Food Industry and Its Advancement

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2.1 Introduction

Interest has grown in the modern world in foods that are safe, nutraceutical, composed of more natural colors and flavors, and produced by environmentally friendly methods. The key to the continuous growth of the food industry is innovations in food processing technologies that target the evolving consumer interests. Food processing is moving towards environmental sustainability by means of employing novel technologies that reduce water and energy consumption (Knoerzer et al. 2015). Such novel methods may also have additional advantages such as preserving nutritional value and enhancing food quality (Barbosa-Cánovas et al. 2011). Since, nowadays consumers are more health cautious and focused on what they eat and how it is produced compared to a few decades ago, innovative approaches also allow producers to meet the mounting demands of the competitive global market. The novel techniques currently employed in the food industry are classified into thermal and non-thermal processing. The capabilities, applications, advantages and limitations of these innovative techniques have been concisely discussed in detail in this chapter.

2.2 Non-thermal Food Processing

Non-thermal processing refers to techniques that are effective at sublethal or ambient temperatures. They have the advantage of saving energy while destroying pathogens. In addition, they can increase the shelf life and preserve the nutrients to greater

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extend in comparison to conventional approaches (Cullen et al. 2012; de Toledo Guimarães et al. 2018). These technologies include pulsed electric fields (PEF), supercritical CO_2, high pressure processing (HPP), radiation, ozone processing, etc.

2.2.1 Pulsed Electric Fields (PEF)

PEF involves the extremely brief (μs to ms) use of electric fields with high voltage (usually 20–80 kV/cm). This technique has to an extent replaced conventional methods for the inactivation of microorganisms and enzymes with the aim of preserving food in an environmentally friendly way that avoids the effects of heating. The PEF method inactivates microorganisms owing to the force of the external electric field, which produces single or multiple pores in the microbial cell membranes and destabilizes the microorganisms (Grahl & Märkl 1996). In continuation, cell membrane functions are interrupted and intracellular contents pour out of the cells, effectively destroying the microorganism (De Silva et al. 2018). PEF was initially patented almost 30 years ago, but was first used for large-scale commercial purposes around 15 years ago. In this time, various highly invested groups in Europe and the United States have worked hard to incorporate PEF into the food industry, and researchers around the world have published a large amount of papers on this novel technology. However, despite these widespread efforts, the food industry has only commercially used PEF to a limited extent. A minimum of six different manufacturers have introduced systems of PEF technology in the past two decades, with an average power rating of between 3 and 600 kW and pasteurization capacities of between 3 and 10,000 L/h. Some of these manufacturers work exclusively on PEF, including the Elea company in Germany, the Scandinova company in Sweden, and the Diversified Technologies Incorporation (DTI) in the United States (Kempkes et al. 2016).

2.2.2 High Pressure Processing (HPP)

Another non-thermal (cold pasteurization) food processing technique is HPP, which preserves foods without the need for additives. HPP has proven itself as a method for producing food products that are safe (pathogen-free) and stable. In addition, this technology improves the quality characteristics of food products such as color and flavor. Although the principles upon which HPP acts to inactive microbes have been known for over a century, the HPP technology has been employed in wide scale only in the past two decades (Muntean et al. 2016). By this technology, pressures of up to 600 MPa are applied to inactivate vegetative bacteria, molds and yeast at ambient temperatures. Moreover, spores can be inactivated at high temperatures in a process known as high pressure thermal processing (HPTP) (Jermann et al. 2015). Food preservation is the prime application of HPP in the food industry. Food products are usually spoiled by enzymes, via the catalysis of biochemical processes, and microorganisms. HPP combats this problem by inactivating most of such enzymes and microorganisms. On the other hand, HPP has only a minimal effect on low molecular weight molecules. Hence, useful substances such as pigments, vitamins and flavor compounds remain largely undamaged relative to thermal processing. However, an irreversible change is made to some compounds by means of HPP. Macromolecules such as proteins and carbohydrates are considerably affected by HPP. Proteins are not resistant to high pressures and may be denatured during HPP while carbohydrates can be gelatinized by applying increased pressure instead of elevated temperature (Muntean et al. 2016). HPP is already used at an industrial scale for processing of different types of fish and meat products. However, the high pressure levels required for microbial inactivation may affect texture or aroma of these products and decrease their quality characteristics. This effect has been attributed to the protein denaturation or lipid oxidation under HP conditions. Hence a choice between microbiological safety and sensory attributes is a challenge in the commercial application of HPP. Nevertheless, the careful adjustment of processing conditions such as temperature, pressure, kinetics, the formulation of the product and packaging may counteract the adverse effects of HPP (Duranton et al. 2014).

2.2.3 Irradiation

Irradiation, the application of ionizing radiation, is a flexible and effective non-thermal antimicrobial process used in food processing (Smith and Pillai 2004). High-energy photons such as X-rays or gamma rays, energize the electrons in the atoms of foods. These electrons may leave the atom which is known as ionization or may increase the energy of electrons which is known as excitation. These processes produce free radicals which are very reactive, due to their unpaired electrons which pair up with outer shell electrons of atoms. Water makes up the bulk of mass in most of food materials, thus most of the energy absorption from irradiation changes water molecules into hydroxyl and hydrogen radicals (Diehl 1999). The interaction between organic molecules within food materials and free radicals is the chief mode of action in irradiation. When the degree of free water is limited (e.g. in frozen or dried products) less free radicals are formed per unit of energy applied. Moreover, the mobility of radicals is reduced. Hence, higher doses of irradiation are necessary for the microbial safety in such products (Thayer and Boyd 1995). Food irradiation has been endorsed by international organizations such as Food and Agriculture Organization of the United Nations (FAO), US General Accounting Office (GAO 2000), the American Dietetic Association (ADA 2000) and the UN World Health Organization (WHO 1999) as a safe and effective food-processing treatment. Moreover, it has been addressed in international standards such as Codex Alimentarius Standard and in standards of the International Plant Protection Convention (IPPC) (Carreño 2017; Niemira and Gao 2012). Many food products are responsible for the occurrence of enterohemorrhagic *E. coli* infection, and hemolytic uremic syndrome and salmonellosis (FDA 2009), therefore processes which ensure their microbial safety are required. Although traditional heat treatments such as pasteurization ensures the microbial safety of food products, they result in the loss of textural attributes, vitamins, color, essential oils, flavor and aroma which play the major role in acceptability of food products. On the contrary, irradiation saves the organoleptic and nutritional properties of food products while ensuring their safety. Moreover, it is considered as the most applicable post-packaging treatment. The application of ionizing radiation for food preservation goes back to more than a century. However, its first industrial use, was around the 1950s and was proliferated after the 1960s in the US. Ionizing radiation was first used for the production of sterile meat products in order to substitute frozen and canned military rations (Blackburn 2017; Ruan et al. 2001). Irradiation has been shown to be effective for improving the microbial safety of fresh, chilled or frozen meat and poultry, fruits, vegetables, seasonings, spices, herbs, animal feed and pet food (Mittendorfer 2016). Other applications of irradiation include decomposition of toxins such as ochratoxin A in wheat flour, grape juice and wine (Calado et al. 2018) and aflatoxin B1 in soybean (Zhang et al. 2018), decomposition of antibiotics (Amoxicillin, Doxycycline, and Ciprofloxacin) in milk, chicken meat and eggs, insect disinfestation in wheat and wheat flour, sprout inhibition in potatoes, control *Trichinella spiralis* in pork and delay ripening in fruits (Mittendorfer 2016).

2.2.4 Ozone Processing

Ozone is a natural gas which is found in the atmosphere, however it can also be formed synthetically. It contains three atoms of oxygen (O_3) which has an isosceles triangle form (Muthukumarappan 2011). Ozone is relatively unstable under normal temperature and pressure conditions and is the strongest antimicrobial agent for food contamination (Mahapatra et al. 2005; Muthukumarappan et al. 2000, 2002). The third oxygen atom in ozone molecule is electrophilic and has a small free radical electrical charge. To balance itself electrically, the third oxygen atom seeks for materials with unbalanced opposite charge. Normal healthy cells have a strong enzyme system and a balanced electrical charge thus cannot interact with ozone or its derivatives. While the pathogens or cells stressed by microorganisms are electropositive and carry such opposite charge and attract ozone or its by-products (Muthukumarappan 2011). Ozone Processing is a powerful disinfectant against various microorganisms such as bacteria, viruses, fungi, protozoa, fungal and bacterial spores (Khadre et al. 2001). Ozone inactivates microorganisms by oxidization. The disinfection ability of ozone in foods can be influenced by extrinsic and intrinsic factors, such as pH of food, relative humidity, temperature and presence of organic compounds in food matric (Kim et al. 1999). The ozone residues decompose to non-toxic products such as oxygen. Therefore, it is considered as an eco-friendly antimicrobial agent for industrial applications (Kim et al. 1999). The strong antimicrobial properties of ozone are mainly due to its high oxidizing potential and diffusion through cell membranes (Hunt and Mariñas 1999). The biocidal effects of ozone are 1.5 times more than chlorine and are useful for inactivation of a wide range of microorganisms (Xu 1999). Ozonation has been approved as an antimicrobial agent in food products by FDA and is recognized as Generally Recognized as Safe (GRAS) substance for food industry applications. Consequently, it has received much attention in processing of different food products. The industrial applications of ozone in the food processing include washing, recycling of poultry wash water, vegetable processing, seafood sterilization, sanitation of equipment and surfaces in beverage manufacturing industry, and the treatment of bottled drinking water (Doona 2010; Patil and Bourke 2012). Presently, there are more than 3000 ozone-based water treatment installations in the world and more than 300 potable water treatment plants in the US (Patil and Bourke 2012; Rice et al. 2000). Other applications of ozone have been listed in Table 2.1.

Table 2.1 Applications of ozone treatment in food processing

Product	Target	Result	Reference
Corn	Degradation of aflatoxin B1 (AFB1) in corn	Ozone treatment is a safe, effective and fast method for the degradation of AFB1 and the degradation rate increased by the concentration of ozone and treatment time	Luo et al. (2014)
Potato starch	Starch modification	Ozone is effective in the modification of potato starch structure and functional properties due to its oxidizing properties	Castanha et al. (2017)
Carrot	Evaluation of ozone type (gas or dissolved in water) on the quality of carrots	Ozone can be used for carrots processing in the form of gas and dissolved in water. However, ozone gas was more effective for shelf life extension of carrots	de Souza et al. (2018)
Grains	Studying the impact of ozone treatment on mycotoxins and physicochemical properties of wheat, rice and maize	Ozone improves the functional properties of grains while ensuring their safety	Zhu (2018)
Cantaloupe melon juice	Assessment of juice quality pasteurized by gaseous ozone	Ozone is a useful treatment in low contaminated juice but has negative effects on its physicochemical and nutritional properties	Fundo et al. (2018)
Water and waste milk	Removal of antibiotics	Ozonation decomposed the antibiotics and their decomposition in milk was more effective than in water	Alsager et al. (2018)
Wheat seed	Reduction of insects and microorganisms	Ozone has the potential to reduce insects and contaminating microorganisms in grains with slight or no effect on their quality	Granella et al. (2018)

Besides the advantages of ozone treatments, it has some shortcomings which limit its applications in food industry. Some of these disadvantages have been noted by Muthukumarappan et al. (2000) as listed below:

- Ozone is a poisonous gas which can cause irritation to the throat and nose, loss of vision, pain in the chest, headache, cough, drying of the throat, increase in heartbeat, edema of lungs or even death if inhaled in high extent.
- Doses of ozone that are large enough for decontamination of food products may negatively affect their color, odor or nutritional quality.
- The presence of organic matter increases the ozone consumption and makes it difficult to predict the supply of ozone required for elimination of microbial population in food products.
- In many fruits and vegetables, aqueous ozone should be used for decontamination which require a large amount of water and techniques to overcome the gas/liquid interface.
- Ozone has a short shelf-life; therefore, the prepared aqueous ozone should be used immediately.

To overcome these drawbacks and achieve the target microbial inactivation the mechanism of the interactions between ozone and food components should be studied precisely and the process parameters such as temperature, ozone concentration, etc. should be optimized.

2.2.5 *Supercritical CO_2*

Supercritical is a state of matter higher than its critical temperature and critical pressure (Chung et al. 2013). Supercritical fluids possess high solvation power due to their high density or liquid- like properties, and high diffusivity due to low viscosity values or gas- like properties (Zabot et al. 2014). Carbon dioxide (CO_2), methanol, methane, ethanol, ethane, acetone, and propane are different supercritical fluids used in industry (Ilgaz et al. 2018). Among them, CO_2 is considered to be a low cost, inert, easily available, odorless, tasteless, environmentally friendly, non-flammable, GRAS solvent and has low critical pressure (73 bar) and low critical temperature (304 K) (Chung et al. 2013; Rahman et al. 2018; Soares and Coelho 2012). Supercritical CO_2 is a desirable, green, non-thermal technology for food processing industries by maintaining nutritional, physicochemical and organoleptic properties of fresh food products (Amaral et al. 2018). Nowadays, the supercritical fluid technology has many applications in the food industry such as decaffeination, sterilization and extraction of bioactive compounds and about more than 150 plants profit from this technology worldwide (Chung et al. 2013; del Valle 2015; Knez et al. 2014). Coffee and tea decaffeination and hop flavor extraction are the common industrial applications of supercritical CO_2 (del Valle 2015).

Based on literature, Supercritical CO_2 is a promising technique for extraction (Derrien et al. 2018) pasteurization (Di Giacomo et al. 2016), sterilization (Di Giacomo et al. 2016; Perrut 2012), drying (Knez et al. 2014; Oualid et al. 2018) and enzyme inactivation (Omar et al. 2018) processes. Supercritical carbon dioxide systems can operate in batch, semi- continuous and continuous modes (Omar et al. 2018). In supercritical fluid technology, pressure vessel, as the process chamber, is the most important part of system (Soares and Coelho 2012).

Supercritical extraction led to a fast, high selective, non-thermal process with no solvent residue in product in comparison to conventional procedures, solvent extraction method (Soares and Coelho 2012; Valadez-Carmona et al. 2018). Investigations on extraction yield of supercritical carbon dioxide demonstrated that there are any differences between laboratory scale and industrial scales, but lower extraction in case of kinetic industrial scales is not avoidable because of the greater size of solid particles (García-Risco et al. 2011).

The drawback of using supercritical CO_2 in extraction processing is its nonpolar characteristic that limits polar compounds extraction (Zabot et al. 2014). In order to overcome this limitation, use of polar co- solvent such as methanol, ethanol, hexane, acetone, chloroform and water is a common procedure (Rawson et al. 2012; Tello et al. 2011). Among this polar co- solvents, ethanol is the most common because of its low toxicity and easily removable characteristics.

Briefly, antimicrobial effect of supercritical CO_2 may be due to different mechanisms. Key enzymes inactivation, intercellular pH decreasing and effect on cell membrane are the most important mechanisms (Rawson et al. 2012).

In spite of application of this technology in industry since 1950s, and its advantages, there is also some resistance to upgrade conventional technologies to supercritical carbon dioxide systems as an emerging technology because of expensive initial installation cost and risk of equipment explosion due to high pressure utilization (del Valle 2015; Rahman et al. 2018; Tello et al. 2011; Zhang et al. 2014). Optimization of process variables and bed geometry are of the most important factors for decreasing operation costs by increasing the yield and decreasing processing time (Tello et al. 2011; Zabot et al. 2014). Moreover, elimination of solvent removal step and recovery of carbon dioxide are some of the factors would reduce the operation cost (Subramaniam 2017). Table 2.2 describes some of supercritical CO_2 applications in food industry.

2.3 Thermal Processing

Novel thermal processing such as microwave, ohmic heating (OH) and radio frequency (RF) heating have been considered as alternatives to traditional heat treatments in recent years.

Table 2.2 Some of supercritical CO_2 applications in food industry

Process	Material	Purpose	Treatment conditions	Results	Reference
Ethanol-modified supercritical CO_2	Camelina sativa seed	Extraction of astaxanthin	Pressure: 41.6 MPa, temperature: 36.6 °C, ethanol concentration: 42.0%	The extracted oil contained higher astaxanthin level and antioxidant activity	Xie et al. (2019)
Supercritical CO_2	Bovine heart	Lipid extraction	Pressure: 30 and 40 MPa, temperature: 40 °C	Unsaturated fatty acids were higher (53.09 g/100 g fatty acids) than the control (45.62 g/100 g fatty acids) and hexane-extracted samples. Moreover, microbes were inactivated and low-fat protein rich meat was produced	Rahman et al. (2018)
Supercritical CO_2	Carrot juice	Preservation	Pressure: 25 MPa, temperature: 313 K, juice/CO_2 ratio (w/w): 0.33	Peroxidase was inactivated completely while inactivation rate in case of pectinesterase: was above 70%	Di Giacomo et al. (2016)
Supercritical CO_2 and high power ultrasound	Coriander	Microbial inactivation and drying	Power: 40 W, pressure: 10 MPa, temperature: 40 °C	Dehydrated products presented satisfying microbial content reduction	Michelino et al. (2018)
Supercritical CO_2	Fresh palm fruits	Waterless sterilization	Pressure: 8–40 MPa, temperature: ≤60 °C	Enzyme and lipophilic microorganisms were inactivated	Omar et al. (2018)

2.3.1 Microwave

Microwaves are electromagnetic waves with frequencies between 1 and 30 GHz. Microwave heating is amongst the methods of thermally processing of food products (Meda et al. 2017). With increased standards of living and greater incomes, consumers have demanded novel food processing methods in recent years. Microwave heating has gained popularity due to being a revolutionary technology that preserves the nutritional value of food products (Kalla 2017; Meda et al. 2017). It is well-recognized in terms of its operational safety and large capacity for the retention of nutrients, meaning that heat sensitive nutrients including carotenoids, dietary antioxidants vitamins B and C, and phenols are sparingly lost during heating (Kalla 2017). Various industries have successfully employed microwave heating for food processing. In comparison to conventional methods, the pasteurization and sterilization of food products via microwave heating is claimed to destroy pathogens more efficiently, with significantly less damage to product quality and significantly faster processing (Zhu et al. 2018b). Microwave heating has various applications in food processing, including baking, blanching and cooking. When compared with conventional methods, microwave heating retains a greater amount of nutritional value, quality, taste and flavor, while also preserving food products more effectively. This technology has also dramatically decreased the amount of energy used for food drying (Kalla 2017).

2.3.2 Ohmic Heating (OH)

OH is an alternative thermal processing method for pasteurization, sterilization and cooking of food products that is considered as a high temperature short time process. During OH an alternating current (typically 50 Hz to 100 kHz) passes through the food material and generates a uniform temperature profile inside food due to its electrical resistance. Therefore, the drawbacks such as fouling, deterioration of product quality due to overheating, and having difficulty in heating viscous foods or products with solid fractions which are observed in conventional heat treatments would not occur in OH. OH is effective in saving energy, nutritional and sensory properties of foods and is a more efficient technique in inactivation of spoilage and pathogenic microorganisms (Ruan et al. 2001). One of the potential applications of OH is in the peeling of fruits and vegetables which eliminates the need of lye (Ramaswamy et al. 2005). Thus, it can be considered as an environmentally friendly peeling technique. These features make OH a suitable choice for susceptible foods, liquids containing particles, slurries, and highly viscous materials. OH technology has been known since the nineteenth century and the very first application of OH in food industry was for the pasteurization of milk (Anderson and Finkelstein 1919). But it was abandoned due to high processing costs and lack of inert materials for the electrodes. In the 1980s OH was revived due to the accessibility of improved electrode materials. However, the initial operational costs and lack of knowledge on validation procedures prevent its extensive application in food industry. Furthermore, dependency on electrical resistance may be a disadvantage in heating products which are not ionically loaded (e.g. distilled water, oil and products with high fat content) (Leadley 2008). Currently, OH has been used for a variety of applications as observed in Table 2.3. It is estimated that around 100 commercial plants in the USA, Mexico, Europe and Japan are using OH technique (Leadley 2008). OH is used in an industrial scale in Japan, England, US and Italy for different purposes including pasteurization of liquid egg, meat and vegetable products, to process ready-to-eat sauces, fruit juices, fruit nectars, fruit purée, fruit slices in syrups, tomato paste, soups, meat products, stews, sauces and treatment of heat sensitive liquid materials (Leadley 2008; Mans and Swientek 1993).

Table 2.3 Applications of ohmic heating (OH) in food processing

Product	Target	Result	Reference
Jerusalem artichoke	Extraction of inulin	OH resulted in higher inulin extraction yield compared to conventional heating method	Termrittikul et al. (2018)
Orange juice waste	Extraction of pectin	OH increased the pectin extraction yield more than the conventional heating	Saberian et al. (2017)
Colored potato	Extraction of phytochemicals	OH enhanced extraction of phytochemicals, reduced treatment time and required lower power consumption with no organic solvents (green extraction)	Pereira et al. (2016)
Fermented red pepper paste	Pasteurization	The quality of the samples pasteurized by OH was higher than conventionally heated samples and a 99.7% reduction was observed in Bacillus strains by OH while this value was 81.9% when conventional heating was used	Cho et al. (2016)
Grapefruit and blood orange juices	Pasteurization	OH preserved the carotenoid profile of citrus fruits	Achir et al. (2016)
Blueberry pulp	Heat treatment	The anthocyanin degradation level in samples treated with low voltage OH was lower or similar to conventional heating. However, degradation was increased at higher voltages	Sarkis et al. (2013)
Pomegranate juice	Concentration	OH is an energy efficient system and concentration time was shortened about 56% by OH	Icier et al. (2017)
Sour cherry juice	Concentration	Evaporation was performed successfully and the process time was shortened	Sabanci and Icier (2017)
Shrimps	Cooking	The cooking times of shrimps was reduced by ≈50% in OH and the treatment was more uniform with less color differences compared to conventional cooking	Lascorz et al. (2016)
Rice	Cooking	OH saves more than 70% of energy in comparison with a commercial rice cooker. Moreover, no fouling of rice was observed on the container after cooking	Kanjanapongkul (2017)
Carrot, golden carrot and red beet	Cooking (texture softening)	OH resulted in greater softening rates and can be applied for modification of vegetables texture	Farahnaky et al. (2012)
Pumpkin	Blanching	OH resulted in a faster inactivation of peroxidase, however similar changes were observed in pumpkin color	Gomes et al. (2018)
Tomato	Peeling	OH is an effective treatment for tomato peeling and it is possible to decrease the lye concentration by using ohmic peeling	Wongsa-Ngasri & Sastry (2015)

2.3.3 Infrared (IR) Heating

IR radiation is an electromagnetic radiation and alternative technology for thermal treatment of food materials (Pawar and Pratape 2017). IR radiation possesses many advantages including equipment simplicity, high speed, low capital cost, uniform heating, low quality deterioration, radiation energy transmission without heating the sample's surrounding air (Adak et al. 2017; Gili et al. 2017; Irakli et al. 2018; Kettler et al. 2017; Van Bockstal et al. 2017; Yılmaz 2016).

Based on IR radiation energy source temperature, three different IR radiation categories are the far-infrared (FIR) (3–1000 μm), middle-infrared (MIR) (1.4–3 μm) and near-infrared (NIR) (0.78–1.4 μm). As the wavelength increases, the penetration depth increases too (Riadh et al. 2015). Far-IR radiation is effective by damaging RNA, DNA, cell proteins and ribosomes to ensure food safety and is applied in pasteurization and sterilization of foods (Hu et al. 2017).

Product energy absorbance depends on the irradiation wavelength and the surface characteristics (Adak et al. 2017). Absorption characteristics of product surface determine the process efficiency (Pawar and Pratape 2017). When the material surface receives IR radiation energy, it transfers to heat and generates into the material with conduction (Gili et al. 2017).

Some of the potential IR applications in food industry are its use for drying, roasting, frying, baking, pasteurization, peeling and blanching (Kettler et al. 2017; Yalcin and Basman 2015). Table 2.4 summarizes some of the application and process conditions of IR heating. Among these, high-quality IR drying of fruit, nuts, and grains, lonely or in combination with other drying methods is its most popular application (Ding et al. 2015). The most important limitation of IR radiation is its low penetration depth that depends on energy wavelength and product characteristics. In order to effective heating of whole food materials, combining IR with heating technologies such as microwave, hot air and other common techniques has been suggested (Adak et al. 2017; Riadh et al. 2015).

2.3.4 Radio Frequency (RF) Heating

RF as a nonionizing electromagnetic radiation is a novel thermal technology in the food industry (Jiang et al. 2018; Pereira and Vicente 2010). Frequencies between 3 and 300 MHz refers to RF but only 40.68, 27.12 and 13.56 MHz are used for medical, scientific and industrial applications, respectively (Huang et al. 2016; Ozturk et al. 2016).

As for microwave heating, the mechanism of temperature rising in RF radiated substance is based on dipole rotation and ionic depolarization and as a consequence, volumetric heating (Kirmaci & Singh 2012; Pereira and Vicente 2010). Volumetric heating reduces heating time, quality deterioration and overheating in comparison to conventional thermal methods and makes RF heating a promising method for

Table 2.4 Infrared (IR) heating applications in food industry

Process	Purpose	Material	Treatment conditions	Results	Reference
Mid-IR radiation in combination with freeze-drying	Drying	Mushroom	Freeze drying time: 4 h Mid-infrared drying after the freeze drying stage at 60 °C until the <12% (w/w) moisture content was reached	IR is a time saving drying process which retains the aroma of products	Wang et al. (2015)
IR radiation heating	Drying	Strawberry	Power: 200 W Temperature: 100 °C Velocity: 1.5 m.s^{-1}	IR drying resulted in retention of nutrients and bioactive compounds and offered good consumer acceptability	Adak et al. (2017)
Hot air and sequential IR	Decontamination and drying	Almond	Hot air and IR drying temperature: 70 °C Tempering: 70 °C	Drying time was decreased in comparison with hot air drying alone Desirable almond oil peroxide value was observed and *Enterococcus faecium* population was reduced	Venkitasamy et al. (2018)
IR radiation in combination with abrasive unit	Dry-peeling system	Hazelnut	Radiation time: 3 min Radiation power: 1600 W Hazelnuts moisture content: 4% (w/w) Abrasive unit: Clearance: 4 mm Rotor speed: 200 rpm Abrasive path length: 36 cm	Process efficiency was: 81.6% and breakage of kernel was 0.87%	Eskandari et al. (2018)
Middle IR radiation	Stabilization	Rice bran	Power: 700 W Time: 7.0 min	Total tocopherol and ϒ-oryzanol contents of treated samples was higher than crude ones Rice bran shelf life was extended to 3 months	Yılmaz (2016)
IR radiation	Stabilization	Wheat germ	Radiation intensity: 4800 W/m^2 Time: 3 min Emitter-sample distance: 0.2 m	Lipase was inactivated, moisture content was reduced and shelf life was extended from 15 to 90 days at room temperature	Gili et al. (2017)

IR radiation	Shelf life improvement	Rough and brown rice	Radiation intensity: 4685 W/m^2 Temperature: 60 °C Tempering: 4 h	Lipase was inactivated and shelf life of brown rice at 35 ± 1 °C and 65 ± 3% relative humidity was extended for 10 months Milling quality was better than ambient and hot air dried samples	Ding et al. (2015)
IR radiation	Final cooking	Meatball	Time: 12 min Application distance: 10.5 cm	Final cooking by IR radiation improved color and texture of ohmically pre-cooked meatballs	Turp et al. (2016)
IR radiation	Roasting	Flaxseed	Radiation intensity: 1150 W/m^2	Hydrogen cyanide (HCN) content of flaxseed was reduced 59%. Tocopherol content of flaxseed oil was increased and higher peroxide value was observed after 6 months of storage	Tuncel et al. (2017)

heating of the semi-solid and solid foods which have low thermal conductivities (Choi et al. 2018; Kim et al. 2012; Ozturk et al. 2016, 2018).

Advantages of RF heating relative to microwave and IR radiation is higher wavelength and penetration depth, which makes it suitable for large bulk and post-package food processing (Jiang et al. 2018; Liao et al. 2018; Zhu et al. 2018a). Due to these unique properties, RF heating is a desired technique for thawing (Erdogdu et al. 2017), drying (Wang et al. 2014), cooking (Schlisselberg et al. 2013), disinfestation (Wang et al. 2010; Zhou et al. 2015), pasteurization (Zheng et al. 2016; Zheng et al. 2017), roasting (Liao et al. 2018), enzyme inactivation (Ling et al. 2018), and tempering (Palazoğlu and Miran 2018), in the food processing industry. Some of the RF applications in food industry is given in Table 2.5.

Application of RF heating in food industry goes back to more than 60 years ago (Rincon et al. 2015). Industrial RF heating systems could be in continuous and batch modes, although continuous systems are more desirable in industrial scale (Erdogdu et al. 2017). Uneven temperature distribution and non- uniform heating is the most important drawback of RF heating prevents its commercialization (Alfaifi et al. 2016). The temperature non- uniformity is related to various factors such as physical, thermal and dielectric properties of food, food and packaging geometries, geometrical configuration of the sample, electrode shape, top electrode voltage, distance between the electrodes, distance between the top electrode and the sample (Erdogdu et al. 2017; Kim et al. 2012; Tiwari et al. 2011).

2.4 Standpoint of Food Experts About Commercialization of Novel Technologies

The acceptance of different food products manufactured by novel technologies is a critical issue in food industries and several researches have been performed to investigate the perception of people about such technologies (Behrens et al. 2009; Evans and Cox 2006). In a study by Jermann et al. (2015) the attitude of people about the potential of novel food processing technologies to be commercialized in future was investigated. To perform this study, two independent groups were designed. One group was based in North America (Survey 1) and the other was located in Europe (Survey 2). Food professionals from universities, industry and government were selected to respond to the surveys in order to identify the currently applied and up-coming food processing technologies, the related regulations, limitations, and factors pertaining to their commercialization. The results of both surveys revealed that microwave (88%), UV (84%) and HPP (80%) were the main currently applied and up-coming (in the next 5 years) food processing technologies in North America. In Europe however, PEF replaced UV in third place. The main motivators behind commercialization were the aims of producing products with higher quality (94%), greater safety (92%) and longer storage life (91%). The main technologies that were identified for current use and use in the next 10 years were HPP and microwave.

Table 2.5 Radio frequency (RF) applications in food industry

Process	Material	Purpose	Treatment conditions	Results	Reference
Hot air-assisted RF heating	Rice bran	Enzyme inactivation	Electrode gap: 10 cm Temperature: 100 °C Hot air treatment time: 15 min	Residual enzymes activities was 19.2% for lipase and 5.5% for lipoxygenase.	Ling et al. (2018)
Hot air-assisted RF heating	Cashew nut kernels	Roasting	Temperature: 120–130 °C	Moisture content of kernels was reduced from 6.2 g/100 g (d. b.) to 1.5 g/100 g within 30 min. Peroxide value and acid value were lower compared with hot air roasted samples (at 140 °C for 30 min)	Liao et al. (2018)
RF heating in combination with antimicrobial agents	Ground beef homogenate	Pasteurization	Temperature: 50 °C	*E. coli* was destroyed (5 log (CFU/ML))	Nagaraj et al. (2016)
Continues RF heating	Tuna fish	Thawing	Frequency: 27.12 MHz	Uniform and volumetric thawing was achieved	Erdogdu et al. (2017)
Continues RF heating	Lean beef	Tempering	Frequency: 27.12 MHz Power: 2 kW	Rapid and uniform tempering of beef was obtained	Palazoğlu and Miran (2018)
Hot air assisted RF heating	Macadamia nuts	Drying	Frequency: 27.12 MHz	Drying was performed uniformly	Wang et al. (2014)

Moreover, geological differences were recognized with Europe having a greater focus on PEF while North America being more centered on UV and radiation technologies. In 10 years' time, Europe anticipated cold plasma and PEF to obtain greater importance while North American professionals thought HPP, microwave and UV will maintain their status as being most important (Jermann et al. 2015).

HPP is the most commercially used novel technology in the food industry and has been applied in an industrial scale in Japan since 1990s. HPP has been reported to be applied in vegetables, fruits, seafood and meat products in order to improve consumer acceptance, inactivation of bacteria, viruses and some of enzymes without affecting nutritional and organoleptic properties of food products. Moreover, experts have stated that HPP has potential to replace conventional heat treatments such as pasteurization (Alegbeleye et al. 2018). It has been documented that PEF technology has been used for commercial applications in different food processing sectors (Deeth and Lewis 2017). For example, the inactivation of vegetative microbial cells (up to 5–6 logs) has been reported for PEF which is identical to ultra-high temperature (UHT) sterilized milk in a very short time (microseconds) (Deeth and Lewis 2017).

2.5 Industrial Applications of Novel Technologies

Based on the unique properties and advantages of novel technologies, in recent years these processes have been applied in a commercial scale in food industry. Table 2.6 gives an overview about the products which are processed by novel technologies in food industry.

2.6 Conclusions

There have been substantial advancements in recent years in the progress of processes with commercial promise in food industry. The application of such treatments led to production of high-quality products, while reducing energy consumption and processing costs. Moreover, most of these technologies are clean and ecofriendly and have less environmental effect than the traditional ones due to replacement of non-renewable resources of energy by renewable ones, reduction of waste water and gas emission. It has also been proven that the application of emerging thermal and non-thermal treatments has the potential to produce safe and healthy food products. However, limitations, such as high investment costs, difficulty in adjustment and control of process operation variables and absence of regulatory approval have retarded a wider exploitation of novel technologies at an industrial scale. To take the advantages of such technologies in a commercial scale and expand their applications, issues associated with consumers' perception and optimization of processing conditions should be considered. To sum-up, some of the novel technologies are already used in food industry and it is expected that some other techniques find more extensive implementation in the food industry within the next few years and replacing or supplementing conventional processing due to being more efficient in preserving the nutritional characteristic of food products, their economic and technical advantages as well as being more environmental friendly.

Table 2.6 Industrial applications of novel technologies

Process	Product	Objectives	Food manufacturers	Equipment supplier
High pressure processing	Juice and beverages, smoothies, sliced and whole pieces of cured ham, chicken or Turkey cuts, ready-to-eat seafoods products, clams, oysters, mussels, crabs, lobsters, cod, shrimp, hake, cheese, baby and infant food	Food safety without artificial preservatives and additives, high nutritional quality, fresh like organoleptic quality, extending the shelf life of the product, enhancement of maturation	Suja, Pulmuone, in 2 food, Hey day, Fruselva, fruity line, Coldpress, AMC juices, Avomix, chic foods, ripe liquid, LA CASA DEL JUGO, Beskyd	Hiperbaric, (Miami, Florida, USA) Avure (Middletown, Ohio, USA)
Pulsed electric fields	Potatoes, sweet potatoes, carrots and cassava, juices and smoothies, dairy products, dried foods, liquid egg products, salad dressing	Restructure raw materials, better production planning, improved quality, bacterial spore inactivation, improved color, low temperature processing, extended market reach, retention of fresh taste, preservation of higher nutritional value, energy saving, extraction of valuable compounds, color extraction, faster extraction, accelerated drying, better sensory attributes, larger volume, better shape, faster moisture release, less shrinkage, in drying, acceleration of brining and marinating in meat products	McCain foods	Elea (Madrid, Spain) Pulsemaster (Bladel, The Netherlands)
Irradiation	Fresh and frozen meat, meat products, poultry, shellfish, fruits and vegetables, sprouts, tubers, natural gums, prepared food, wheat flour, herbs and spices, shell eggs, sea food, grains, cereals and pulses	Disinfestation of foods, disinfestation of spices, insect population control, consumer safety through pathogen reduction, inhibition of sprouting	Krushak foods, Huiskens meats, Omaha steaks, Schwan's food service	Nordion (Ottawa, Canada), Steris (Mentor, Ohio, U.S.A), Gray Star Inc. (Mt. Arlington, New Jersey, USA)

(continued)

Table 2.6 (continued)

Process	Product	Objectives	Food manufacturers	Equipment supplier
Ozonation	Meat and poultry products, seafood, sushi, breweries and wineries, fruits and vegetables, ice	Pest management, food storage, seafood processing, meat and poultry production and processing, Washing fruits and vegetables, cleaning in place (CIP) applications, surface sanitation	Tyson foods	Ozono Elettronica Internazionale (Milan, Italy), Spartan environmental technologies (Beachwood, Ohio, USA)
Supercritical CO_2		Decaffeination, edible oil extraction, Cork treatment,	Diam	Natex (Ternitz, Austria)
Ohmic	Pasteurized liquid eggs, dairy products	Rapid pasteurization and sterilization, improvements in the fermentation process	Campbell	C-Tech innovation (Chester, United Kingdom)
Microwave	Fried snacks, puff snacks, malt, green tea, modified starch, caramel, muesli, meat, bacon, fish, fruits and vegetables	Drying, curing, heating, cooking thawing, dry sterilization, proofing of bakery products	TOPS foods, Profood	Massalfa microwave (Jinan, China), Cellencor (Ankeny, Iowa, USA)
Infrared	Nuts, grains,	Baking, cooking, dehydrating, drying, melting, toasting, roasting, blanching, peeling,	–	Ceramicx (Cork, Ireland),
Radio frequency	Bakery products, snacks, nuts, fruits, vegetables, poultry, meat, fish	Baking and post-baking drying, rapid thawing and tempering, pasteurization, disinfestation and sanitization of nuts, cereals, grains, pulses, seeds	–	Stalam (Nove, Italy), Strayfield (Reading, United Kingdom), Litzler company (Cleveland, Ohio, USA)

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