**Pasteurization in the Kitchen**

Gabriela Precup and Dan-Cristian Vodnar
Faculty of Food Science and Technology, Institute of Life Sciences, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Calea Mănăștur 3–5, 400372 Cluj-Napoca, Romania

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**Introduction**

Thermal processing methods used in the kitchen, like pasteurization, sterilization and blanching, are of crucial importance for food safety and the sensory quality of food (Szponar et al., 2017).

These methods have been extensively used in the food industry to control the spoilage of food by bacteria, fungi and other microorganisms, as well as undesirable enzymes in foods. As a result of applying thermal processing to foods and dishes, physical, chemical and biochemical reactions take place, leading to changes in nutritional value and flavour. Moreover, long heating at high temperatures can also cause quality degradation and render the food product unwholesome (Fellows, 2009). For instance, colour changes, development of off-odours or off-taste, and loss of freshness or nutrients occur frequently during and after thermal processing (Liaotrakaon, 2013).

The scientific understanding of the cooking processes, including the transformation of raw products during thermal processing, is the objective of molecular gastronomy. This “science exploring cooking” offers scientific explanations of the chemical and physical processes related to the preparation and consumption of dishes (This, 1995; 2003; 2013).

Pasteurization is a form of thermal processing that is widely used worldwide in order to reduce spoilage organisms and eliminate vegetative bacteria but not bacterial spores (Fellows, 2017). The method is named after the French chemist and microbiologist Louis Pasteur, who accidentally discovered, during a summer holiday in Arbois in 1864, that microorganisms could cause food spoilage. He had conducted an experiment in order to correct the frequent acidity of the local aged wines and discovered that it was sufficient to heat a young wine to only about 50–60 °C for a short time to kill the “microbes”. He had also noticed that the wine could subsequently be aged and still retain its quality. In honour of Pasteur, the process became known as “pasteurization” (Wilbey et al., 2007).

Later on, the practice of pasteurization became popular in order to improve the quality and shelf-life of foods and ensure consumer safety. It was originally used as a way of preventing wine and beer from souring (Carlisle, 2004). Today, pasteurization has been widely accepted as an effective preservation method for reducing the unwanted vegetative cells of pathogenic and spoilage microorganisms in foods with minimal loss of desired food quality. The goals of pasteurization, besides food decontamination, are also to extend the food shelf-life, promote food safety, and allow the reduction and elimination of chemical preservatives added to foods. In order to satisfy these goals, new techniques have been developed in recent years. The appearance of these emerging techniques also requires a broadening of the definition of pasteurization. However, there is no universally accepted definition for pasteurization. In the United States, the National Advisory Committee on Microbiological Criteria for Foods (NACMCF) defined pasteurization as any process, treatment or combination thereof that is applied to food to reduce the most resistant microorganism(s) of public health significance to a level that is not likely to present a public health risk under normal conditions of distribution and storage.

A great variety of techniques are applied to different foods for pasteurization, including thermal (steam and hot water heating, ohmic heating, microwave heating, infrared processing, etc.) and non-thermal techniques (high-pressure processing, ultraviolet radiation, irradiation, pulsed electric field, chemical treatments, ultrasound, filtration, high-voltage arc discharge, etc.). Many of these techniques (e.g., ohmic heating and pulsed electric fields) can provide higher product quality and better productivity and have less impact on the environment (lower energy consumption, water savings) (Masanet, 2008; Pereira, 2010).

Today, pasteurization as a thermal treatment is applied to many foods, including milk, meat and fish products (e.g., cured cooked ham, hot smoked fish), liquid eggs, crab, fruit juices, beer, wine, dairy products (e.g., milk for making cheese), some sauces, pickles, sauerkraut and food ingredients. The elimination of pathogenic bacteria in foods consumed directly is of paramount importance, while in food products that do not present public health threats, control of spoilage bacteria is the main goal (Silva et al., 2014).

Several types of pasteurization are used in the food industry, including low-temperature, short-time (LTST), high-temperature, short-time (HTST), higher-heat, shorter-time (HHST) and steam pasteurization. The higher the heat, the shorter the time needed to pasteurize a food. Depending on the type of food matrix,
the parameters used are different, but mild heat treatments are preferably used.

**Pasteurization Processes Used in the Food Industry**

**Low-Temperature, Short-Time Pasteurization**

This method depends on a mechanism in which low heat and low pressure are utilized to pasteurize foods such as dairy products. The parameters used might be, for example, at 60–65 °C for 20–40 min. Myer et al. (2016) demonstrated the effectiveness of low-temperature short-time pasteurization (LTST) to extend the shelf-life of milk, as well as keeping equal or better organoleptic characteristics without increased energy consumption and with a significant reduction in microbial load.

**High-Temperature, Short-Time Pasteurization**

High-temperature short-time (HTST) processing, or flash pasteurization, is a method of heat pasteurization of perishable beverages like fruit and vegetable juices, milk, beer and wine. Flash pasteurization is performed to kill spoilage microorganisms prior to filling containers, in order to make the products safer and to extend their shelf-life compared with the unpasteurized foodstuff (Giribaldi et al., 2016).

HTST is extensively used in the milk industry. It involves heating milk rapidly to 72 °C, keeping it there for a few seconds (usually 15 s) and cooling it down immediately. Compared with other pasteurization processes, it maintains colour and flavour better, preserving the functionality of its biologically active components (Browne and Candy, 2001). Modern pasteurizers have many advantages: they are capable of both small and large scales of operation, they are energy efficient, and the process is continuous. Pasteurization should ideally be used in conjunction with sterile fill technology (similar to aseptic processing) to prevent post-pasteurization contamination and ensure product quality (Browne and Candy, 2001).

A pasteurized product has a relatively short expiration date, because only the pathogenic microorganisms are eliminated in order to preserve the organoleptic characteristics of the foodstuff. It is important to note that pasteurized foods can become contaminated, and therefore hygienic practices like handling food properly with clean hands and keeping it at a safe temperature are crucial.

**Steam Pasteurization**

This technique uses heat to control or reduce harmful microorganisms in beef. This system passes freshly slaughtered beef carcasses that are already inspected, washed and trimmed through a chamber that exposes the beef to pressurized steam for approximately 6 to 8 s. The steam raises the surface temperature of the carcasses to 88–93 °C. The carcasses are then cooled with a cold-water spray. This process has proven to be successful in reducing pathogenic bacteria, such as *Escherichia coli* O157:H7, *Salmonella* and *Listeria*, without the use of any chemicals. Steam pasteurization is used on nearly 50% of U.S. beef.

**Sous-Vide Cooking**

“Sous-vide” cooking or “under vacuum” is a method of cooking food in vacuum-sealed plastic bags at precisely controlled temperatures; bags are placed in a water bath or steam environment for longer than normal cooking times (usually 1 to 7 h, up to 48 h or more in some cases). The technique is also defined as a “low-temperature-long-time” cook, or the “cook-in-bag” system. In sous-vide cooking, typical temperatures around 50–85 °C are used, which is why it requires longer heating times compared with conventional cooking methods.

From a culinary viewpoint, this method is used to obtain a uniformly cooked product, ensuring that the inside is properly cooked without overcooking the outside, and to retain moisture. In addition, it contributes to the development of desired organoleptic flavours, creating a consistent and appealing texture, and limits off-flavours due to oxidation (Baldwin, 2012).

Sous-vide cooking has been extensively used and studied since the 1990s, but only in the early 2010s did this method begin to be utilized in restaurants and homes. American and French engineers developed under-pressure cooking as a solution for food preservation in the mid-1960s. They discovered that the food texture and flavour improved when pressure was applied through vacuum sealing. A French chef, Georges Pralus, adopted the method in his kitchen and noticed, for example, that foie gras maintained its appearance and presented a better texture when cooked under pressure. He developed sous-vide cooking and cooked at high temperatures. Another pioneer was Bruno Goussault, who developed the parameters of cooking times and temperatures. In 1974, he presented a study on sous-vide cooking of beef shoulder, which highlighted that using this cooking method would prolong the shelf-life to 60 days. Since then, sous-vide has remained a standard method for cooking beef and other meats in restaurants worldwide.

Compared with other cooking methods, like bain-marie, roasting and grilling, cooking under vacuum has many benefits. It allows heat to be efficiently transferred from the water (or steam) to the food; it increases the food’s shelf-life by eliminating the risk of cross-contamination during storage; it inhibits off-flavours from oxidation; and it prevents evaporative loss of odorant volatiles and moisture during cooking (Baldwin, 2012). Sous-vide cooking applied to vegetables requires temperatures closer to 100 °C, whereas for meat the temperatures could be reduced to 65–70 °C. During cooking at a temperature between 82 and 85 °C, the structure of vegetables dissolves, which results in softening, but the cells walls remain almost intact (Sila et al., 2006). Compared with traditional cooking, sous-vide cooking of vegetables also reduces the degradation and oxidation of pigments, such as chlorophylls and carotenoids (Chiavarro et al., 2012). In the case of meat, sous-vide cooking is applied at 58–63 °C for 10–48 h (beef, pork or lamb), resulting in intense collagen solubilization, which in turn leads to great formation of gelatine, making the meat tender.

Moreover, overcooking can be prevented, as the temperature of the bath is already set and cannot get higher. Therefore, very precise control of cooking and temperature can be achieved (Stringer and Metris, 2017). In order to ensure product safety after mild heat treatment, effective refrigerated storage (time, temperature)
is subsequently necessary, as some bacteria could survive the heat treatment and grow at refrigeration temperatures, contaminating the food products (Baldwin, 2012).

**Pathogens of Concern for Thermal Pasteurization**

As already mentioned, pasteurization has the objective of inactivating pathogenic vegetative microorganisms of public health significance. A mild heat treatment (70–100 °C) inactivates vegetative cells and many enzymes while preserving the nutritional quality of heated vegetables (Aamir et al., 2013).

Recently, *Listeria monocytogenes* has become the target microorganism for pasteurization of meats, seafood and vegetables, instead of *Mycobacterium tuberculosis*, which was the most feared in the past. Pasteurization temperatures are not sufficient to inactivate the spores of *Clostridium botulinum*; therefore, pasteurized foods, especially vegetables with a pH higher than 4.6 and water activity higher than 0.92, need to be refrigerated. However, some pathogenic bacteria can grow even at refrigeration temperatures, resulting in a shorter shelf-life for the food products, of about one month or less (Aamir et al., 2013).

In order to design an optimal pasteurization process and ensure food safety, parameters like the pH, initial microbial load and resistance of the target microorganism, but also the structure and nature of the food product, are important. Therefore, several combinations of time and temperature are selected for microbial control (Aamir et al., 2013).

According to the European Chilled Food Federation, the target for pasteurized and chilled foods is to have a 6 log reduction of the most heat-resistant vegetative pathogen *Listeria monocytogenes* (this treatment will control other vegetative pathogens) or *Clostridium botulinum* (this treatment will not control other spore-forming pathogens such as *Bacillus cereus*) (ECFF, 2006). Therefore, a mild pasteurization at 70 °C for 2.0 min for low-acid food would be suitable for a shelf-life of maximally 10 days at 5 °C, with a 6 log cycle reduction in numbers of *L. monocytogenes*. In addition, a severe pasteurization process at 90 °C for 10.0 min, aiming at a 6D inactivation (heat treatments proposed to eliminate 10^6 non-proteolytic spores) of non-proteolytic *C. botulinum*, allows a product shelf-life of up to six weeks at 5 °C (ECFF, 2006).

For sous-vide cooking, the main pathogens of interest are *Salmonella* species and pathogenic strains of *Escherichia coli*. There are, of course, many other food pathogens, but these two species are relatively heat resistant and require very few vegetative bacteria per gram to make an immunocompromised person sick (Baldwin, 2012). Foods treated with moist heat (steam or hot water immersion) reduce populations of surface organisms that may be responsible for spoilage or cause illness and can also lead to enhanced refrigerated shelf-life (Aamir et al., 2013).

**Physical-Chemical Modifications of Foods during Pasteurization**

The application of different temperatures in the range of 60–100 °C to different foods, for specific periods of time, results in physical, chemical, microbiological and nutritional changes of the final food products.

**Meat**

During processing of meat products, heat is often applied in different ways to enhance their flavour, to extend their shelf-life and to improve their hygienic quality by the inactivation of pathogenic microorganisms. Traditional methods for cooking meat products involve heating the product by immersion in hot water or by steam cooking. In such cooking processes, heat is predominantly transferred by convection from the cooking media to the product surface and then by conduction from the surface to the geometrical centre of the products. This could lead to overheating of the surfaces while waiting for the interior to reach the required temperature. In contrast, low-temperature cooking, between 50 and 65 °C, can generally maintain the nutritional values of the cooked products and is widely used in the food industry (Yu et al., 2017).

**Protein Modifications**

Meat is one of the richest sources of dietary protein. Since meat contains all the essential amino acids that the body requires daily to build proteins, it is also classified as a high-quality, complete protein. The amount of protein present in one portion of meat varies by type and cut, and the content of early postmortem muscle is about 19 g/100 g wet weight (Lawrie and Ledward, 2006). Proteins are responsible for the texture-forming properties of muscle foods, including water-holding, fibre-swelling, extractability, gelation, emulsification and binding. The cooking processes can introduce a wide range of structural changes of its proteins, as meat is composed of approximately 75% water, 20% protein, and 5% fat and other substances. The effects of pasteurization temperature and time on different physico-chemical and microbiological parameters of meat have been studied by many researchers.

Thermal processing causes the oxidation of lipids and proteins, which could finally result in a decrease of meat quality and acceptability (Roldán et al., 2015). When meat is cooked, oxidative changes continue during refrigerated storage, as free radicals from lipid oxidation may induce further oxidation of fatty acids and proteins (Christensen et al., 2013).

Heat will denature the proteins in meat by changing their native conformation and providing the polypeptides with kinetic energy and thus breaking the weak intramolecular forces (such as non-polar interactions, various kinds of electrostatic interactions, and disulfide bonds) that hold the proteins together. Temperature will influence which type of proteins will be denatured and to what extent. As the temperature increases, a protein starts to unfold. When almost all the tertiary and secondary structures are lost, the unfolded proteins may aggregate, have their disulfide bonds shuffled (be oxidized with non-native disulfide bonds), undergo side-chain modifications, and cross-link with other polypeptides. Thus, heat-denatured proteins whose hydrophobic groups have turned outward into the surrounding water, in order to adopt a lower energy state, can interact through non-polar interactions (Yu et al., 2017).

During heating, the myofibrillar proteins (mostly myosin and actin) and the connective tissue proteins (mostly collagen)
contract, while the sarcoplasmic proteins (soluble proteins, enzymes and myoglobin) expand. Specifically, the muscle fibres begin to shrink transversely at 35–40 °C, and shrinkage increases with temperature up to 80 °C. Above 60–65 °C, the muscle fibres shrink longitudinally and cause substantial water loss, and the extent of this contraction increases with temperature. The aggregation and gelation of sarcoplasmic proteins begins around 40 °C and finishes around 60 °C. Connective tissues start shrinking around 60 °C but contract more intensely above 65 °C (Yu et al., 2017).

Changes in meat tenderness and juiciness during cooking strongly depend upon the cooking temperature and time applied; these factors determine collagen solubilization and shrinkage of myofibrillar proteins (This, 2006). The tenderness of meat is increased by dissolving collagen into gelatine and reducing inter-fibre adhesion, which is an important feature when cooking tough meats, which take either a long time or high temperatures to cook. The temperature of 65 °C increases tenderness, as the sarcoplasmic proteins aggregate and gel, and it becomes easier to fracture the meat with the teeth. Over 65 °C and up to 80 °C, the meat is tougher, because the elastic modulus increases and requires higher tensile stress to extend fractures, which means that the meat converts from a viscoelastic to a more or less elastic material (Yu et al., 2017).

Prolonged cooking has been shown to double the tenderness of the meat by dissolving all the collagen into gelatine and reducing inter-fibre adhesion to almost nothing. Cooking beef muscular tissues for 24 h at 55 °C and 60 °C increases its tenderness due to weakening of connective tissue, inactivation of proteolytic enzymes and decreasing myofibrillar tensile strength. Collagen begins to dissolve into gelatine above 55 °C (Tornberg, 2005). Furthermore, the sarcoplasmic protein enzyme collagenase remains active below 60 °C and can significantly tenderize the meat if held for more than 6 h (Becker et al., 2016). In the case of tough cuts of meat, like beef chuck and pork shoulder, it takes 10–12 h at 80 °C or 1–2 days at 55–60 °C to become fork-tender. Intermediate cuts of meat, like beef sirloin, only need 6–8 h at 55–60 °C to become fork-tender, because the tenderization from the enzyme collagenase is sufficient (Becker et al., 2016). Chicken and turkey breasts are moist, plump and juicy when pasteurized between 58 and 63 °C and duck breasts are usually pasteurized at 57 °C for different periods of time in order to kill pathogenic bacteria (Becker et al., 2016).

**Lipid Modification**

Lipids play an important role in food product quality, making them more desirable by improving the organoleptic properties of flavour, colour and texture. In addition, they confer nutritive value on the product, constituting a source of metabolic energy, essential fatty acids and fat-soluble vitamins. On the other hand, the lipid components are susceptible to attack by molecular oxygen, resulting in lipid oxidation, with the generation of cholesterol oxides and alteration of fatty acids.

Oxidation of lipids, also called “autoxidation”, is one of the most important factors in the non-microbial degradation of meat (see also the chapter on this question in this handbook). Lipid oxidation has been extensively investigated in meat because some products of the reaction can readily react with proteins, leading to organoleptic modification and the loss of nutritional value. Lipid oxidation occurs in three phases as a result of many radical chain reactions (initiation, propagation and completion). During the first two phases, compounds like conjugated dienes and hydroperoxides are produced, which further decompose into carbonyl compounds, ketones, alcohols and aldehydes (Broncano et al., 2009; Figueras et al., 2010).

During cooking, lipid oxidation in meat is important for the formation of taste and odour compounds, but at the same time it produces undesirable modifications of consistency, rancidity level, production of toxic compounds or nutritional losses. The major prooxidants in meat lipid oxidation are considered to be the ferric haem pigments. Pigment and lipid oxidation are interrelated, and ferric haems are believed to promote lipid oxidation. The resulting oxidation destroys the haems. Non-haem iron and ascorbic acid may also function as prooxidants in meat. Sodium chloride accelerates oxidation of the triglycerides, although the mechanism of salt catalysis is not completely known. Cooked meat undergoes rapid deterioration due to tissue lipid oxidation. The meat pigment in the cured pink ferrous form does not promote the rapid oxidation undergone by cooked uncured meat.

However, in order to control the lipid oxidation in meat, it is of utmost importance to use the right parameters for temperature and time of cooking. Lower cooking temperature could reduce energy consumption, but a final internal temperature of 65–85 °C must be reached to ensure safety. It is known that high temperatures and long heating times produce oxidative changes in food, which could be highly negative for quality.

The most common method to measure lipid oxidation in meat is the thiobarbituric acid (TBA) test, which determines malondialdehyde (MDA) content; MDA is in many instances the most abundant individual aldehyde that results from lipid peroxidation in foods, and its concentration in meat and fish products can reach 300 μM or more (Reitznerová et al., 2017). The flavour of cooked meat comes from many chemical reactions, among them the glycation reactions, which occur intensely around 130 °C and provide savoury, roast and boiled flavours. Cooked flavour also arises from the thermal and oxidative degradation of lipids (Belitz et al., 2004).

**Fruits and Vegetables**

Fruits and vegetables are a primary source of macronutrients, including fibre and saccharides, micronutrient vitamins (folate, vitamins A and C), minerals (potassium), phenolics, carotenoids and glucosinolates. A range of phytochemicals have high antioxidant capacity and are crucial for preventing nutritional deficiencies and oxidative stress and reducing the risk for various types of cancer, heart disease, diabetes, diverticulosis, stroke, hypertension, birth defects, cataracts and obesity (Barba et al., 2017).

However, fruits and vegetables are highly perishable and need appropriate preservation techniques to prolong shelf-life while maintaining nutritional and sensory qualities. Thermal processing technologies have been commonly used in order to meet these consumer needs.
During the thermal pasteurization of fruits and vegetables, one of the goals is to maintain a fresh-like quality besides achieving microbial inactivation for safety reasons. The endogenous enzymes from fruits and vegetables are inactivated during pasteurization, as they could have a negative effect during processing and storage. While fruits and vegetables are a rich source of vitamins and minerals, boiled or steamed vegetables lose nutrients to their cooking water.

Several articles have reported the effects of thermal pasteurization on the quality of fruits and vegetables, including colour, texture, carotenoids, phenolics, antioxidant activity, vitamins and other nutritional attributes (Barba et al., 2012). The pasteurization of whole fruits and vegetables affects the matrix and its structure; thus, it has an influence on the bioaccessibility of the bioactive compounds therein. It helps release the compounds from the food matrix by hydrolysing the pectins in cell walls, making bioactive compounds more accessible to absorption (Barba et al., 2017). Recent research has now established that food processing operations have positive effects that improve the quality and health benefits of foods (Augustin et al., 2016).

**Saccharide Modification during Pasteurization**

During cooking, the cell walls of fruits and vegetables undergo textural changes and become softer due to chemical and structural transformations of some of their saccharides (mono- and disaccharides). Plant cell walls are complex polysaccharide matrices with diverse structural and physiological roles; the saccharides or dietary fibres found in fruit and vegetable cell walls comprise pectins, cellulose and hemicelluloses (Peng et al., 2017).

Pasteurization of fruits and vegetables causes the hydrolysis of pectins, gelatinization of starches, solubilization of hemicelluloses, and loss of cell turgor. Increased temperatures during pasteurization lead to the breakage of weak bonds between polysaccharide chains. Also, glycosidic linkages in the dietary fibre polysaccharides may be broken. These changes are important from analytical, functional and nutritional points of view.

A decreased association between fibre molecules and/or a depolymerization of the fibre results in solubilization. If the depolymerization is extensive, alcohol-soluble fragments can be formed, resulting in a decreased content of dietary fibre. Moderate depolymerization and/or decreased association between fibre molecules may have only a minor influence on the dietary fibre content, but functional (e.g., viscosity and hydration) and physiological properties of the fibre will be changed. Other reactions during pasteurization that may affect the dietary fibre content and its properties are leakage into the processing water, formation of glycation products, thus adding to the lignin content, and formation of resistant starch fractions. Structural alterations in the cell wall architecture are also important to follow during pasteurization, as these are highly correlated with sensory and nutritional characteristics (Houška and da Silva, 2017).

**Colour and Texture**

Colour plays a vital role in consumer choice and acceptance (Pathare et al., 2013). Such visual appeal comes mainly from pigments such as chlorophylls, anthocyanins and carotenoids. The pasteurization process leads to changes in food colour, influenced by various mechanisms, such as degradation of pigments, oxidation of ascorbic acid, enzymatic browning and non-enzymatic browning (glycation reactions) (Ling et al., 2015).

Colour degradation in fruits and vegetables by thermal pasteurization depends mainly on the heat intensity, duration, media, compounds responsible for colour, and storage time. For example, Koskiniemi et al. (2013) pasteurized three vegetables (broccoli, red bell pepper and sweet potato) and found that the green colour of broccoli florets changed the most, while the sweet potato colour was stable over the course of processing.

Texture is another important characteristic for consumer acceptance and involves a series of physical characteristics that arise from the composition and structure of the food. The texture of the food matrix is modified through pasteurization, and the mechanisms that contribute to texture loss include turgor loss due to the breakdown of cellular membranes and cell wall degradation due to solubilization of pectic material. For example, the texture of starchy vegetables (beans, peas and lentils) is changed at 80 °C by the gelatinization of the starch granules in their cells, making them more digestible. Sous-vide cooked vegetables have been shown to be preferred to boiled vegetables, as the cell walls remain mostly intact and the vegetables become more tender because some of the cementing material that holds the cells together is dissolved, while the nutritive value is also retained (Baldwin, 2012).

**Antioxidant Activity**

Antioxidant capacity depends on the levels of some bioactive compounds in foods, such as phenolics, vitamin C and lycopene. Thermal processing (10 min at 80 °C) of red-grape waste and red-beet waste increased total antioxidant activities when compared with fresh samples due to the increase in levels of betacarotenes and other polyphenols (Vodnar et al., 2017). In addition, the same paper highlighted that the thermally processed samples exhibited stronger inhibitory activity against Salmonella typhimurium when compared with fresh samples. Similarly, processed tomato and sweet corn exhibited higher antioxidant activities than fresh samples due to the increased release of bound phenolic compounds in the food matrices (Dewanto et al., 2002). However, other researchers did not find differences in the antioxidant activity between fresh and pasteurized tomato juice, and explained this by the formation of novel compounds, such as products from the glycation reactions, which have antioxidant activity (Odriozola-Serrano et al., 2008).

**Phenolic Compounds**

Phenolics are important phytochemicals that act as bioactive compounds and exert antioxidant activities. Effects of thermal pasteurization on the total phenolics in fruits and vegetables depend on the matrix, package and storage conditions. For instance, canning of raspberries (100 °C, 28 min) and blueberries (100 °C, 22 min) increased the phenolic content and antioxidant activity by 50% and 53%, respectively (Sablani et al., 2010; Syamaladevi et al., 2012). Strawberry juices pasteurized at 90 °C for 60 s showed a 10% increase in anthocyanin content (Odriozola-Serrano et al., 2008).
Carotenoids

Carotenoids are among the predominant organic pigments and micromotrients present in yellow, orange and dark green leafy vegetables, and include α- and β-carotenes (yellow/orange), lycopene (red/orange), xanthophyll (yellow), lutein and zeaxanthin (green/yellow). Carotenoids are classified on the basis of chemical structure as oxycarotenoids or xanthophylls. The primary carotenoids required by plants for photosynthesis are β-carotenes (yellow/orange), lycopene, violaxanthin and neoxanthin. Other carotenoids localized in fruits and flowers include α-carotene, β-cryptoxanthin, zeaxanthin, antheraxanthin, capsanthin and capsorubin (Lichtenthaler, 1987; Lichtenthaler and Buschmann, 2001). These are important bioactive compounds, and α- and β-carotenes found in carrots and sweet potato have antioxidant roles, being important for vision and reducing the risk of degenerative diseases. Lycopene, another important bioactive compound, which gives the red colour to tomatoes, is considered a potential antioxidant and cancer-preventing agent.

However, carotenoids are not stable to processes like thermal pasteurization and storage, depending on the heat intensity and properties of the products. For example, lycopene and α- and β-carotenes may undergo isomerization, oxidation and other chemical changes during thermal processing and storage due to their highly unsaturated structure (Rodriguez-Amaya and Kimura, 2004). Total carotenoids found in vegetables are relatively stable to mild pasteurization, unless oxygen or ultraviolet light is present (Peng et al., 2017).

In general, thermal processing results in the decrease of total carotenoid content and an increase of carotenoid bioaccessibility, as the food matrix is changed through cell wall softening (Benlloch-Tinoco et al., 2015).

Bioaccessibility refers to the fraction of a nutrient that is released from its food matrix during digestion and made accessible for absorption into the intestinal mucosa. However, there is not yet a consensus on the effects of thermal processing on carotenoid bioaccessibility, as diverse papers have reported various effects on bioaccessibility, from no changes to significant increase or decrease.

An increase in total carotenoid content was observed for lycopene and β-carotene from tomato juice at a temperature of 90 °C for 30 s or 60 s due to the heat treatment conditions. However, the concentrations of α- or β-carotene from carrots did not notably change at temperatures of mild (70 °C, 2 min) or severe pasteurization (90 °C, 10 min), due to the protective role of the matrix (Vervoort et al., 2012). The carotenoid content of vegetables was reported to decrease after pasteurization in some studies: for carrot juice at 100 °C for 10 min (Rayman et al., 2011) or for red sweet pepper after pasteurization at 70 °C for 10 min (Hernández-Carrión et al., 2014). In the case of lycopene, pasteurization of tomato juice at 90–100 °C for 7 min resulted in a 1.1–1.7% decrease in lycopene, but at a higher temperature, at 130 °C for 7 min, the loss was even greater (17.1%). The nature and extent of lycopene degradation depend upon temperature and time of heating (Aamir et al., 2013).

Vitamins

Fruits and vegetables are great sources of various essential vitamins, in particular vitamin C (ascorbic acid), which is a thermolabile vitamin. In the presence of oxygen and light, it is rapidly degraded. High pasteurization temperatures accelerate the degradation process of ascorbic acid, and high loss is recorded (Plaza et al., 2006; Torregrosa et al., 2006; Elez-Martínez and Martín-Belloso, 2007; Koo et al., 2008). For instance, thermal pasteurization of gazpacho (a cold vegetable soup) at 90 °C for 1 min reduced the vitamin C level to 79.2% of its initial value (Elez-Martínez and Martín-Belloso, 2007). The content of vitamin C also decreased in thermally treated pumpkin (85 °C for 5 min) by 19.2%. Other vitamins, such as vitamins E and D, have also been reported to decrease in vegetable beverages after pasteurization (Barba et al., 2012).

Novel Pasteurization Methods

At present, novel processing technologies such as high hydrostatic pressure (HHP), pascalization or high-pressure processing (HPP), high-intensity pulsed electric fields (HIPEF), ultrasound (US), ultraviolet light (UV), irradiation and cold plasma, among others, are being applied or explored to process foods at low temperatures, avoiding the negative changes induced by heat. Microwave volumetric heating (MVH) is the newest available pasteurization technology. It uses microwaves to heat liquids, suspensions or semi-solids in a continuous flow. During the last few years, different studies have demonstrated that these non-thermal treatments may represent gentle food preservation techniques capable of inactivating pathogenic microorganisms and deteriorative microorganisms and enzymes, providing safe and fresh-like products with minimum changes to their nutritional, physico-chemical and sensorial properties (Houška and da Silva 2017; Johnson et al., 2017).

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