1 Introduction

Historically, man has always sought his dominion over nature. The set of techniques used to grow plants for food, beverages, fiber, energy, raw material for clothes and construction, medicines, tools, or just for aesthetics contemplation is part of agriculture. Agriculture is the science, art, or practice of cultivating the soil, producing crops, and/or raising animals at different levels for marketing or for own consumption (Merriam-Webster, 2016). The very definition of agriculture is broad and refers to the most basic instincts of human beings such as the ability to produce food to satisfy his hunger and for the survival of the species. The etymology of the word agriculture comes from the Latin agricultura "cultivation of the land," composed of ager (field, territory) and cultura (cultivation, growing), in the strict sense of cultivation. The history of agriculture is closely linked with human history, due to its importance in path followed by the human life, as the emergence of agriculture separates the Neolithic period from the immediately previous age, which was the period of the chipped stone (Alexandratos et al., 2006).

With the emergence of agriculture and the man shaping nature in his favor begins the development of new techniques, tools, and consequently the possibility of small settlements, which was previously impossible because the man was essentially hunter and...
collector following the preys where they are going. Therefore, the itinerant and nomad nature of man is changed and a new era begins.

The locations indicated in Fig. 1 show where the first regions of agricultural production were identified (Ladizinsky, 1998):

1. Mexico-Guatemala,
2. Peru-Ecuador-Bolivia,
2A. Southern Chile,
2B. Southern Brazil,
3. Mediterranean,
4. Middle East,
5. Ethiopia,
6. Central Asia,
7. Indo-Burma,
7A. Siam-Malaya-Java,

From the analysis of these sites, it can be seen that these locations subsequently formed the basis for large societies, thus demonstrating how the evolution of agriculture has affected and changed humankind and how it generally shaped our society.

The people who created and mastered new tools had an advantage compared with those who did not have this same capability and as today productivity is of paramount importance, more than just an economic advantage as it was and is still a strategic advantage.

Fig. 1 First regions of agricultural production (centers of origin identified by Nikolai Vavilov (Ladizinsky, 1998).
With the evolution of tools and techniques and with the increasing use of animal power in agricultural production (see Fig. 2), an increase in productivity was achieved, making the societies that mastered the techniques grow more than others and became empires and superpowers at their time.

Fig. 2 Daily scenes of agricultural production in Egypt (note the use of animal force to ensure greater productivity) (Seidel & Shedid, 1991).
The agricultural production system underwent a large evolution during the Industrial Revolution. At approximately the same time, Great Britain was undergoing an agricultural revolution. This revolution was caused by the implantation of new tools, by the use of fertilizers (a new technology at the time) and new techniques of planting, resulting in a very significant increase of labor and land productivity. The evolution of the major commodities (weight and price) during this period is shown in Fig. 3.

Fig. 4 shows the farming area in Great Britain during that same period: the increase in agricultural production was ~340%, while the cultivated area decreased ~2%.

This outstanding increase in production despite maintaining practically the same cultivation area is explained by the several techniques and tools created during that period. Productivity values experienced a sharp increasing trend.

However, this productivity increase had consequences attached. The environmental impact that, before the Agricultural Revolution, was practically zero, increased with the use of fertilizers, machines with burning of fossil fuels, deforestation, mining, and other activities. According to Intergovernmental Panel on Climate Change (IPCC), these activities lead to the increase of the global warming.

These human activities result in a high degree of concentration of greenhouse gases (GHGs) (CO₂, CH₄, N₂O) in the atmosphere since the beginning of the Industrial Revolution around 1750 (Parry et al., 2007). Carbon dioxide (CO₂) in the atmosphere increased from 280 parts per billion per volume (ppb) to an outstanding value of 379 ppb since the preindustrial revolution era to 2005. The same applies to methane (CH₄) concentrations. This increase was even more significant since the increase of its atmospheric concentration was ~250%, from 715 to 1774 ppb over the same period. Nitrous oxide (N₂O) had an atmospheric concentration of ~270 ppb before the Industrial Revolution, and increased to 319 ppb in 2005 (Parry et al., 2007).

Climate change poses various difficulties and aggravates the shortage of availability of drinking water on the surface of the planet. This increasing problem is due to significant changes and variables affecting the normal water circle, which would be precipitation, infiltration, runoff, evaporation, and condensation. The shift of the rainfall season in some places that previously had well-defined seasons of drought and rain had significant consequences on the local environment.

The quality of surface water also declined, which represents only 0.006% of the total volume of water in the planet. This is a direct consequence of the chemical inputs into the air, of the
environment where it is located, and of the biochemical processes that these inputs transform within the system itself. The inputs are from natural processes and/or human activities, such as the atmospheric deposition in the course of the aquatic system or direct discharge of pollutants in the watercourses, and direct

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Fig. 3  Evolution of major commodities (weight and price) in Great Britain during the Agricultural Revolution: wheat, oats, beans, and turfs; seed nectar and oats are included in maize. Meat, wool, dairy products, and cheese are included in animal production) (Allen, 1994). (A) Increase in the production of major commodities and (b) increase in the price of major commodities.
chemical injections of pollutants into the aquatic system (Anderson et al., 2011). The water flows into the river basins through several types of vegetation, soils, and ecosystems, contributing each one to extract, add or chemically transform it before reaching a stream. Although, the opposite can also happen, this water can chemically alter the region that it bathes. The path that the hydrological flow that water takes through the natural course of the river basins, and the resulting transformations that occur along that route will determine its chemical and physical characteristics when entering the surface water system (Anderson et al., 2011). The changes in the region's hydrological system are not only local but can and probably will be broader as chemical changes in water follow their natural course.

In agriculture, pesticides are a major polluter of aquifer systems. The literature review concerning the use of pesticides estimates that commercial pesticide runoff losses in agricultural fields are around 0.5% or less of the quantities initially applied, unless severe precipitation occurs between 1 or 2 weeks after it application. Exceptions are related to the application of organochlorine insecticides, as the aquifer systems may absorb about 1%, regardless of the climatic pattern, due to their long persistence in the production fields. The chemical formulations of wettable powder herbicides applied to the soil surface can be lost up to 5%, depending on the time and inclination of the terrain, due to the ease of powder removal (Wauchope, 1978).
The behavior and the destination of the pesticide losses are usually unknown and it is necessary to be studied. Thus, information on the factors such as the time and distance that this pesticide can affect the capacity of a certain ecosystem must be determined. The ability of the local ecosystem to recover from a transient pesticide concentration and its dissipation capacity in the local aquatic ecosystem should also be studied.

Meanwhile, the livestock sector has always been and always will be a strategic sector, because it is directly connected to the human race survival. Although the richness of farming products has declined over the last decade (today the sector accounts for about 4% of the world's GDP), it still amounts to about US $3125 billion per year.

The impact that the agricultural sector has on our planet goes far beyond the deforestation for the cultivation of crops. This procedure has consequences on thousands of animals and plants, reducing the number of trees (being this condition directly linked to global warming), saturating land due to the effects of the continuous planting of the same crop on the land, particularly on the loses of specific nutrients, and including chemical pollution with the use of agrochemicals. Therefore, balancing the productivity increase with the environmental cost is a current discussion on the several productive sectors of the agriculture, since each action field has its own characteristics, which are very different from each other. Therefore, it is necessary to study the intrinsic characteristics of each productive sector, since for example, the livestock production has not the same techniques, machinery, and tools as the cereal production sector.

Thus, studying each field of agricultural production separately is inevitable, mainly due to the enormous production process and product chain differences. In this way, the next section describes separately the main agricultural sectors, for example, the sectors that have more worldwide production and the highest overall market value.

2 Cereals Sector

Cereal production accounts for a large part of world agricultural production. According to FAO, the world cereal production was expected to reach 2571 million tons in 2016, which is ~16.7% higher than the production obtained in 2015, although well below the target of 3.0 billion tons expected by 2050 (Alexandratos & Bruinsma, 2003).

Cereals (corn, rice, and wheat) account for more than 50% of the calories that a human normally eats throughout the day.
Therefore, cereals are the food base for most populations around the globe. The increase of production can no longer depend on an intensive supply of inputs, such as the increased use of agrochemicals. Soil degradation and toxin accumulation in rice production systems is already a reality in Asia and a cause for concern due to the slowdown in productivity growth. Thus, the intensive use of pesticides to ensure productivity increase will not guarantee an increase in productivity.

Techniques have been developed to ensure an increase in productivity without the introduction of new inputs. In China, it was found that applying a genetically diverse rice variety in the same paddy reduced significantly the incidence of fungal diseases, so farmers were able to avoid the application of fungicides which besides reducing costs reduced the environmental impact. Another example is related to farmers in Zambia who grow acacia trees, Faidherbia albida, near their cornfields. They use the acacia

(see examples of these kinds of plantation in Fig. 5). Therefore, cereals are the food base for most populations around the globe. The increase of production can no longer depend on an intensive supply of inputs, such as the increased use of agrochemicals. Soil degradation and toxin accumulation in rice production systems is already a reality in Asia and a cause for concern due to the slowdown in productivity growth. Thus, the intensive use of pesticides to ensure productivity increase will not guarantee an increase in productivity.

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leaves, rich in nitrogen, as a natural fertilizer and as a protective vegetable cover during the rainfall season. These farmers managed to triple their yields with this relatively simple and inexpensive technique (Garrity et al., 2010).

There are even more techniques and production systems that seek to maximize the agricultural production, combining good energy performance and low environmental costs. These opportunities, as stated, are not exclusive to the cereals sector.

Chinese farmers receive governmental incentives to invest in clean production plantations, that is, without environmental impacts or at least with mitigated impacts. The lack of knowledge about these incentives is the major problem for adherence. Only 21 farmers of the 259 farmers surveyed used the incentives. In all, 174 farmers claimed that they did not know the incentive program and 64 farmers pointed out their lack of technical knowledge (Luo et al., 2014).

Climate change affects cereal production in a variety of ways such as long periods of drought or rain, extremely harsh winters and scorching summers, and plagues on crops. According to Garrick and Liburd (2017), climate change can cause variation of weather events that may increase the CO₂ concentration and the global temperatures. Pest development is highly influenced by environmental factors such as temperature. As temperature rises, it becomes more conducive to pest development and its geographical scale of influence becomes larger. As populations of pests’ increase, natural control programs focused primarily on the direct application of pesticides to sprays had to evolve to a greater management and efficiency. The uncontrolled application of pesticides can cause several problems, such as altering the chemical properties of the soil, which can make it less profitable or reduce its capacity to produce as before.

There should be government programs for pest control. These programs should cover a local sphere of production and rely on the cooperation of local associations and cooperatives, private industry (pest control and agrochemical companies), and the public in general that deals with the problem daily (Garrick & Liburd, 2017).

The indiscriminate use of pesticides can be a double-edged sword because it may lead to entering a cycle of increasing use of pesticides, thus causing a greater environmental impact. In addition, the greater application of pesticides may cause lower agricultural production due to soil characteristics modification, thus requiring a greater amount of fertilizer. The sum of greater application of pesticides and fertilizers can have relevant negative impacts on the environment, causing more emissions of GHGs,
contributing to the increase in the global temperature, which in the last instance will finally promote a higher incidence of pests. Consequently, rising temperatures due to climate change will strongly affect economic growth around the world, not only of farmers but also of all kinds of business.

3 Livestock Sector

Another large sector of the agroindustry is the livestock sector for activities related to animal husbandry or animal agriculture. The word livestock has a Latin origin Pecus means “head of cattle” (see Fig. 6) and has the same Latin root of pecunia (coin, money). In ancient Rome, animals raised for slaughter were also used as a monetary value stored.

The livestock sector nowadays covers several types of products from food to clothing, although the sectors with more emphasis are meat (bovine, pork, ovine, caprine, poultry, etc.), eggs, milk, and honey because these are sectors that generate greater income. The secondary sectors are leather, wool, and silk, the use of animal power to perform work and even dry manure as fertilizer and food preparation. Thus, the scope and field of action of livestock farming is gigantic, increasing the difficulty of evaluating the general environmental costs or their ecological footprint. As each production system has its particularities, likewise in other sectors of agriculture, the study of the ecological footprint must be done on a case basis.

Although it is well known that occidental societies eat much more meat than needed, the worldwide consumer preference regarding the use of meat in their diet continues to increase.
The global production of meat is expected to reach 470 million tons in 2050, more than the double of the 229 million tons verified in 1999/2001 (Nigel et al., 2010).

Currently, meat product industries play a major role in many global economies and, in many countries, it is the industry with a higher economic weight within the food industries. The types of meat most produced and consumed, at both international and national level, are beef, pork, and poultry. According to Silva et al. (2016), the worldwide most per-capita consumed type of meat is pork (15.8 kg/year), followed by poultry (13.6 kg/year), and finally by beef (9.8 kg/year).

The amount of drinking water for consumption of livestock: cows, pigs, sheep, and chickens in intensive farming were calculated, respectively, at 103, 17, 9, and 1.3 to 1.8 L/day. Approximately 8, 4, and 1 kg of cereals are needed to produce 1 kg of bovine, porcine, and poultry meat, respectively (Alexandratos et al., 2006). Therefore, although poultry production is the highest energy efficient, it is still the most energy demanding in cereal production.

The ruminant livestock has one more aggravating factor in relation to the other types of livestock, that is enteric fermentation. Enteric fermentation is the digestive process that occurs in the rumen of ruminant herbivorous cattle (bovine, ovine, and caprine). The result of this biological process is the CH$_4$ gas, a large enhancer of the greenhouse effect. According to Thorpe (2009), the digestive process is responsible for ~600 Tg of CH$_4$ annually in the atmosphere. This value represents, unsatisfactorily, a large slice of ~55% to 70% of all CH$_4$ gas emitted annually into the atmosphere.

Overall, the worldwide global demand for meat is growing, but at different rates in different regions. The worldwide beef, pork, and poultry production in 2012 was 63.3, 109.1, and 105.6 million tons (FAOSTAT, 2016). In Europe and in the United States, the biggest meat producers in the 20th century, consumption is growing slowly. On the other hand, in the fast-growing economies in Asia, such as China and India, an 80% increase in the meat sector is expected by 2022 (HBF-FEE, 2014).

The increase in food production, especially regarding the increasing sources of highly protein foods to meet the future demand of the population, is faced by certain challenges (Singh-Ackbarali & Maharaj, 2017):

- There is not enough land for the expansion of livestock.
- If predatory ocean fishing continues, this activity may deplete resources for future populations.
- The high cost of feeding animals puts in debate if that food should be used for animals rather than being used for feeding starving population around the world.
- Increased competition for water resources.
The production process of different types of meat is identical, except for poultry. The production process of the latter product has some different stages.

The meat production process is composed of two fundamental processes: slaughter and processing. The preparation process of raw meat and meat products (from slaughter to storage and conservation in cold) requires several external resources, such as water, thermal, and electrical energy. The storage and/or transport of meat or its derivatives also involve the consumption of large quantities of energy. The cold storage is used to ensure the maintenance of the organoleptic properties. Thus, the entire process of production of meat and meat products involves the use of large amounts of energy (Silva et al., 2016).

The production of meat products as sausages and ham is mainly industrial, although based on traditional processes. Changes introduced in the traditional process mainly involve the mechanization and the use of drying and/or smoking mechanisms under temperature and humidity control. This technological evolution enabled a continuous production throughout the year, without the influence of climatic conditions.

Refrigeration systems are indispensable within the production processes of meat industry to prevent changes in meat composition, bacteria action, and development of microorganisms and to obtain the stabilization and the organoleptic characteristics of the products (Savell & Mueller, 2005). The consumption of electricity for refrigeration systems in these industries are 60%–90% in slaughterhouses (EC, 2003; Marlow & Colley, 2007) and 40%–50% in meat processing industries (Ramírez et al., 2006a,b,c; Alcázar-Ortega et al., 2012). Electricity costs may correspond to two-thirds of the total energy costs in meat processing industries (HTC, 2009).

The typical process of meat slaughter, except poultry, comprises essentially the following operations: reception, ante-mortem inspection, animal’s slaughter, carcasses and offal cleaning, postmortem inspection, cooling, cutting, processing, and dispatch. For each animal species, there is a specific circuit where carcasses are moved through fast cooling tunnels and refrigeration or freezing chambers.

Rapid cooling is one of the most used methods (Bowater, 2001). First, it consists in rapidly lowering the initial temperature of the postmortem carcasses from 38–40°C to 15–20°C. Afterwards, the meat temperature needs to be stable on a value below 7°C. To achieve this temperature in the inner center of the meat, it must be placed in a rapid cooling tunnel or in a cold room with strong air circulation. The air temperature and relative air humidity must
be around $-1^\circ C$ to $2^\circ C$ and $82\%$ to $90\%$, during $\sim 4$ h for bovine carcasses and $2$ h for porcine and ovine carcasses. Following, the carcasses must be placed inside cold storage chambers with low air circulation. In case of freezing the meat, the temperature and relative humidity values must be $-28^\circ C$ to $-40^\circ C$ and $85\%$ to $95\%$, respectively.

There is a great diversity of traditional sausages, produced with different raw materials and ingredients, but they all have a similar production process. The manufacturing process of sausages is composed of several operations. Cutting, mixing, and filling operations are held in air-conditioned rooms with a $12^\circ C$ maximum temperature. During the maturation operation, the mixture of meats with condiments is kept in cold storage chambers, with temperatures between $1^\circ C$ and $6^\circ C$ and a relative humidity of $80\%$–$85\%$, from 24 to 48 h. The drying process of sausages is accomplished by controlled atmosphere or through smoke drying. The operation time varies according to the size of the sausages. Typically, between 5 and 15 days for thin products and 30–60 days for thicker products (Arnau et al., 2007). The drying process with smoke requires exposing the sausages during 3–5 days to the action of heat and smoke resulting from combustion of wood.

Ham is a product obtained artificially in cold rooms from the aging of the hind legs of white pigs during an approximate period of 6 months. The production process consists of a set of operations with different values of temperature, relative humidity, and air circulation. The main stages of the production process include salting, postsalting, drying, and stuffing. Salting is intended to provide the proper amount of salt to the legs, keeping them involved in salt from 8 to 12 days. This phase takes place inside the cold storage chambers with high humidity and low temperature (Arnau et al., 2007). In the postsalting phase, the salt diffusion toward the inner part of the leg takes place from 30 to 45 days, considering the low air temperature and high humidity ($6^\circ C$ and $85\%$ relative humidity). Following, the leg dehydration takes place slowly during a period of $\sim 45$ days. The temperature is gradually increased to $14^\circ C$ while the relative humidity is lowered slowly to $75\%$. The stuffing operation ensures the specific organoleptic characteristics of the ham. It requires a minimum period of 15 days. The temperature is gradually increased to a maximum of $26^\circ C$ and the relative humidity is kept close to $75\%$. After being manufactured, the hams are kept inside cold storage chambers for final stabilization during a minimum period of 15 days.

Livestock is an industry that generates a lot of income. Therefore, there is worldwide interest in this particular sector.
Nevertheless, due to the increased environmental impact of this sector, there is a need to develop new strategies and products to overcome its negative effects without putting at risk the food chain. On the other hand, a report from Van Huis et al. (2013) recommended the use of insects for human and animal consumption as a viable and sustainable source of protein. Entomophagy, or species of edible insects for food and feed, is an informal and widespread feeding practice for ~80% of the world’s population. Insects are part of the traditional diets of at least 2 billion people according to Van Huis et al. (2013).

According to Singh-Ackbarali and Maharaj (2017), the market in general and the potential consumers will have to be convinced to accept edible insects and food products with insect ingredients as tasty, viable, and safe for consumption. Masking the shape of the insect can be a good strategy. An example is the use of insect powder in protein bars. Including insect ingredients on test dishes in popular restaurants can also promote acceptance among the population and offer opportunities for more adventurous chefs to develop new recipes using the delicacy. The market increase will drive a greater volume of business to the insect farms and this will help the insect farmers to overcome the market challenge and boost the expansion.

Searching for cleaner production alternatives or changing our customs and paradigms about food becomes necessary to meet the population’s future food demands. It is evident the need for change in the sector of livestock production whether by adding new and cleaner products such as the above-mentioned example encouraging the insects’ consumption that has a more sustainable ecological footprint. If the livestock sector remains focused on animal creation, it will be unable to attend the world population needs for food in the near future.

Price inflation of livestock products should also be discussed. The livestock production is still very much dependent on manual labor. The increasing demand for products of animal origin can increase its market price and making it difficult to achieve a healthy diet with a good amount of protein for the low-income population.

4 Dairy Sector

The dairy sector is one of the livestock subsectors of greater importance. Products such as milk, cheese, and yogurts are consumed worldwide and are of paramount importance for people’s food base. In addition, some of these products have an added
value due to ancient and artisan processes used in their manufacture. Cow's milk is the most produced and consumed worldwide, but also the milk of other mammals is used for consumption such as milk of sheep, buffalo, and goat. Dairy products are an important source of protein and calcium, playing an important role in nourishing the gastronomic levels.

The consumption of dairy products is significant in areas of the world such as Europe and the United States. In turn, in high-density populated areas such as China, there is a low per-capita consumption of such products (Silva et al., 2016). The dairy industry employs thousands of people around the world, from livestock to distribution. This industry branch is currently highly advanced in terms of technology, consisting of fully automated processes focusing on improved food safety. See an example of a dairy plant in Fig. 7. Before reaching the consumer, the milk is subject to thermal processes such as pasteurization or ultra-pasteurization to ensure its food security. The milk suffers a heating process followed by a cooling process to ensure the destruction of potential harmful bacteria.

Cheese is a subproduct of milk widely consumed worldwide. It can be manufactured from the milk of various animals such as cow, sheep, or goat. It derives from the coagulation of milk, by separating milk into curd and whey. The whey is removed and the curd undergoes bacteriological processes leading to the production of cheese. The final characteristics of the cheese depend on the production method. There are hundreds of types of cheese throughout the world. More than half of world’s cheese is produced in Europe. The three largest European cheese producers and consumers are Germany, France, and Italy.
During the last four decades, milk production grew by 64%, reaching a value of 790 million tons in 2012. The cheese production is around 27% within this sector. In the last decade alone, the world cheese production increased by 32% (Mikkelsen, 2014). Predictions suggest that in 2020 the world production of cheese will reach up to 25 million tons. In the course of their activities, dairy companies use electrical energy to drive cooling systems, pumps, fans, compressed air systems, lighting, and one or more types of fuel to burn in combustion plants (boilers), for water heating or for steam production (cleaning operations or production processes). The increase of population in cities and the increase of food quality and safety standards turns the supply chain to be more energy demanding, especially on the refrigeration systems (Artés, 2004; Coulomb, 2008; James & James, 2010), which are major electrical energy consumers (Ramírez et al., 2006a,b,c; Gautherin et al., 2007; McFarland & Bivens, 2007; Tassou et al., 2010; Gaspar et al., 2014; Silva et al., 2014). Some authors highlight the possibility of assessing the energy performance of food industry, such as cheese making, using benchmark indicators as the specific energy consumption (Reindl et al., 2005; UNIDO, 2010; Xu & Flapper, 2010; Nunes et al., 2014a, 2015, 2016).

The manufacturing process of cheese from raw milk involves several steps that are similar in all traditional cheese industries. However, there are industries that carry out all steps using technology while others still perform some of the steps by hand, in particular, salting, pressing, and periodically washing the cheese. In general, the ripened cheese manufacturing has a duration of between 30 and 45 days. The main raw materials used for the cheese manufacture are sheep and goat milk. Some industries also manufacture fresh cheese (pasteurized milk without maturation and with a short life span) and cheese curd (resulting from whey heated to a temperature of 90–95°C, for 2–2.5 h, followed by filtration). The conservation of these two products is performed in cooling chambers at a temperature of 4–6°C and relative humidity of 85%–90%. The manufacturing process of these latter products requires more use of cold and heat, particularly, the use of refrigeration systems to cool down and preserve the milk and cheese products.

5 Horticultural Sector

Fruits and vegetables (horticultural products) are part of agricultural products. The horticultural products possess an active metabolic state even after the harvest, making them highly...
perishable (Fraser, 1998; Álvaro, 2001; Filho, 2008). In addition of being the most consumed foods products, horticultural products are also widely used as raw materials in various food industries (wine, olive oil, juice, and frozen). The driving factor of the increase of the production of horticultural in the world is the growth of the world population.

Fruits form parts of horticultural products are settled in the human diet due to their nutritional context. The fruit production has been increasing with the years, following the growth of the world population. The largest worldwide production of fruits consists of bananas (100 million tons), watermelons (99 million tons), apples (71 million tons), and grapes (68 million tons). On the other hand, fresh vegetables (249 million tons) and tomatoes (154 million tons) are the most produced vegetables in the world. The production of vegetables increased worldwide between 2009 and 2012. In 2009, the fresh vegetables represented 24.4% of horticultural products produced worldwide. The largest vegetable producers are Asian countries, particularly China, Japan, and India. The per-capita consumption varies from region to region of the world due to the eating habits and living standards of each country. At the World level and European level, the highest per-capita consumption occurs in the sector of cereals, followed by vegetables and fruits.

Most of the horticultural products are produced seasonally and they are highly perishable. Thus, it shelf life is very short. Additionally, harsh handling of horticultural products promotes their mechanical damage, stimulates weight loss, and increases exposure to the attack of microorganisms. Exposure of horticultural products to a fast reduction of vapor pressure, the use of low relative humidities and unnecessary air currents are harmful to the quality of products (López & Rodríguez, 2000). Refrigeration with controlled atmosphere is used to minimize the above effects and extend the shelf life of horticultural products (Parikh et al., 1990). According to López and Rodríguez (2000), Marville (2001), and Rosset et al. (2002), a fast temperature decrease of the horticultural products avoids many of the aforementioned problems associated with the postharvest period. The immediate application of cold allows reducing the loss of vitamins and sugars, organic acids, water as well as the speed of biochemical and enzymatic reactions (IIF, 2008). The best conservation temperature range for most of the fruits is 0–4°C. The ideal temperature range for the conservation of vegetables is 3–6°C (López & Rodríguez, 2000; Álvaro, 2001).

Given the relevance of rapid cooling to remove the heat of harvest, several technologies have been developed for these
applications in the last years, such as cooling chambers with variable-speed fan evaporators, cooling tunnels with water, vacuum and immersion, or spraying techniques with ice water (Marvillet, 2001; IIF, 2008).

6 Food Processing Industry

The main aim of the agrifood industry is to provide consumers and society with a range of safe, healthy, nutritionally rich, economically accessible, and sustainable food products, while maintaining their competitive capacity. Typically, the agrifood industries are processing plants, which have specific characteristics, namely the use of limited resources with a high level of perishability, and therefore their use should be as efficient as possible. In general, this industry transforms agricultural products, not only for the production of foodstuffs for humankind, but also for animals, given their indirect importance in the human food chain. Owing to its positioning between agriculture and the markets for consumer products, the agrifood industry has its own characteristics, which makes its development sensitive to the behavior of raw materials and to the organization of markets. In fact, in the majority of cases, it works with raw materials, which begin to deteriorate soon after collection. In addition, the specific characteristics of certain products, such as vegetables, fruits, and dairy products, and their seasonality must be taken into account. The evolution of consumption habits and distribution circuits, the increasing segmentation of markets, the multiplicity of products marketed, and the economic constraints imposed by competition have led agrifood industries to develop their own strategies and production tools. Nowadays, there is a great development of specialized methods in the manufacture of food products, with the conservation and processing of raw materials, with widespread application of refrigeration, freezing, and dehydration (Wang, 2008).

The agrifood industry is part of the manufacturing sector. At the European level, it is one of the largest sectors, with a very significant weight in the economy. In fact, the agrifood industry was the leader in the European Union's employment sector, with 28,900 companies and 4.25 million jobs, and had a turnover of 1089 billion euros (FoodDrinkEurope, 2016). The role of small- and medium-sized enterprises (SMEs) is very significant, with 49.5% of total turnover and 62.8% of total employment. Exports of food products to countries outside the European Union amounted to 98.1 billion euros, equivalent to 17.8% of global exports (FoodDrinkEurope, 2016).
Refrigeration systems are used throughout the production process to preserve the physical and chemical characteristics of products, prolonging their life span. The main aim is to obtain environmental conditions, in terms of temperature and, where appropriate, relative humidity, that prevent the development of microorganisms, which may deteriorate the products. Refrigeration systems are also used in the processes of rapid freezing, rapid cooling, and dehydration of products. Some products, such as fruits and vegetables, meat or milk, for effective preservation, require a rapid decrease in their temperature, and cooling systems must be used to promote rapid cooling. In the production processes of dehydration/hydration it is intended to control water activity in food products, making them more stable at room temperature (Arnau et al., 2007). For these processes, systems are required to control the temperature and the relative humidity of the air, generally using air treatment units, such as air-to-air heat pumps. Typically, these systems are used in the processes of manufacturing sausages, hams, and cheeses. The great diversity of functions of the refrigeration systems used in the agrifood industries means that the associated energy consumption is strongly dependent on their characteristics and operating conditions. When just only the ambient temperature of the cold chambers is to be maintained, the energy consumption will be lower than in specific cases, where a rapid decrease in ambient temperature is required. In systems for maintaining ambient temperature inside the refrigeration chambers, it is necessary to withdraw the amount of heat relative to the thermal loads generated therein, namely those related to heat transfer on the chamber walls, air infiltrations, lighting, machines, people movement, and the products themselves. From the foregoing, it becomes clear that an intensive and widespread use of refrigeration systems in agrifood industry is essential, which results in a high consumption of energy. Therefore, the search for greater sustainability in the agrifood industry requires the introduction of technologies that are less energy intensive and environmentally demanding. In fact, energy consumption of refrigeration systems in food industries has increased due to increased food manufacturing and requirements imposed by quality, hygiene, and food safety standards (Ramírez et al., 2006a,b,c). Due to the high level of utilization, in many industrial processes, refrigeration systems are considered energy intensive (Xu et al., 2009; Xu & Flapper, 2010; Nouri et al., 2013). Due to the characteristics of the agrifood industry, which is composed of a large number of small food processing industries, the group also contributes to the high consumption of electricity in various countries (Ramírez et al., 2006a,b,c). As an example, in
2008, in the EU-27, the majority (99.8%) of the industries present in the economy were SMEs—approximately 20.9 million—and more than nine companies out of ten (92%) were classified as microenterprises employing <10 workers. This scenario is most relevant in Southern European member states, such as Italy, Spain, and Portugal (Eurostat, 2016). In some sectors, energy consumption increased considerably as a result of increased activities and use of refrigeration systems (Ramírez et al., 2006a). These systems consume large amounts of electrical energy, contributing significantly to the operating costs of the industries with significant cooling needs. For these industries, refrigeration systems can account for around 85% of global energy consumption (Victoria, 2009).

In the United Kingdom, 11% of the final energy was consumed by the food industry and some sectors used more than 90% of electrical energy with cooling systems (Swain et al., 2009). Many economic sectors need to remove the initial thermal load from the products, often by rapidly cooling the products. Swain et al. (2009) points out that in the United Kingdom there are six categories where it is necessary to withdraw this energy: milk (532 GWh/year), meat (114 GWh/year), potatoes (154 GWh/year), other vegetables (36 GWh/year), fish (6.5 GWh/year), and fruits (5.9 GWh/year). Furthermore, using the best technologies for cooling available in the United Kingdom, annual energy savings of 59 GWh in potato cooling, 128 GWh in cooling milk, and 51–80 GWh in cooling of the carcasses can be achieved. Burfoot et al. (2004) have found that 18% of the annual energy consumption of United Kingdom refrigerated food sector is used in industries to maintain low temperatures to prevent the growth of microorganisms in food. In France, industrial refrigeration accounted for 4% of electricity consumption and almost 7% of electricity consumption. It was estimated that electric energy consumption in the dairy sector was ~2.9 TWh, and of this quantity, 26% was exclusively consumed by cooling systems (Gautherin et al., 2007). In terms of electricity consumption, the dairy sector occupied the fourth position, following the large food distribution (3.6 TWh), the cold storage (2.45 TWh), and the local business (1.4 TWh). This consumption was above the consumption of electricity in other food activities, such as cattle slaughterhouses (370 GWh), charcuteries (369 GWh), and breweries (203 GWh) (Gautherin et al., 2007). According to these authors, the electricity consumption for liquid milk production, butter production, cheese production, and other dairy products corresponded to 1, 0.18, 1.2, and 0.56 TWh, respectively. In particular, the energy consumption related with the use of refrigeration systems in each of these sectors was 34%, 6%, 41%, and 19%, respectively. Dairy establishments, particularly in
the manufacture of cheese and meat processing, are particularly energy intensive because they need it both for refrigeration and for heating. For example, Ramírez et al. (2006b) point out that in the Netherlands dairy production and the production, processing, and conservation of meat account for about 15% and 9% of the total energy consumed in the food sector, respectively.

The amount and the type of energy used vary greatly depending on the type of products manufactured. For the Australian dairy industries, particularly for the manufacture of cheese, the use of electric and thermal energy is in the order of 27% and 73% of total energy, respectively, while in the manufacture of milk for human consumption these values are around 66% and 34%, respectively (Prasad et al., 2004). Industries that mainly produce milk for consumption and cheese use energy for heating, milk pasteurization, refrigeration and cooling, lighting, compressed air, air conditioning, pumping and processing equipment, and auxiliary operations. Industries that manufacture concentrated milk products and certain types of powdered cheese require additional thermal energy to perform agitation, separation, concentration, evaporation, and drying operations.

In view of the high-energy consumption, food-processing establishments are now in a position to analyze and take care of them by implementing measures and actions that promote good energy use. Energy efficiency can offer a range of savings across a number of domains such as reducing energy costs, reducing maintenance costs and confidence in the system, improving safety, increasing productivity, better cooling load adequacy and equipment capacity, better working environment and reduction of resource consumption, and greenhouse gas emissions (Victoria, 2009). The value of energy savings in cooling systems is related to the number and type of measures applied and the quality of the technology used. A simple improvement in operational practices or good construction of the plant with a minimum of expenditure can often lead to a reduction in energy consumption of up to 15% or even more, while using the best techniques of the cooling system elements can lead to a potential energy consumption reduction of between 15% and 40% (Manske et al., 2001; Victoria, 2009; Guilpart, 2010). According to Victoria (2009) the improvement of energy efficiency in the existing systems can be achieved by means of an action plan that involves the following steps:

(i) analysis of the required cooling capacity,
(ii) analysis of the quality of the thermal insulation used,
(iii) evaluation of the distribution of the refrigerant in the system,
(iv) evaluation of system control systems and heat rejection processes,
(v) optimize maintenance and finally, (vi) to evaluate the improvement of the system after the intervention.

Landymore (2012) also points out that there have already been significant improvements in refrigeration technology in the refrigeration sector, but some of the solutions are difficult to implement by small- and medium-sized establishments because they are very costly. In refrigeration and air conditioning systems, the compressor is the largest consumer of electricity, and in most cases, it consumes about 70% of the total electricity. One of the ways to combat the consumption of electricity is to shorten its operating time. In the dairy sector, a set of energy-efficiency measures are being implemented in both terms of the refrigeration facilities themselves and production processes and manufacturing (Gautherin et al., 2007). These measures include lowering the condensing temperature, increasing the evaporation temperature, using variable speed drives, using advanced control of refrigeration plants, resizing pasteurizers, assessing energy savings, the estimation of the number of equipment used in the processes, and the associated energy consumption. The estimated energy gains in relation to the initial consumption values are between 10% and 20%. According to Mirade et al. (2012) the precise analysis of the consumption of energy in the cheese manufacturing industry allows to highlight four main areas of energy consumption, two of them corresponding to the consumption of electricity and the other two to thermal energy. Pumps, fans, conveyor motors, lighting systems (35%), refrigeration systems, and milk storage equipment (20%) are the electricity consumers in dairy industries. Thermal energy is consumed by heating systems, evaporators and dryers (40%), and equipment used in the daily cleaning process (5%). Overall, large energy savings can be achieved in food industry if efficient management systems and energy consumption monitoring policies are implemented (Fritzson & Berntsson, 2006; Muller et al., 2007; AlQdah, 2010) and if existing technologies and conventional systems are targeted for maintenance tasks (IIR, 1982; Gigiel & Collett, 1989; James & James, 2010). Energy savings can also be achieved if current systems are improved, such as using high-efficiency electric motors (EC, 2006; Worrell et al., 2009) or implementing variable speed systems in the engines (Tassou & Qureshi, 1998; Abdelaziz et al., 2011). Finally, it can be by the development of new food conservation technologies with a very low potential for environmental impact together with the reduction of food waste (Lung et al., 2006; Pereira & Vicente, 2010; Tassou et al., 2011; James & James, 2011).
7 Recent Developments and Future Scenarios

The goal of FAO in the coming years focuses on sustainable consumption and sustainable production. According to FAO, it is vital to ensure sufficient, accessible, nutritious production and consumption, maintaining the natural resources and ecosystems of which they are part. Agricultural production chains play a central role in all societies and are fundamental to ensuring sustainable development.

Sustainable food systems are key points to address food security, poverty alleviation, and adequate nutrition, and play an important role in building a society able to recover the balance between environmental and production costs.

However, our agricultural production system is under strong pressure to answer to increasing demand, climate, and soil changes, mostly due to human interference itself. Some noteworthy projections that highlight the need for sustainable food systems are the following:

- Demand: It is estimated that by 2050 the world population will be 9 billion. Today, we are 7.2 billion;
- Waste: Today, we waste around 30% of the total food produced;
- Hunger: 12.9% of the population in developing countries suffer from chronic hunger;
- Obesity: About 30% of the world's adults suffer from obesity;
- Prices: People in the poorest areas spend 50%–80% of their income on food, so they are extremely vulnerable to price rise;
- Climate change: Agricultural production is a natural resource, so it is extremely vulnerable to climate change on the planet;
- World productive system: Agricultural production itself is a major cause of environmental impacts. It is estimated that 70% of the waters, large part of deforestation, and biodiversity loss was caused by agricultural production.

Finding ways to produce food without adding more inputs, not increasing the area of agricultural production through deforestation, reducing the waste in production, and bringing the countryside closer to cities, thus avoiding transport waste and reducing emissions with transport, are the challenges that all agricultural sectors must overcome in the coming years. One of the strategies is related to the promotion of the concept of sustainable cities. According to Peter and Swilling (2012), the implementation of food resilience with the boost of local production and consumption, encouraging agricultural production activities in the cities and their surroundings, may contribute to mitigate the effects of global climate change.
The effects of a major global environmental impact can make vulnerable the food supply to cities. The encouragement of the use and local production of organic products are measures that reduce the carbon footprint in food and transportation. With the purchase of local products, it is predicted the reduction of green gases emissions due to burning of fossil fuels, intermediates, and food waste, mainly of horticultural products, since they are products more sensitive to transport and storage.

Another facet that may contribute to reduce the environmental impact caused by food systems is related to the need of a refrigeration system to maintain the organoleptic characteristics of food products. All types of coolant fluids used in refrigeration applications have a negative impact on the environment.

First, the hydrochlorofluorocarbons (HCFCs) were phased out due to their high ozone depletion potential (ODP). HFCs originally replaced the HCFCs. However, HFCs are also a significant contributor to global warming. Thus, countries such as the EU and the United States began to phase out their use independently. In October 2016, the Kigali Accord signed by more than 170 countries aims to counter further climate change by cutting the worldwide use of HFCs. If the application of this accord is successful, it will result in the reduction of the equivalent of 70 billion tons of carbon dioxide between 2020 and 2050. Thus, this accord marks a significant milestone in the development of the global HVAC/R industry because this type of refrigerant is used extensively. In the near future, equipment manufacturers must start developing equipment for a world where also HFCs are banned. Contributing to this end, extensive tests on the use of hydrocarbons (HCs) and hydrofluoroolefins (HFOs) have been performed by academia and industry. Some of these refrigerants will only grow in importance as real alternatives to the actual state of the art. It must be pointed out that while some newer refrigeration equipment can be retrofitted to use alternative refrigerants, the older ones have to be replaced because retrofitting is not cost effective. It is important to highlight that short-term investment required to replace older refrigeration equipment can be diluted during the years of operation due to the increased efficiency and reduced operating and maintenance costs.

The technology based on the thermodynamic vapor compression cycle is widely used in industrial, commercial, and domestic refrigeration systems. It is a technology with proven merits and accepted by many different sectors. It continues to be a constantly evolving technology, by the technological enhancement of the various components of the system (compressor, evaporator, expansion valves, and condenser) and its accessories. These advances include the application of new materials, new coolant
fluids with greater heat exchange capacity and reduced environmental impact, technological solutions and innovative designs and the precise control, regulation, and command of the refrigeration system. This latter technological advance may lie in the adoption of a multiplicity of sensors for direct or indirect monitoring of numerous parameters, actuators with operation regulation, and the use of microcontrolled systems with algorithms that may use intelligent control techniques. However, depending on the specificity of the industrial process, there is a need to develop further the refrigeration system and its components, both by considering innovative solutions at the level of the system components and of control, regulation, and command that enable the processing of food products with the required nutritional and organoleptic characteristics.

On the other hand, the current demand for healthier products with superior organoleptic quality and that have specific health and well-being properties (such as functional foods or bioactive properties) has grown exponentially. These trends added to the need of ensuring the microbiological safety and the extension of shelf life promoted the development of new and emerging alternative technologies for food processing. The competition with emerging economies allows delivering products to the market at increasingly competitive prices, forcing the agrifood industry to compete through innovation and creation of value-added products.

The thermal processing includes a set of unit operations such as bleaching, pasteurization, and sterilization, based on external heat generation and its transfer by conduction, convection, and radiation mechanisms. To avoid compromising the microbiological safety, all these operations end up affecting the quality parameters, reducing nutritional value, and causing changes in organoleptic properties, namely flavor, texture, color, and aroma.

To overcome the limitations of traditional methods of pasteurization and sterilization, it is increasingly necessary the strict control of the applied heat treatment and of other processing/nonheat technologies to ensure food safety with the highest quality. In this context, the development and implementation of emerging and innovative food processing technologies that aim, besides overcoming the limitations of food quality, to increase efficiency and production rates are required.

Beyond the traditional food preservation methods of thermal processing, freezing, salting, and drying, new methods of processing and packaging continue to emerge. These methods can extend the shelf life and freshness of perishable foods. A brief description and some possible future applications for each of these technologies are given in Tables 1 and 2. Table 1 includes
### Table 1 Description of the Emerging Nonthermal Technologies and Their Future Applications

<table>
<thead>
<tr>
<th>Technology Type</th>
<th>Process</th>
<th>Applications and Trends</th>
<th>Advantages and Limitations</th>
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<tbody>
<tr>
<td>High hydrostatic pressure (HHP)</td>
<td>High-pressure processing is carried out with intense pressure in the range of 100–1000 MPa, with or without heat, allowing most foods to be preserved with minimal effect on taste, texture, or nutritional characteristics</td>
<td>It has been applied to shellfish, sliced meats, vegetables, cheese, meat, fish, juices, and smoothies, ready to eat meals, sauces, and salsas successfully. Several rice-based foods are available with novel textures induced by high-pressure treatment. Commercial products have now been appearing in the United States and Europe.</td>
<td>The main advantage of high-pressure processing compared with thermal sterilization and pasteurization is maintenance of sensory and nutritional characteristics of treated food products. The limited effect of HPP (at moderate temperature) on covalent bonds provides a minimal effect on food chemistry. HPP provides a means for retaining the food quality while avoiding the need for excessive thermal treatments or chemical preservation.</td>
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<td>Pulsed electric fields (PEF)</td>
<td>PEF processing involves treating foods placed between electrodes by high-voltage pulses in the order of 20–80 kV (usually for a couple of microseconds). The applied high-voltage results in an electric field that causes microbial inactivation</td>
<td>PEF is restricted to food products without air bubbles and with low electrical conductivity. In the treatment of products with PEF we find skimmed milk and fruit juices. This technology has also been applied for pasteurization of foods such as juices, milk, yogurt, soups, and liquid eggs.</td>
<td>The advantages of this technology are an ongoing process: obtaining quality fresh produce; nutrient retention in products; application for acidic foods. This technology spends less treatment time, withstands low temperature during treatment, replaces conventional heat pasteurization, extend shelf life, and maintain food safety with low processing costs. Disadvantages include the high cost of capital, not suitable for solid food, and restricted to food products without air bubbles and with low electrical conductivity.</td>
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<td>High-intensity light pulses</td>
<td>The pulsed light processing can be described as a sterilization or decontamination technique used mainly</td>
<td>Liquid foods (cold pasteurization of liquid food such as milk and juices) and solid foods (fruits, vegetables, eggs, shellfish, and meat).</td>
<td>The advantages are the intensity of light that lasts for only a second, is 20,000 times brighter than sunlight, but there is no thermal effect, so quality and nutrient content are retained. As a disadvantage of the process, a possible food</td>
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<td>Technology Type</td>
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<td>Applications and Trends</td>
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<tr>
<td>Membrane technology</td>
<td>Reverse osmosis (RO)</td>
<td>Future surface treatment of foods and package material decontamination applications are anticipated using pulsed light technology</td>
<td>preservation problem arises because the folds or cracks in the food may protect the microbes from being exposed to pulsed light</td>
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<td></td>
<td>Ultrafiltration (UF)</td>
<td>The primary goal of UF in fruit industry is to replace the holding filtration and decantation steps of traditional process. Both RO and UF have promising uses in fruit and vegetable juice industry as a unit operation for concentration or aroma recovery and clarification of juices, respectively</td>
<td>UF system generates cost savings and work force reduction; process control is simple; no cooling water equipment is needed and products have better flavor. RO is a well-established process for concentration/preconcentration of raw and clear depectinized juice from fruits and vegetables. It consumes 10 times less energy for renouncing water when compared with conventional evaporators</td>
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<td>Irradiation</td>
<td>A process where food is exposed to ionizing energy, utilizing gamma photons emitted by 60 Cs (or much infrequently by 137 Cs) radioisotopes, machine-generated X-rays of max. 5 MeV, or,</td>
<td>Food irradiation is effective against a wide variety of pathogens such as bacteria, fungi, viruses, and parasites. Main applications are inhibition of sprouting, insect disinestation, parasite disinestation,</td>
<td>The process of food irradiation is used throughout the world to reduce the risk of illnesses and food poisoning. In addition to some safety concerns, irradiated food has other disadvantages, such as poorer taste and nutrient content. Irradiated food can be more expensive, due to the upfront costs of a food irradiation facility. Irradiation cannot</td>
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Table 1 Description of the Emerging Nonthermal Technologies and Their Future Applications—Cont’d

<table>
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<tr>
<td>Food preservation with ozone</td>
<td>Ozone is a safe, powerful disinfectant, and it can be used to control biological growth of unwanted organisms in products and equipment used in the food processing industries</td>
<td>shelf-life extension (radurization), and elimination of nonspore forming pathogenic bacteria (radicidation) In aqueous solutions, ozone can be used to disinfect equipment, process water, and some foodstuff. In gaseous form, ozone can act as a preservative for certain food products and can also sanitize food-packaging materials. Some products currently being preserved with ozone include eggs, fresh fruits and vegetables, and fresh fish</td>
<td>eliminate pesticides and other chemicals in food, nor can irradiated food be handled and packed in unsanitary conditions without contamination recurring As main advantages, it stands out that ozone is a powerful oxidizer available, instantly destroys microbes, eliminates chemical storage, environmentally friendly; stops mold spores, does not affect product taste, and no harmful by-products and can be used in air and water</td>
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<td>Modified and controlled atmosphere storage</td>
<td>Controlled atmosphere (CA) is the alteration of the natural gaseous environment (usually O₂ and CO₂ levels) and maintenance of this atmosphere at prespecified conditions throughout the storage time. Modified atmosphere (MA) is the initial alteration of the gaseous environment in the immediate vicinity of stored and packaged product</td>
<td>CA and MA are mainly used on fruits and vegetables. The CA- and MA-based technologies are expected to go on contributing to meet the increasingly rising quality standards demanded by the fresh food market</td>
<td>CA storage is normally preferred for long-term storage of large quantities of single commodities, mostly apples and pears, although an ever-increasing variety of crops (e.g., banana, cabbage, and kiwifruit) have also been tested with success. CA storage is claimed to be expensive because of the initial capital investment on equipment, coupled with the sustained energy requirement needed to maintain the storage conditions at preset values</td>
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### Table 2  Description of Emerging Thermal Technologies and Their Future Applications

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<tr>
<td><strong>Ohmic heating</strong></td>
<td>An AC current is passed through a food sample, which leads to generate internal energy in foods. As a result, an inside out heating pattern is generated. The heat generated destroys microorganisms in a manner similar to classical thermal processing. Ohmic heating is distinguished from other electrical heating methods either by the presence of electrodes contacting the food, frequency, and waveform</td>
<td>Ohmic processing has the potential to impinge on the frozen foods market because its product has the taste, texture, color, and vitamins of fresh, homemade food</td>
<td>The advantage of this technique is that it uniformly heats food with different densities. It saves significant time energy in hot air and freeze drying of foods and enhances extraction yields of some processing operations. Another advantage is its ability to heat materials rapidly and uniformly, including products containing particulates. The system instantly and evenly heats liquids and solids. With ohmic processing, the sterilization process takes place at very high temperatures, very quickly and therefore a high-quality product is obtained</td>
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<td><strong>Infrared (IR) heating</strong></td>
<td>Infrared (IR) heating technology consists of exposing an object to IR radiation (wavelength from 0.78 to 1000 μm), with the energy generated being absorbed by food products</td>
<td>IR has been applied in drying, baking, roasting, blanching, pasteurization, and sterilization of food products. Scaling up and commercialization of the IR-based technologies are expected to open new avenues to deliver desirable foods to consumers that have a reduced footprint regarding the consumption of natural resources and provide significant socioeconomic benefits to the society</td>
<td>IR provides significant advantages over conventional heating, such as reduced heating time, uniform heating, reduced quality losses, absence of solute migration in food material, versatile, simple, and compact equipment, and significant energy saving. Combinations of IR heating with MW heating and other common conductive and convective modes of heating have been gaining momentum because of increased energy throughput</td>
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### Table 2: Description of Emerging Thermal Technologies and Their Future Applications—Cont’d

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<tr>
<td>Microwave (MW) heating</td>
<td>A wave is propagated and reflected according to the laws of physics in the frequency range from 300 MHz to 300 GHz. MW works well with smaller quantities of product with a dipolar nature</td>
<td>The industrial MW processing applications currently in use can be summarized as dehydration of low moisture solids, precooking of meat products, pasta drying, and tempering of frozen products. The recent MW heating applications in the food industry may be listed as MW baking, drying, frying, thawing and tempering, pasteurization and sterilization, roasting, blanching, and extraction</td>
<td>MW processing delivers more homogeneous heat treatment at a faster rate than the conventional method of heating. MWs are endowed with some special characteristics such as high penetrating quality which results in the uniform heating of materials, selective absorption of radiation by liquid water and capacity for easy control. These impart some unique effects to the dehydrated material such as improved quality and good texture</td>
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<td>Radio frequency (RF) heating</td>
<td>An RF generator creates an alternating electric field between two electrodes. The material to be heated is placed between the electrodes, where the alternating energy causes polarization, wherein which the molecules in the material continuously reorient themselves to face opposite poles. RF technology uses electromagnetic radiation in the frequency range from 300 kHz to 300 MHz. RF works well with large quantities of material with high ionic conductivity</td>
<td>Some of the known applications of the RF heating system are bakery products and comminuted meat products. Other potential applications include reduction of Salmonella in eggs and destroying harmful bacteria in fresh fruit juices. The potential of RF is greater when used in hybrid systems that take the volumetric heating advantages of dielectric heating and couple them with conventional processing for efficient, rapid, and high-quality results</td>
<td>RF overcomes many heat transfer problems as water is preferentially heated and provides a considerable decrease in processing time. It acts as a moisture leveling process and it has good overall energy efficiency. The RF equipment has high initial capital cost and it is subject to fluctuations in the price of electricity. Skilled labor is required for the tuning and all generators and applicators must be properly shielded and specially designed to meet product-specific requirements</td>
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nonthermal technologies such as high hydrostatic pressure (HHP) (Medina-Meza et al., 2014; Hsiao-Wen et al., 2017), pulsed electric fields (PEF) (Cacace & Palmiere, 2014), high-intensity light pulses (Cacace & Palmiere, 2014), membrane technology (Cacace & Palmiere, 2014), irradiation (Albert, 2008; Odueke et al., 2016), food preservation with ozone (Cacace & Palmiere, 2014), and modified and controlled atmosphere storage (Fonseca & Malcata, 2003). Table 2 includes the description of the thermal technologies such as ohmic heating (Ahmed & Ramaswamy, 2007), infrared (IR) heating (Krishnamurthy et al., 2008), microwave (MW) heating (Ahmed & Ramaswamy, 2007; Tewari, 2007), and radio frequency (RF) heating (Fu, 2004; Tewari, 2007).

There are some other new nonthermal food technologies under development such as cold plasma, electrolyzed water, and thermosonication.

Cold Plasma: A second surface technology is cold plasma. Plasma is a high-energy gas that is created when an electrical current is passed through a gas. A well-known application of this principle is in fluorescent lighting. Until recently, plasmas could only be created at relatively high temperatures in a vacuum and the use of plasma in the agrifood sector and the packaging industry was therefore impractical. In the last few years, technological breakthroughs have made it possible to produce cold plasma under atmospheric conditions. Thus, it is now possible to apply the plasma technology in the food industry. Noble gases are used when radical formation is unwanted while oxygen is used for the production of ozone in the plasma. Depending on the used gases, temperature, activity, and stability of the plasma can be varied. No commercial equipment is available now. Low-temperature, atmospheric pressure plasmas have been shown to possess very effective germicidal characteristics. Their relatively simple and inexpensive designs, as well as their nontoxic nature, give them the potential to replace conventional sterilization methods in the near future.

Thermosonication: The combination of ultrasound and heat at moderate temperatures can cause enhanced inactivation of microorganisms. This may be particularly useful for pasteurization of certain beverages where a reduced temperature is desirable. Ultrasound has potential application for emulsified foods, especially where a product’s rheological qualities can be improved by ultrasound treatment.

Electrolyzed Water (EW) is gaining popularity as a sanitizer in the food industries of many countries. It has been regarded as a new sanitizer in recent years. Production of EW needs only water and salt (sodium chloride). EW is produced by passing a diluted
salt solution through an electrolytic cell, within which the anode and cathode are separated by a membrane. By subjecting the electrodes to direct current voltages, negatively charged ions such as chloride and hydroxide in the diluted salt solution move to the anode to give up electrons and become oxygen gas, chlorine gas, hypochlorite ion, hypochlorous, and hydrochloric acid, while the positively charged ions such as hydrogen and sodium move to the cathode to take up electrons and become hydrogen gas and sodium hydroxide. EW has the following advantages over other traditional cleaning agents: effective disinfection, easy operation, relatively inexpensive, and environmentally friendly. The main advantage of EW is its safety. EW, which is also a strong acid, is different from hydrochloric acid or sulfuric acid in that it is not corrosive to skin, mucous membrane, or organic material. EW has been tested and used as a disinfectant in the food industry and other applications. Combination of EW and other measures is also possible to use to improve the process of disinfection of food.

In addition, joule heating and hydrostatic high pressure emerge at the forefront of the narrow range of technologies considered the most promising with these capabilities. Both technologies allow obtaining products with differentiating properties similar to those of a minimally processed product or even natural product in the case cold pasteurization (without heat input).

Joule heating consists in the principle that the electric current passing through the food allows the generation of internal energy, dissipated as heat. This technology is not dependent on heat transfer phenomena from an external source, allowing to reach levels of energy efficiency of around 90%. The main advantages of this technology are (Knirsch et al., 2010; Sastry et al., 2014) the following:

- ideal for the processing of viscous and particulate products, according to high-temperature short-time principle,
- precise control of heating rates, and
- low maintenance costs and easy coupling to existing thermal processing lines;

The operative mode of this technology is based on the dependency between time and temperature as in the widely established pasteurization and sterilization operations. However, the high investment and initial operating costs added to the lack of information and research on a large number of industrial processes have limited the applicability of the technology to the industrial level.

Hydrostatic high-pressure technology is a nonthermal method of preservation. It is presented as an alternative to conventional pasteurization. This process is performed at room temperature
or even at refrigeration temperature, ensuring better maintenance of the nutritional and organoleptic attributes of a fresh perishable product, resulting in the production of premium or gourmet quality products.

The main advantages of this technology are the following:

- Nonthermal pasteurization;
- Effect of processing independent of the size/geometry of the products, which makes the scale-up process unnecessary. Thus, the transition from a laboratory to industrial level is a simple process of adaptation, extremely fast and basically without inherent costs; and
- Possibility to process liquids, solids, and mixtures thereof without the limitation of thermal processing, especially for solids.

Owing to its industrial development, hydrostatic high-pressure technology is nowadays, among emerging food conservation technologies, the technology with most commercial applications, being one of the most promising of the new applications and the fastest growing technology in the industry. This technology also allows for cold gelation of proteins and polysaccharides, with new properties as new textures, which can result in new organoleptic sensations, thus being very promising for the functionalization of ingredients.

Recently, hydrostatic high-pressure technology has proven to be very interesting for food sterilization when combined with temperature, in a process known as pressure-assisted thermal sterilization (PATS). This process allows the production of products without the need for refrigeration, but with better quality than the current sterilized ones due to the minor time and consequently lower thermal load. Ultrahigh-pressure homogenization is a technology that has also received attention. The main advantages of using high-pressure homogenization in emulsions include a narrow size distribution of particles, an aseptic processing, and the possibility of being used in highly concentrated as well as diluted formulations (Floury et al., 2004; Håkansson et al., 2009).

Until now, prospects of future scenarios cover new and emerging processing and conservation method of food products, but these are closely related with its energy consumption that also define the sustainability of the systems. The energy consumption resulting from the conversion process of fossil fuels in usable energy (electrical and thermal energy) release GHGs to the atmosphere. Thus, sustainability requires the reduction or rationalization of energy consumption (Garcia & Coelho, 2010). Agrifood industry shows continuous energy consumption by the cooling systems to ensure food safety, making this sector one of the largest
energy consumers. Several studies have been carried out to provide new tools, concepts, and solutions for improving refrigeration technologies along the European food cold chain (Eden & Colmer, 2010; Gogou et al., 2013; Evans et al., 2014a,b). The evaluation of barriers to energy consumption levels and benefits of implementing food security management systems, development of eco-efficiency indexes to qualify company performance, power management method in the sector, analysis of resource efficiency in companies, local food retail chains as method of energy reduction, among others, have been developed to help improving the energy consumption of agrifood companies (Hennigsson et al., 2004; Maxime et al., 2006; Muller et al., 2007; Karaman et al., 2012; Mundler & Rumpus, 2012; Nunes et al., 2011, 2014a,b, 2015, 2016; Santos et al., 2013; Campos et al., 2013; Neves et al., 2014; Silva et al., 2014, 2016; Gaspar et al., 2014, 2016; Gaspar, 2015). In addition, through the quantification of indexes related to the level of GHGs emissions applied to agrifood industries is possible to qualify companies according to their emissions performance. The life cycle analysis of a food product allows to analyze all aspects related to its sustainability (Plassmann et al., 2010; Ruviaro et al., 2012).

Most of these authors are consensual on several best practices to improve the overall energy performance of agro-food industry. Recommended actions to reduce energy and maintenance costs, to improve facilities security, to increase productivity and competitiveness, and improve the environmental impact of a company can be gathered (Nunes et al., 2016; Silva et al., 2016):

- Improved building infrastructure (thermal resistance materials with proper thickness and/or good quality of the insulating materials, low thermal conductive roofing materials, open recesses, among others) and new layout design have a high energy savings potential.
- Cold rooms’ insulation: Cold rooms should be built in polyurethane panels at least with 100 and 120 mm thick, respectively, for chilled and frozen food products. The doors of the cold rooms should be well insulated with seals in good conditions (periodic verification of cold doors’ rubber seals should be performed) and remain closed as long as possible as an operative procedure to increase the energy savings. Similarly, lighting of unoccupied cold rooms should be turned off. Optionally, electronic controllers for lighting could be implemented. Finally, the replacement of incandescent lighting with compact fluorescent or LED lighting is strongly recommended. In relation to the management of food products inside cold rooms, a uniform product cooling should be achieved by a careful
distribution of products within the cold room, avoiding product placement close the cold air inlets, partial load of cold rooms, and exceeding the maximum storage capacity.

- Refrigerant ducts insulation: Avoid lack of insulation in refrigerant ducts. Old refrigeration system, mainly the compressor, should be replaced by new ones with high-efficiency motors. The condensers should be installed in shaded ventilated areas and cleaned regularly. The adequate (proper system) and regular (control system) defrosting of the evaporators is highly recommended.

- Periodic preventive maintenance procedures: Maintenance procedures should be regularly performed, such as detecting and repairing air leaks of compressed air systems, checking the operating parameters of steam generators, inspecting the regulator of boiler combustion, and cleaning of heat exchange surfaces.

- Energy-efficiency management: Several procedures may be taken such as the systematic analysis of energy bills to detect larger power consumers and power factor irregularities. Whenever possible, the use of renewable energy may be implemented. An energy management plan should be developed taking into account the above recommendation.

Several of these practice measures are very cost effective and provide significant energy savings. Most of these are related with regular checks included in maintenance, monitoring, and service tasks. The remainder recommendations have a large scope of paybacks.

8 Conclusions

This chapter provides an overview of the current food production methods and technologies in terms of energy use, environmental impacts, and sustainability. The evolution of food production processes and technologies is presented over time, from a stage where agriculture had a reduced or zero environmental impact to date, where this impact cannot be avoided, resulting from the intensive use of the soil, by way of deforestation, use of fertilizers, diverse machinery, among others. This chapter shows that human action on nature has left an indelible mark from the earliest days of the Industrial Revolution to the present day, leading to an increase in CO₂ content in the atmosphere from 280 to 375 ppb, from CH₄ from 715 to 1774 ppb and N₂O concentrations that increased from 270 to 319 ppb. Climate change resulting from this human action together with the excessive
use of pesticides causes difficulties and aggravates the problem of availability of drinking water on the surface of the planet as well as its quality. Of course, due to the intrinsic characteristics of each productive sector, as for example, the livestock production has not the same techniques, machinery, and tools as the cereals production, the corresponding environmental costs are different. The world cereal production was expected to reach 2571 million tons in 2016, and with an expected target of 3.0 billion tons by 2050, but, in fact, climate change can affect seriously these expected production values in a variety of ways such as long periods of drought or rain, extremely harsh winters and scorching summers, and plagues on crops. Another large sector referred to in this chapter is the livestock sector, which covers several types of products from food to clothing (meat, eggs, milk, honey, among others). The scope and field of action of livestock farming is gigantic, increasing the difficulty of evaluating the general environmental costs or their ecological footprint. Just the global production of meat is expected to reach 470 million tons in 2050, more than the double of the 229 million tons verified in 1999/2001. The amount of livestock’s drinking water consumption: cows, pigs, sheep, and chickens in intensive farming was calculated, respectively, at 103, 17, 9, and 1.3–1.8 L/day. Approximately 8, 4, and 1 kg of cereals are needed to produce 1 kg of bovine, pork, and poultry meat, respectively. In fact, the increase in food production, especially regarding the increasing sources of high-protein foods to meet the future demand of the population, has certain challenges to face: there is not enough land for the expansion of livestock; if predatory ocean fishing continues, this activity may deplete resources for future populations; the high cost of feeding animals puts in debate if that food should be used for animals rather than being used for feeding starving population around the world; increased competition for water resources.

The dairy sector is another important livestock subsector referred to in the chapter. Products such as milk, cheese, and yogurts are consumed worldwide and are of paramount importance for people’s food base. This industry branch is currently highly advanced in terms of technology, consisting of fully automated processes focusing on improved food safety. The milk production in the last four decades grew by 64%, reaching a value of 790 million tons in 2012 with the cheese production accounting by around 27% within this sector. This chapter also highlights the importance of food products in the horticultural sector, which apart from being the most consumed food products are also widely used as raw materials in various food industries (wine, olive oil, juice, and frozen foods). In 2009, the fresh vegetables...
represented 24.4% of the horticultural products produced worldwide. The largest vegetable producers are Asian countries, particularly China, Japan, and India. The per-capita consumption varies from region to region of the world due to the eating habits and living standards of each country. For the coming years focus on sustainable consumption and sustainable production is required. In fact, sustainable food systems are key points to address food security, poverty alleviation, and adequate nutrition, and play an important role in building a society able to recover the balance between environmental and production costs.

Some noteworthy projections left in this chapter highlight the need for sustainable food systems: as population grows from 7.2 billion today to the prediction of 9 billion people by 2050; 30% waste of the total food production; 12.9% of the population in developing countries suffer from chronic hunger; it is estimated that 70% of the waters, large part of deforestation, and biodiversity loss was caused by agricultural production. The increase of local production and consumption, encouraging agricultural production activities in the cities and their surroundings, may contribute to mitigate the effects of global climate change.

Novel preservation technologies are an interesting option to produce high-quality food products with an extended shelf life. The starting point of an evaluation of the possibilities of novel technologies will therefore be the effect on quality combined with the safety of the product after processing. Interest in nonthermal food processing technologies has increased appreciably in the past decade. Current limitations of emerging nonthermal technologies can be overcome when they are combined with conventional preservation methods. Especially using higher or lower temperatures than room temperature is an interesting option to increase the effectiveness of novel technologies. Additionally, the development and implementation of emerging and innovative food processing technologies, as for example, joule heating and hydrostatic high pressure, are required to increase efficiency and production rates. Furthermore, the life cycle analysis of a food product constitutes a scientific working tool allowing to analyze all aspects related to its sustainability.

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Chapter 1 INTRODUCTION TO SUSTAINABLE FOOD PRODUCTION


Further Reading


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Abstract:
This chapter presents an overview of the current production methods for food and food ingredients, and describes the options for making healthier foods in a more sustainable manner. The current manner of producing food products has a large impact on the environment. Three main causes are responsible for inefficiencies in food production. Those are the increased use of products from animal origin, the inefficient use of food products once produced, resulting in waste generation, and the current setup of food processes and processing chains. This chapter summarizes the recent developments and sketches future scenarios for novel designs of food processes and process chains aimed at reduced environmental impact.

Keywords: Agrifood industry, Sustainability, Environmental, Energy, Technology