Food waste valorization

10

Stella Plazzotta and Lara Manzocco
Department of Agricultural, Food, Environmental and Animal Sciences, University of Udine, Udine, Italy

Chapter Outline

10.1 Introduction and main definitions

In the last years, food waste has been increasingly considered not a critical discard, but rather a valuable biomass that can be successfully converted into profitable products. In fact, food waste presents interesting characteristics: it is a source of different compounds including carbohydrates, proteins, lipids, and bioactive molecules (Ravindran and Jaiswal, 2016), it is renewable (i.e., available on a continuous basis), and cheap (Elmekawy et al., 2013). Based on these characteristics, food waste has been exploited to obtain not only energy and biofuels, but also enzymes, antioxidant extracts, novel biodegradable materials, and many other derivatives with a commercial value. In other words, food waste presents a great potential for valorization in a holistic biorefinery view. The term *biorefinery* refers to the production of bioenergy/biofuels and value-added derivatives from renewable biomass sources, with the final aim of substituting fossil fuels and reducing the

Saving Food. DOI: https://doi.org/10.1016/B978-0-12-815357-4.00010-9

depletion of other natural sources (Cherubini and Ulgiati, 2010). To this aim, different valorization strategies can be applied to food waste (Galanakis, 2012). A general definition of *valorization* can be based on the definition of *recovery* given by the Waste Framework Directive (2008/98/EC, 2008). Recovery refers to any operation whose result is waste serving a useful purpose by replacing other materials, which would otherwise have been used to fulfill a specific function in the plant or in the wider economy. Recovery can be based both on the direct exploitation of waste or after a modification of its characteristics. However, it should be added that valorization aims not only at recovering a waste material, but also at maximally exploiting its features, reaching the highest possible added value. In this regard, the term *food by-product* is increasingly used among researchers in the sector of food waste valorization instead of *food waste*. This term posits waste as raw material for the recovery of food and nonfood compounds intended for the development of novel value-added products (Laufenberg et al., 2003). However, it must be underlined that the legal definition of *by-product*, given by the European Commission, requires meeting conditions other than the possibility to develop a commercial value from a waste substance. In fact, according to Directive 2008/98/EC, a substance or object resulting from a production process, the primary aim of which is not the production of that item, may be regarded as by-product and not as waste only if:

1. the further use of that substance is certain;
2. the substance can be directly used, without any further processing other than normal industrial practice;
3. the substance is produced as integral part of the production process; and
4. further substance use fulfills legal requirements in terms of environment, safety, and quality.

The same Directive also defines the “end-of-waste” status: in this case, waste shall cease to be a waste if it has been somehow recovered and is in accordance with the following conditions:

1. the substance is commonly used for specific purposes;
2. a market or demand exists for such a substance;
3. the substance meets technical requirements, existing legislation and standards; and
4. the recovery will not lead to adverse environmental or human health impacts.

Food waste valorization strategies are often addressed to substances that do not meet conditions set by this Directive. In fact, many of them require a deep modification of waste before using it as a new marketable product. In addition, they are often based on the pioneering exploitation of food waste to produce outputs whose added value, legal classification, and impact on the food supply chain sustainability is unknown. In this work, the term *food waste* will be used to generally indicate substances discarded from a food process, which have a potential for valorization.

Based on these considerations, the present chapter discusses traditional and innovative valorization strategies of waste deriving from different food processing. In addition, a guideline for the development and implementation of new valorization strategies is proposed.

10.2 Sources and targets of food waste valorization

Food waste can be classified based on different criteria. The first one relies on the point in the food supply chain in which it is generated (harvesting, postharvest, industrial process, distribution, retail, consumption). For implementing a valorization strategy, the availability of substrates presenting a homogeneous composition and a segregated localization is crucial. In fact, the absence of these features hinders the implementation of valorization strategies, since additional collection and separation processes would be required. This would pose significant cost issues and, besides, would also increase the time needed between food waste collection and processing intended for its valorization. This aspect is of critical importance, since food waste is extremely perishable, presenting a high concentration of water and nutrients that make it a perfect substrate for the growth of pathogens (Galanakis, 2012). Currently, the collection of homogeneous wastes, concentrated in rather few locations, is possible only in the initial steps of the food supply chain (harvesting, postharvest, and industrial processing) while, in most cases, food waste generated during distribution, retailing, and consumption is a mixture of heterogeneous and not-segregated materials (Ravindran and Jaiswal, 2016). For these reasons, food waste intended for valorization is commonly collected in the first steps of the food supply chain and, among them, in the postharvest and industrial processing steps. In industrialized countries, in fact, food waste is mainly generated during these steps of the food supply chain, due to different causes, including postharvest evaluation of raw materials based on quality standards requested by retailers and programmed overproduction (FAO, 2011; Segrè and Falasconi, 2011).

A second possible classification criterion for food waste sources relies on the food sector origin. Based on this criterion, food wastes can be classified in two main groups represented by animal- and plant-origin wastes, which can be further declined into subcategories. Animal-origin waste includes materials discarded from meat, fish and seafood, and dairy industries; plant-origin waste originates from cereal, root and tuber, oil crop and pulse, and fruit and vegetable industries.

10.3 Defining priorities in food waste valorization

A possible criterion for prioritizing food waste valorization can be represented by the amount of waste generated along the food supply chain. In this regard, most studies have highlighted that perishable food items account for the highest proportion of food waste. Based on these considerations, valorization strategies should focus their attention on such waste, mainly deriving from fruit and vegetables, dairy products, meat, and fish (Pekcan et al., 2006; Morgan, 2009; WRAP, 2010; Thönissen, 2009).

Another criterion based on relative waste amount compares animal- and plant-derived waste. The latter has been reported to represent a higher proportion (about 63%, on wet basis) of food waste produced in industrialized countries in comparison to the former (Pfaltzgraff et al., 2013).

However, it must be underlined that different food products have different environmental impact, as clearly stated by the Climate Smart Agriculture Sourcebook (FAO, 2013). Based on this consideration, the Barilla Centre for Food and Nutrition (BCFN) elaborated the so defined *Double Pyramid* model, which classifies foods based not only on their nutritional supply but also on their environmental impact. The latter was evaluated based on the life cycle assessment (LCA) methodology, which considers the impact on environment of all the phases of the production process, including waste generation and management. This pyramid could thus be used to define priorities in food waste valorization. In this regard, the Double Pyramid model neatly highlights that foods for which the highest consumption is recommended (fruit and vegetables) also present the lowest environmental impact. Similarly, animal products, for which a lower weekly consumption is recommended, are characterized by the highest environmental impact (BCFN, 2010).

Alternatively, valorization strategies can be prioritized based on the so-called Waste Hierarchy, which is independent of the waste characteristics and origin. According to this classification, stated by the directive 2008/98/EC on waste, waste management strategies should be prioritized in the following order: prevention and minimization, reuse, recycle, energy recovery, and disposal. If the scope is obtaining valuable products from waste, applicable management strategies are those based on reuse, recycle, and energy recovery. In fact, prevention would allow preventing waste generation, eliminating the need for its valorization, while disposal is not recommended, since it simply consists in the landfilling of waste, with significant transport and disposal costs as well as high environmental impact. In particular, reuse indicates valorization strategies based on the use of waste materials after no or minor modification of waste characteristics (e.g., checking, cleaning, repairing); recycle refers to valorization strategies based on a deep modification of waste materials, through which they are reprocessed into products, materials, and substances whether for the original or other purposes; energy recovery indicates those interventions performed to recover energy contained in the waste material (Kothari et al., 2010).

Finally, valorization strategies can be compared based on the produced added value. In this regard, when food waste is used as a feedstock to produce energy (e.g., through incineration and anaerobic digestion), fuels (e.g., conversion into bioethanol, biohydrogen, biomethanol), animal feeding and fertilizers (e.g., composting), its interesting functional molecules are lost or, at best, underutilized (Pfaltzgraff et al., 2013). The latter are instead maximally exploited when food waste serves as a source of bioactive compounds, functional ingredients, and biocompatible materials to be exploited for human consumption. Thereby, it has been recently proven that the conversion of food waste to bulk chemicals is about 3.5 and 7.5 times more profitable than its conversion to animal feed or transportation fuel respectively, confirming the marginal economic value of these first-generation valorization strategies (Papargyropoulou et al., 2014). Thus herein the attention is focused on valorization strategies aiming at the maximal exploitation of food waste potentialities.

10.4 Valorization and sustainability

To understand the role of food waste valorization on food supply chain sustainability, the first step is surely the definition of the sustainability concept. According to the Brundtland Commission, “sustainability is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). Even if this definition puts the accent on the fact that a sustainable development should not compromise resources for future generations, it gives no indications to companies about what should be done and what should be avoided for achieving a sustainable development. Such indications can be found in the “corporate social responsibility” definition, according to which, organizational sustainability must include not only economic performances (profit) but also environmental and social impact: only by balancing these three components, long-term sustainability can be achieved (Elkington, 1994). If specifically referring to the food supply chain, sustainability can be achieved by a proper “product stewardship”, that is, “minimizing the health, safety, environmental, and social impacts of a product and its packaging throughout all lifecycle stages, while also maximizing economic benefits”. The manufacturer, or producer, of the product has the greatest ability to minimize adverse impacts, but other stakeholders, such as suppliers, retailers, and consumers, also play a role. Consequently, food supply chain sustainability depends on all the stakeholders and affects economic, social, and environmental frameworks (Product Stewardship Institute, 2011).

Food waste valorization could improve all the three aspects of sustainability. The economic sustainability would be increased both directly, by reducing waste management costs and creating new value-added products from a cheap and always available source and indirectly, by giving companies the possibility to build an eco-friendly image.

Social sustainability may also be improved by food waste valorization, since it would increase food production and optimize the resource used as food to feed an ever-increasing world population.

Environmental sustainability would be directly improved by food waste valorization, due to a reduction in waste to be disposed of and to the conversion of waste materials into new renewable resources, to be used in production processes without depleting other primary resources.

Nevertheless, data available on the real impact of food waste valorization on the sustainability of food supply chain are still limited and this topic is worthy of further investigation. For example, despite that the extraction of bioactive compounds from food waste using classical solvent procedures is simple and cheap, it has been demonstrated to have a negative impact on the environment, due to huge solvent amounts to be disposed of. Similarly, the application of novel extraction technologies can result in high investment costs, and is not sustainable from an economic point of view (Chemat et al., 2012).

10.5 Valorization of animal waste

10.5.1 Definition and quantification

10.5.1.1 Meat and poultry

Waste produced by meat industries consists of the portions of slaughtered animals that cannot be processed and sold as meat or meat products and are not intended for direct human consumption (Jayathilakan et al., 2012). This definition thus excludes all those edible products such as fat, lard, or internal organs (kidney, liver, tripe, brains, spleen) that fall under the definition of by-products given by the Directive 2008/98/EC. Rather, meat-derived waste includes heterogeneous materials such as bones, tendons, skin, portions of the gastrointestinal tract and other internal organs, and blood. Waste generated by slaughtering of cattle, pigs, and lambs represents more than 50% of the live animal weight (Russ and Meyer-Pittroff, 2004). Animal blood is the first product obtained after slaughter and constitutes 3%−5% of the live weight of animals. According to the different animal species, hides/skins and bones could represent respectively 4%−11% and 15%−22% of the live animal weight (Halliday, 1973; Wanasundara et al., 2003).

10.5.1.2 Seafood

Waste generated by seafood processing typically ranges from 20% to 60% of the initial raw material, with an average of 20 million tons globally (Suresh and Prabhu, 2013; Pangestuti and Kim, 2014). Fish and seafood waste mainly consists (27% of the fish) of offal, head, and tails collected by the eviscerating, cutting, and filleting processes. A second major residue is also represented by skins, fishbones, and blood (25% of the fish) (AWARENET, 2004).

10.5.1.3 Dairy

Dairy and cheese processing plants generate large volumes of liquid waste, mainly represented by cheese whey. The latter is the waste liquid portion produced during cheese-making or during coagulation of the milk casein process. In particular, to make 1 kg of cheese approximately 9 kg of whey is generated (Audic et al., 2003), leading to a current total worldwide production of whey of about 190 million tons/year (Yadav et al., 2015).

10.5.2 Valorization strategies

Animal waste derivatives have been recovered for centuries to serve a wide range of applications: animal blood, skin, and bones have been used for the production of foods such as sausages, snacks, soups; hides and feathers have been used since prehistoric times for shelters, clothing, containers, filler, adornment, and forage (Jayathilakan et al., 2012); cheese whey has been used for animal feeding (Audic et al., 2003; Schingoethe, 1976). Moreover, in the past, animal waste (especially animal blood and cheese whey) was disposed of in the environment by spraying on agricultural fields or composting. However, these strategies present several issues. For example, strict legal requirements limit the use of meat waste in food and feed, due to possible health and hygienic issues (Ofori and Hsieh, 2014). Similarly, land spreading of animal waste is not allowed or strongly hindered, due to the environmental problems caused by its physicochemical characteristics such as high solid content, elevated biochemical and chemical oxygen demand, and production of landfill leachate and polluting gases (Nowak and von Mueffling, 2006; Del Hoyo et al., 2007; Prazeres et al., 2012). Finally, composting can absorb only a reduced amount of animal waste, as it is a slow process, requiring space and regular maintenance to avoid environmental pollution and off-odor generation (Mittal, 2006).

Since animal waste represents a cheap source of high-quality proteins and nutrients, alternative strategies can be applied to maximally valorize this waste (Table 10.1).

10.5.2.1 Meat and poultry

Blood, hides/skins, and bone meals are prepared from meat waste by the rendering process. The latter consists in cooking, defatting, and grinding of meat waste to obtain two separate fractions of fat and flour, generally referred to as meat and bone meals. These substrates have been commonly used in animal feed and as ingredients for pet food, due to their high concentration of available essential amino acids, minerals, and vitamin B12. However, as a result of the bovine spongiform encephalopathy (BSE) crisis in the European beef industry, the use of meat and bone meal for cattle feed has not been allowed since 2000. Therefore, particularly interesting is the valorization strategy based on the incineration of meat and bone meals, leading to ashes rich in phosphate and cadmium. The latter have been used as source for phosphoric acid production, phosphate source for industry, agricultural soil enrichment, heavy metals immobilization in soil or water, and for the development of phosphate rich materials and for biosorbents to be used in wastewater treatment (Hodson et al., 2000; Deydier et al., 2005).

Moreover, both hides and bones contain large quantities of collagen, which is the most abundant animal structural protein, representing about 30% of the total animal protein content (Pal et al., 2015). The controlled hydrolysis of collagen produces gelatin. Both collagen and gelatin are widely used in various industrial sectors: collagen can be used as emulsifier and filler in meat products, while gelatin is added to a wide range of foods, forming a major ingredient in jellied desserts, aspics, and as a stabilizer for ice cream and other frozen desserts. Gelatin is also widely used in the pharmaceutical industry, to produce capsules, medicated tablets, and pastilles and can also be turned into sterile sponges used in surgery. In addition, based on the excellent emulsifier and stabilizing properties of gelatin, it is used in cosmetic emulsions and foams (Mokrejs et al., 2009). Even if currently the primary sources of commercial collagen are bovine and porcine skin, bones, and hides, in recent decades, the production of land-based animal's collagen has decreased, due to the concerns about outbreaks of BSE, foot mouth disease, and other prion

Table 10.1 Targets of valorization strategies applied to animal waste and their possible use

Waste origin	Waste material	Target	Use/possible use	References
Meat and poultry	Skins, hides, bones	Ashes	Source of phosphoric acid and phosphate; components of bioadsorbent materials	Deydier et al. (2005), Hodson et al. (2000)
		Collagen	Emulsifier, foaming, filler, gelling agents for food, pharmaceutical, medical and engineering applications	Pal et al. (2015)
		Hydroxyapatite	Biomaterial for craniofacial, oral, maxillofacial and orthopedic applications	Kowalski et al. (2008)
	Blood	Proteins	Emulsifying agents, protein supplements, fat replacers; growth factors of microbial culture media, reactants of biological assays	Viana et al. (2005), Kurbanoglu and Kurbanoglu (2004)
		Plasma	Ingredients for food and pet food with high-quality protein content and palatability	Coffey and Cromwell (2001), Polo et al. (2005), Fernández-Michel et al. (2006), Yousif et al. (2003)
		Hemoglobin	Ingredients for food iron fortification	Walter et al. (1993)
		Fibrinogen, fibrinolysin, serotonin, immunoglobulins, and plasminogen	Chemical and medical uses	Young and Lawrie (2007)
		Plasma flour	Ingredients for protein fortification of bakery products	
	Internal glands and organs	Cholesterol, melatonin, bile, vitamin B12, progesterone, estrogen, heparin, insulin	Substrate for vitamin D3 synthesis; active substances in drugs for treatment of several diseases	Jayathilakan et al. (2012)
	Feathers	Keratin	Biomaterials for medical and bioengineering applications	Ji et al. (2014)

Seafood	Mixed seafood waste	Fish meal	Pet food, animal feed and fertilizer	Ferraro et al. (2010)
		Fish oil	Ingredient in shortenings and margarines; component in soaps and creams	Ferraro et al. (2010)
	Skins, scales, bones, fins	Collagen	Emulsifier, foaming, filler, gelling agent for food, pharmaceutical, medical and engineering applications	Pal and Suresh (2016)
		Hydroxyapatite	Biomaterial for craniofacial, oral, maxillofacial and orthopedic applications	Huang et al. (2011), Muhammad et al. (2016)
	Liver and flesh	PUFA	Ingredients in the formulation of nutritional supplements	Sahena et al. (2009)
		Free amino acids	Ingredients in the formulation of food supplements, energy drinks, infant formulas, drugs	Kang et al. (2009)
Seafood	Shells	Chitin and chitosan	Components in drugs (delivery systems, hypocholesterolemic agents); food adjuvants (beverage clarification), antimicrobial and emulsifying agents, fat mimetics, components of edible films	Cahú et al. (2012)
		Carotenoids	Antioxidants and immune system enhancers; natural food colorants	Sánchez-Machado et al. (2006)
	Blood	Antifreeze proteins	Adjuvants in cryopreservation and cryosurgery; ingredients in frozen and low-fat foods	Feeney and Yeh (1998)
	Internal organs	Enzymes (proteases, lipases, chitinolytic)	Additives in polyester production and wastewater treatment; adjuvants in meat tenderization, protein hydrolysate production, enzyme-assisted extraction	Gildberg (2004)

(*Continued*)

Table 10.1 (Continued)

Waste origin	Waste material	Target	Use/possible use	References
Dairy	Whey	Whey powder, whey protein concentrate, whey protein isolate	Food emulsifying, foaming, water binding, and gelling agents; components of edible and active films and coatings	Yadav et al. (2015), Ramos et al. (2012)
		α-Lactalbumin	Regulator of serotonin, lipid oxidation and mineral absorption; antimicrobial activity and immunomodulatory agents	De Wit (1990)
		β-Lactoglobulin	Emulsifying and gelling agent; carrier for fat-soluble vitamins and lipids	De Wit (1990)
		Bovine serum albumin	Carrier for fatty acids	Korhonen (2009)
		Immunoglobulins	Antimicrobial, antitoxins and antiviruses agents; milk replacers in infant formula	Mohanty et al. (2016)
		Lactoferrin and lactoperoxidase	Antimicrobial and antifungal agents	Hernández-Ledesma et al. (2011)
		Bioactive proteins	Ingredients in feed and pet food formulation; antimicrobial agents	Mohanty et al. (2016)
		Biopolymers (exopolysaccharides, xanthan gum)	Food viscosants and gelling agents	Prazeres et al. (2012)
		Enzymes (e.g., lipase, α-amylase)	Adjuvants in biotechnological applications	Yadav et al. (2015)
	Whey permeate	Lactose	Source of lactulose and lactitol for foods and pharmaceutical formulations	Audic et al. (2003)

diseases. Besides, use of mammalian collagen is a hurdle in the development of kosher and halal products, due to religious factors (Wang et al., 2014).

Animal bones have been recently exploited as a source of natural hydroxyapatite. This mineral is the primary constituent of bones, calcified cartilage tissues and teeth and finds large use in craniofacial, oral, maxillofacial, and orthopedic applications. Since hydroxyapatite is currently mainly derived from chemical synthesis, its extraction from animal waste would offer the possibility of obtaining a biomaterial with interesting stability, biocompatibility, and inertness features (Kowalski et al., 2008).

Plasma is the blood liquid fraction, thus excluding the cellular fraction (red and white blood cells and platelets) and is rich in proteins, which are used as natural binders in whole meat processing, emulsifiers in meat systems, protein supplements, fat replacers in meat products and enzymatic inhibitors in some fish derived products presenting high endogenous protease activity (Viana et al., 2005). Moreover, blood protein derivatives can be used as growth factors for culture media and as reactants of different biological assays (Kurbanoglu and Kurbanoglu, 2004). Plasma has also been used in the formulation of food for both pets and farm animals, to increase its nutritional quality, texture, and palatability (Coffey and Cromwell, 2001; Polo et al., 2005). Similarly, flour derived from plasma has been exploited in the formulation of protein-rich bakery products (Fernández-Michel et al., 2006; Yousif et al., 2003).

By contrast, the use of cellular fraction of blood is limited due to the undesirable sensory properties imparted to the final product in terms of color, odor, and taste (Duarte et al., 1999). Nevertheless, this fraction is exploited for the extraction of hemoglobin, to be used for food iron fortification (Walter et al., 1993).

Finally, many blood components such as fibrinogen, fibrinolysin, serotonin, kalikreninsa, immunoglobulins, and plasminogen are isolated for chemical or medical uses (Young and Lawrie, 2007).

Internal organs and glands are a source of different compounds such as cholesterol and hormones. Cholesterol can be extracted from brains, nervous systems, and spinal cords and is used as raw material for the synthesis of vitamin D3 and as emulsifier in cosmetics. The pineal gland is a source of the hormone melatonin that is used for the treatment of different diseases such as schizophrenia and insomnia. Similarly, the gall bladder is used for the extraction of bile, used for the treatment of indigestion, constipation, and gastrointestinal tract disorders. Moreover, liver extract is used as a source of vitamin B12 and heparin, used to treat anemia and coagulation disorders. Progesterone and estrogen, hormones used to treat reproductive problems in women, can be extracted from pig ovaries, while the pancreas provides insulin and glucagon, which are used in the treatment of diabetes and low sugar diseases, respectively, as well as chymotrypsin and trypsin, used to improve healing after surgery or injury (Jayathilakan et al., 2012).

Feathers from the poultry industry have been recently used as a source of keratin. It is known, in fact, that feathers contain usually more than 70% (w/w) of this structural protein that has important applications in different sectors, including the production of biomaterials, flocculants, and adhesives (Ji et al., 2014).

10.5.2.2 Seafood

Most seafood waste is currently processed in fish meal plants, where fish meal and fish oil are produced. Fish meal production consists in mincing, cooking, and pressing fish waste to separate the solid cake (the fish meal) from a liquid phase, which is centrifuged to obtain the fish oil. While fish meal is used as animal feed, pet food, or plant fertilizer due to its rich composition in protein and minerals, fish oil can be exploited for both food and nonfood uses according to its composition. Among food uses, the production of margarine and shortenings is the most common use of fish oil; nonfood applications include production of soap, glycerol, fertilizers, and substrates for fermentations (Ferraro et al., 2010).

Skin, scales, fins, and bones deriving from seafood waste can represent a valuable alternative to meat waste to produce collagen and gelatin, not presenting issues related to prion diseases and religious factors (kosher and halal products). Moreover, with respect to animal gelatin, seafood gelatin presents analogous functional properties, associated to an enhanced digestibility (Woodard et al., 2007).

Similarly, seafood bone can represent an alternative to animal waste to produce biocompatible materials such as hydroxyapatite (Yamamura et al., 2018).

The liver and residual flesh of some fishes (cod fish, mackerel) are important natural sources of polyunsaturated fatty acids (PUFA), which are used in the production of PUFA concentrates and nutritional supplements. PUFA, in fact, are well known to be associated to numerous biological and physiological functions in the human body (Zuta et al., 2003).

Fish waste can also be considered a source of free amino acids, such as taurine and creatine, which are largely used for producing sport drinks, food supplements, infant formulae, and drugs. Free amino acids, in fact, present different biological activities: for example, taurine is involved in renal functionality and antiinflammatory activity, while creatine is responsible for skeletal and muscle regeneration and contraction. Nowadays these free amino acids are mainly produced by chemical synthesis. However, the final products contain process contaminants and by-products that can have negative health effects. For these reason, a lot of research is being dedicated to the possibility of extracting these amino acids form fish flesh. In particular, raw mussels, fresh clams, and raw fish flesh are particularly rich in taurine, while herring, salmon, and cod are valuable sources of creatine (Kang et al., 2009; Ferraro et al., 2010).

Shell waste from crabs, shrimps, and krill are the main sources for the extraction of chitin and chitosan. These ubiquitous marine polysaccharides are used in food, pharmaceutical, and health industries. In particular, chitin, chitosan and their oligomers are used in nutraceutical formulation for their role as dietary fibers, in lipid absorption reduction and hypocholesterolemia effect. In the food industry they are used as additives for beverage clarification, as texturing and emulsifying agents, fat mimetics, and to produce edible films. Chitinous materials are also used as antimicrobial agents and in drugs as delivery systems and helpers in wound healing. Other applications include water purification from dyes, pesticides, and phenols and laboratory application as chromatographic separation agents and enzyme immobilizers (Kim et al., 2008; Kumar, 2000).

The production of chitinous materials from seafood shell waste is a well-established and profitable process, especially if it includes also the recovery of pigments such as carotenoids (e.g., astaxanthin). In this regard, crustacean cells represent a major source for the recovery of these compounds, which present interesting characteristics for use in food and medical applications. In particular, they are used as natural colorants and powerful antioxidants. Medical uses exploit their protection activity against chemically induced cancers and age-related macular degeneration, as well as their enhancement of the immune system (Sánchez-Machado et al., 2006).

Seafood waste is also a very promising source of antifreeze proteins, which prevent fish from freezing and are thus present in fish adapted to very cold sea waters, such as cod. Antifreeze proteins find large application in frozen foods, low-fat products, cryopreservation, cryosurgery, and aquaculture. In frozen foods they allow lowering the freezing point, thus reducing cellular damage and maintaining texture. Their structuring ability has also been exploited in low-fat ice cream production (Feeney and Yeh, 1998; Ferraro et al., 2010).

Aquatic invertebrates as well as the internal organs of fish and the shells of crustaceans constitute natural sources of enzymes. At present, proteases constitute the dominant group of marine enzymes with a commercial value. They mainly include gastric, intestinal, and hepatopancreas proteinases but also nonproteolytic enzymes, such as transglutaminase, lipases, and chitinolytic enzymes. These enzymes present a wide range of well-established or possible applications in food (e.g., extraction of pigments, production of protein hydrosilates, meat tenderization) and nonfood sectors (wastewater treatment, polyester production) (Kim and Dewapriya, 2014).

10.5.2.3 Dairy

According to Galanakis (2012), whey derivatives represent the majority of the labeled products deriving from food waste. Whey proteins and their derivatives, in fact, have found a wide range of applications, due to their excellent functional and nutritional properties. To transform whey into value-added products, two main procedures are usually carried out. The first one is processing of whey to obtain whey powder, whey protein concentrate, whey protein isolate, reduced lactose whey, lactose, and other protein fractions (Yadav et al., 2015). Whey powder, whey protein concentrate, and isolate can be used for food and feed formulation, due to their high nutritional value. Moreover, they are largely used as emulsifying, foaming, water binding, gelling, and texturizing agents (Morr and Ha, 1993).

Viable materials have been successfully produced from whey proteins. Based on their wide-range mechanical properties, such materials can be used either as primary coatings or as packaging films; in addition, their ability to serve other functions, such as carriers of antimicrobials, antioxidants, or other nutraceuticals, will add value for eventual further commercial applications (Ramos et al., 2012).

In addition, the isolation of specific proteins from whey produces highly functional compounds. β-Lactoglobulin is an excellent emulsifying and gelling agent and can also be used as carrier for fat-soluble vitamins and lipids. α-Lactalbumin helps serotonin regulation, and thus leads to positive effects on cognitive performance, mood, and sleep; in addition, it helps the regulation of lipid oxidation and mineral absorption and possesses antimicrobial activity and immunomodulatory effects. Bovine serum albumin is often used as carrier for fatty acids, while immunoglobulins present antimicrobial, antitoxin, and antiviral activity and are used in infant formula as milk replacers (Korhonen, 2009; Mohanty et al., 2016; De Wit, 1990). Lactoferrin and lactoperoxidase are mainly used for medical applications, due to their antimicrobial and antifungal activity (Hernández-Ledesma et al., 2011).

A second approach for whey valorization involves biotechnological processing, where whey is used as substrate for various microbial/enzymatic processes to obtain valuable products. The latter include bioactive proteins such as nisin (bacteriocin) and peptides with a desired aminoacidic profile for feed and pet food formulation, biopolymers such as exopolysaccharides and xanthan gum to be used as food viscosants/gelling agents, and enzymes (e.g., lipase, α-amylase) for biotechnological applications (Siso, 1996; Prazeres et al., 2012).

The residual fraction from the production of whey protein derivatives is called whey permeate and is used for lactose recovery. In this regard, Peters (2005) assessed that the transformation of whey into whey protein concentrate, isolate, and/or single protein fractions generates a large stream of whey permeate, which needs further processing to make the valorization process profitable. Lactose, in fact, represents the raw material to produce functional derivatives such as lactulose, widely used in pharmaceutical and feed applications, and lactitol, used in ester emulsifier production (Audic et al., 2003).

10.6 Valorization of plant-origin waste

10.6.1 Definition and quantification

10.6.1.1 Cereals

Cereals are a primary human food source, being the staple food for a large sector of the world population. Cereal waste is produced during the milling process, in which bran and germ are eliminated. The latter are rich sources of dietary fibers, phenolics, vitamins, and minerals (Elmekawy et al., 2013). According to the cereal, the amount of generated waste can be different. For example, it is estimated that during the production of white wheat flour, 150 million tons of wheat bran are produced per year worldwide (Prückler et al., 2014). Similarly, rice production generates about 29.3 million tons of rice bran annually (Sharif et al., 2014).

10.6.1.2 Roots and tubers

Among the several roots and tubers, potato is the largest crop worldwide, while cassava is very popular in South Asia and America (FAO, 2009). Processing of potatoes is conducted mainly for the production of chips or French fries and corresponding solid wastes consist of peels or cull potatoes (Schieber et al., 2001). The amount of the waste depends on the used peeling process, reaching on average 27% of the initial weight, accounting for more than 100 million tons in 2013 (Guechi and Hamdaoui, 2016).

Similarly, cassava peels constitute 10% wet weight of the roots and represent the second waste generated during processing of cassava, following the so defined cassava pulp or pomace, representing 15%−20% of initial cassava weight (Jamal et al., 2011).

10.6.1.3 Oil crops and pulses

Olive and olive oil production is mostly located in Mediterranean countries, where more than 98% of the world's olive oil is produced (an estimated 2.5 million tons/year). Upon oil extraction, a solid fraction called olive pomace (olive cake) containing olive pulp, skin, and stones, and a liquid one (olive mill wastewater) are produced. According to the production process, 1 ton of olives generates about 200 kg of olive oil, 400−600 kg of solid waste, and 600−1200 kg of wastewater (Azbar et al., 2004).

In the case of oil crops and pulses, sunflower and soybean are the dominating crops in Europe and North America, respectively (Galanakis, 2012). Sunflower is cultivated for the high oil content, which represents up to 80% of its economic value. Sunflower oil extraction typically has a yield of 85%, while the remaining 15% is represented by residual press cake (Evon et al., 2009).

In the case of pulses, soybeans have been cultivated in Asian civilizations for thousands of years and are one of the most important food crops globally today. Okara is the Japanese term referring to the soy pulp, that is, the ground soybean insoluble residue remaining after filtering the water-soluble fraction during soymilk and soybean curd production. Since about 1.1−1.2 kg of okara is produced from every kilogram of soybeans, huge quantities of okara are produced annually, especially in Asian countries with high soybean consumption. The amount of okara generated from the soybean manufacturing sector is about 800,000 tons in Japan, 310,000 tons in Korea, and 2,800,000 tons in China. The amount of okara produced annually in Singapore alone is at least 10,000 tons, comparable to that produced in Canada (Vong and Liu, 2016).

10.6.1.4 Fruit and vegetables

Fruit and vegetable processing can generate different waste amount, due to the removal of peels, stones, and other inedible parts (Ajila et al., 2012). For example, fresh-cut processing generates at least 25%−30% of waste, up to, in some cases, 50% (Sagar et al., 2018; Plazzotta et al., 2017), while during juice production, generated waste can amount up to 10%−20% (Argun and Dao, 2017). Overall, a total of 42 and 70 million tons of annually produced waste has been estimated for fruits and vegetables, respectively (Sagar et al., 2018).

10.6.2 Valorization strategies

Traditional uses of plant waste include soil amendment, composting, bioenergy recovery, and animal feed. However, soil amendment practice, which is based on the ability of organic waste to immobilize trace metals and metalloids, is often difficult to put into practice, due to the high biological instability of plant waste, responsible for pathogen growth risk and off-odors generation (Clemente et al., 2015). Moreover, in some cases, such as olive mill wastewater, pretreatments are required to remove specific phytotoxic components (Dermeche et al., 2013). Similarly, despite that composting is an ancient eco-friendly method to convert organic waste into organic fertilizer, it is well established that anaerobic digestion is a more attractive strategy to produce fertilizers from plant waste, due to the energy recovery as biogas. In this regard, it must be noted that a significant portion of some crops, such as soy and cereals, is not intended for food use, but for producing biofuels, as a biobased alternative to fossil sources (Milazzo et al., 2013). However, codigestion of plant waste with other organic waste with a richer composition (e.g., animal manure) is usually recommended to increase process yield (Sharma et al., 2000). Plant-based waste can also be exploited to formulate animal feeds with increased nutritional value. However, these waste materials are not always suitable for animal feed, due to the high water content, the low protein concentration, and the presence of indigestible compounds (especially insoluble fibers) or antinutritional factors (such as trypsin inhibitors present in soy-derived waste) (Stanojevic et al., 2013). Moreover, composition of vegetable products varies according to season, forcing manufacturers to often change feed formulations (San Martin et al., 2016).

Beside these issues, traditional recovery strategies are not able to maximally valorize functional compounds of plant food waste, leading to the need for alternative valorization strategies (Table 10.2).

10.6.2.1 Cereals

Cereal milling process produces bran, which is a by-product so as defined by European legislation, that is, presenting a common use in food sector. Bran includes the outer shell of the seed, which is particularly rich in fiber and protein. The most common types are corn, rice, and wheat bran, which are commonly used as ingredients to increase nutritional value of different foods, including bakery products and breakfast cereals (Elmekawy et al., 2013).

Biovalorization of cereal waste based on microbial fermentation has been reviewed by Elmekawy et al. (2013). According to the cereal type, used microorganisms, and fermentation mechanisms, different outputs can be obtained. They include organic acids, such as lactic, citric and succinic acid, which are widely used in food, pharmaceutical, leather, and textile industries. Also, enzymes can be obtained by cereal waste fermentation. They include α-amylase, β-glucosidase, cellulase, glucoamylase, and proteases, which find wide uses in food and nonfood sectors, such as pharmaceutical, paper, textile, detergent, and tanning industries.

Table 10.2 Targets of valorization strategies applied to plant waste and their possible use

Waste origin	Waste material	Target	Use/possible use	Reference
Cereals	Corn, rice, and wheat bran	Dietary fiber	Ingredients for bakery products and breakfast cereals with enhanced fiber content	Elmekawy et al. (2013)
		Antioxidant compounds	Natural antioxidants for food and pharmaceutical applications	Yen and Razak (2014)
	Corn mill waste	Organic acids (lactic, citric, succinic)	Additives and adjuvants in food, pharmaceutical, leather, and textile industries	Li et al. (2006)
		Pullulan	Component of biodegradable packaging films, adhesives, molded articles, coatings, fibers	Sharma et al. (2013)
	Wheat mill waste, rice bran	Enzymes α-amylase, β-glucosidase, cellulase, glucoamylase and proteases	Additives and adjuvants in food, pharmaceutical, paper, textile, detergent, and tanning industries	Kammoun et al. (2008), Ng et al. (2010)
	Corn husk	Antibiotics and biosurfactants	Components in drugs, ingredients in food emulsified systems	Mahalaxmi et al. (2010)
		Arabinoxylans, xylitol,	Low calorific value sweetener	Zhang et al. (2014)
		Furfural	Component in the synthesis of different solvents, lubricants, medicines and adhesives	Sánchez-Bastardo et al. (2017)
	Corn, rice mill waste, and wheat bran	Vanillin	Flavoring and antimicrobial agent in food industry; intermediate in herbicides, drugs and antifoaming agents; component of household products (polishes and air fresheners)	Di Gioia et al. (2007)
	Brewer's spent grain	Xylitol	Sweetener for food and pharmaceutical formulations	Mussatto and Roberto (2005)

(*Continued*)

Table 10.2 (Continued)

Waste origin	Waste material	Target	Use/possible use	Reference
	Rice bran	Polyhydroxyalkanoate	Component of biodegradable packaging materials	Saranya Devi et al. (2012)
	Oat mill waste	β-Glucan	Gelling agent	Patsioura et al. (2011)
Roots and tubers	Potato peel	Reducing sugars with antioxidant properties	Food preservatives and cosmetic sector	Pathak et al. (2018)
		Lactic acid	Component in polylactic acid production	Liang et al. (2014)
		Tissue structure	Biosorbents for the treatment of effluents or other contaminated sources containing dyes, pigments, and metals	Tiwari et al. (2015)
	Cassava	Enzymes (cellulolytic and amylolytic)	Additives in food, pharmaceutical, detergent, and tanning industries	Silva et al. (2009), Ofuya and Nwajiuba (1990)
		Organic acids	Preservatives, acidulants, flavoring agents	John et al. (2006)
		Xanthan	Viscosant in jams, puddings, sauces, and canned and frozen food and drinks; stabilizer in emulsions, suspensions, and foam products; additive in textile industries, paint and automotive oils, ceramic coatings	Padmaja and Jyothi (2016)
Roots and tubers	Cassava	Pullulan	Component of biodegradable packaging films, adhesives, molded articles, coatings, fibers	Padmaja and Jyothi (2016)
Oil crops and pulses	Olive pomace	Fat-balanced flour	Highly nutritional feed	Servili et al. (2015)
		Cell wall polysaccharides	Microcrystalline or powdered cellulose, gelling agents and fat replacers	Galanakis et al. (2010)

	Olive stone	Porous structure	Biosorbents for water purification and other decontamination processes	Spahis et al. (2008)
	Olive wastewater	Polyphenols	Antioxidant, antiinflammatory and antimicrobial agents for food and pharmaceutical applications	Servili et al. (2015)
	Sunflower oil waste	Proteins	Emulsifying, foaming, and whipping agents	Pickardt et al. (2015), Rodrigues et al. (2012)
	Okara from soy processing	Dietary fiber, proteins	Ingredient for functional food production (snacks, bakery and meat products)	Park et al. (2015), Olga and Etelka (2013), Grizotto et al. (2012)
			Source of nanofibers	Fung et al. (2010)
		Bioactive peptides and free amino acids	Ingredients of food supplements, energy drinks, infant formulas, drugs	Vong and Liu (2016)
		Isoflavones	Ingredients of functional food formulation	Preece et al. (2017)
		Oil	Nutritional ingredient for food and pharmaceutical formulations	Quintana et al. (2018)
Fruit and vegetables	Fruit and vegetable waste	Antioxidant phenolic compounds	Natural antioxidants for food and pharmaceutical applications	Laufenberg et al. (2003)
		Carotenoids, anthocyanins, betanin and chlorophylls	Natural colorants	Bridle and Timberlake (1997)
		Dietary fiber	Flour intended for bakery product fortification	Plazzotta et al. (2018c), Ferreira et al. (2015)
		Tissue structure	Biosorbents for wastewater treatment; templates for solvent imbibition	Plazzotta et al. (2018b), Azouaou et al. (2008)
		Water	Water for use in industries facilities	Anon (2017)

(*Continued*)

Table 10.2 (Continued)

Waste origin	Waste material	Target	Use/possible use	Reference
	Apple, orange, carrot, waste	Pectin	Gelling agent for fruit derivatives and bakery fillings	Perussello et al. (2017), Balu et al. (2012)
	Citrus peels	Essential oils	Flavoring agents in foods; anti-inflammatory and antibacterial in drugs; component of toilet soaps, perfumes, cosmetics	Boukroufa et al. (2015)
	Grape waste	Seed oil	Food oil rich in linoleic acid and polyphenols	Gowe Chala (2015)

Vanillin can also be obtained by wheat, corn, and rice waste. In fact, ferulic acid, which is the main vanillin precursor, can be released from these substrates by proper physicochemical and enzymatic treatments and bioconverted into vanillin. The latter is used as flavoring and antimicrobial agent in the food industry, as intermediate in herbicides, drugs, and antifoaming agents, as a component of household products (polishes and air fresheners) (Di Gioia et al., 2007).

Biopolymeric materials have been also produced from cereal waste. Brewer's spent grain has been used as a medium for producing xylitol, corn waste as nutrient for pullulan production, and hydrolyzed rice bran as substrate for polyhydroxyalkanoate production. Xylitol is used in the food and pharmaceutical industries as a low-calorific-value sweetener (Mussatto and Roberto, 2005). Due to its unique structure, biodegradable nature, and characteristic physical properties, pullulan has a wide range of industrial applications such as packaging films, adhesives, molded articles, coatings, and fibers. Similarly, polyhydroxyalkanoates bear similar physicochemical properties to conventional polymers such as polyethylene (PE/LDPE) and polypropylene (PP). These waste-derived materials present applications in pharmaceutical, food, and cosmetic industries and represent attractive alternative to petrochemically derived ones, since their use can minimize the detrimental impact of persistent plastics on the environment (Saranya Devi et al., 2012).

Finally, specific microorganisms can ferment cereal waste and produce antibiotics (e.g., rifamycin) and biosurfactants, leading to value-added compounds of natural origin, able to substitute chemically synthesized ones and increasingly appreciated by consumers (Elmekawy et al., 2013).

Beside bioconversion, cereal waste can also be exploited for selective extraction of specific compounds. In this regard, oat mill waste has been suggested for the extraction of β-glucan with advanced gelling properties (Patsioura et al., 2011).

Similarly, rice and wheat bran have been used for the extraction of antioxidant compounds (Yen and Razak, 2014).

Moreover, arabinoxylans can be extracted by hydrothermal methods, chemical treatments, enzymatic extractions, and mechanical processes, hydrolyzed into xylose and arabinose and then further hydrogenated to obtain xylitol. Another product to be produced from xylose is furfural, which is employed in the synthesis of different solvents, lubricants, medicines, and adhesives (Sánchez-Bastardo et al., 2017).

10.6.2.2 Roots and tubers

A widely studied valorization strategy for potato peels is the extraction of reducing sugars intended for antioxidant extract preparation, possibly applicable in food and cosmetic sectors (Al-Weshahy and Rao, 2012; Pathak et al., 2018). In this regard, the efficiency as a food preservative of an ethanolic extract from potato peels was tested on fish fillets and soybean oil (Amado et al., 2014).

Carbohydrates from potato peels were also exploited for microbial bioconversion into useful organic compounds such as acetic and lactic acid, long chain fatty acid, alcohols, or hydrocarbons. In this regard, scale-up studies were conducted on the bioconversion of potato peel waste in lactic acid intended for production of polylactic acid, an added-value biodegradable plastic (Liang et al., 2014).

Over the past few years, one of the major applications of potato peels has been the development of bioadsorbents for the treatment of effluents or other contaminated sources containing dyes, pigments, and metals. For this application, potato waste has been submitted to different treatments such as pyrolysis, acid treatment, and hydrothermal (Tiwari et al., 2015).

Around 50%–60% of the unextracted starch from cassava tubers goes along with the residue, and hence this biowaste is a cellulose-starch product, that can be thus exploited for efficient bioconversion into commercially important compounds such as cellulolytic and amylolytic enzymes, organic acids (lactic, citric) and polysaccharides such as xanthan and pullulan (Ofuya and Nwajiuba, 1990; Silva et al., 2009). These compounds find a wide range of applications in food and nonfood sectors. Organic acids are widely used as preservatives, acidulants, and flavoring agents (John et al., 2006). Xanthan is employed as a stabilizer in emulsions, suspensions, and foam products and is also used as an additive in textile industries, paint and automotive oils, and ceramic coatings. It is used in various food products such as jams, puddings, sauces, and canned and frozen food and drinks. Pullulan, as anticipated, represents a biodegradable alternative to traditional plastic materials (Padmaja and Jyothi, 2016).

By contrast, cassava peel valorization is limited due to its high content of toxic cyanogenic glucosides, which make it not suitable for direct soil fertilization. However, if properly fermented, cassava peel can serve as a potential resource for animal feeds contributing up to 10% or more to feed composition (Jamal et al., 2011).

10.6.2.3 Oil crops and pulses

A proper valorization of olive oil pomace and vegetation wastewater can be obtained by different strategies. Olive pomace can be dried and stoned to obtain highly nutritive feed, presenting interesting characteristics in terms of fat content and balanced composition of PUFA. These features have been shown to exert positive effects on milk and meat quality in terms of reduction of saturated fatty acids, increase in monounsaturated fatty acids and vitamin E and improvement of oxidative stability (Servili et al., 2015).

Cell wall polysaccharides can also be recovered from olive pomace. These compounds include cellulosic, hemicellulosic, and pectic carbohydrates and have been proposed as a source of microcrystalline or powdered cellulose, gelling agents, and fat replacers (Galanakis et al., 2010).

Moreover, the peculiar porous structure of olive stone has been exploited for its absorption capacity of different contaminants (e.g., dyes, metals), finding thus applications in the field of water purification and other decontamination processes (Spahis et al., 2008).

The extraction of phenolic bioactive compounds is a possible strategy for valorizing oil vegetative wastewaters. In this regard, during extra virgin olive oil extraction, only 2%–3% of bioactive phenolic compounds is transferred into the oil. The remaining portion is retained in waste portions (Servili et al., 2015). Different technologies have been proposed to this aim, including enzymatic preparation, solvent extraction, supercritical fluid extraction using carbon dioxide, and high-energy ultrasounds. The obtained phenolic extracts hold promising potential as antioxidant, antiinflammatory, and antimicrobial agents, exploitable as antioxidant agents in food and pharmaceutical applications.

Press cakes generated from sunflower oil extraction are promising sources of food proteins, due to their widespread availability, the high protein content, and the low amounts of antinutritive compounds. In particular, sunflower proteins have been proposed as alternative to soy-derived ones, which present allergy issues. Overall, literature data on the functional properties of sunflower proteins are contradictory due to the diversity of employed methods and pretreatments, as well as the large variety of investigated products. However, sunflower proteins have shown emulsifying properties comparable to those of soy proteins and formed stable foams, suggesting them as emulsifying and whipping agents (Pickardt et al., 2015).

Being rich in dietary fiber and protein, okara (waste from soybean processing) can be directly used in food formulations to enhance their nutritional profile. In this regard, Préstamo et al. (2007), reported okara as an effective weight-loss supplement with a potential prebiotic effect. For these reasons, wet okara has been incorporated in different snacks and bakery products (Park et al., 2015). Unfortunately, the use of fresh okara in the food industry is limited because of its high water content (70%–80%), which makes it prone to quick spoilage, even under refrigerated conditions (Radočaj and Dimić, 2013). To avoid these limitations, drying has been exploited to obtain okara flour, which has been proposed for the production of functional foods (Li et al., 2013). Recent studies have focused on applying okara flour in the production of bakery and meat products presenting enhanced fiber, protein, and bioactive content and a concomitant lower fat amount (Grizotto et al., 2012). However, drying process of okara is costly and energy intensive, due to the high amount of water to be removed.

An alternative valorization strategy is based on okara fermentation, with the purpose of producing extractable bioactive compounds or using the fermented foodstuff as functional ingredient. Microbial biotransformation of okara may offer some important advantages. Firstly, fermented okara has improved digestibility; moreover, the bioconversion of high molecular weight okara proteins to smaller ones may increase the solubility of protein isolates, and generate bioactive peptides and amino acids. Trypsin inhibitors and fatty acids may also be degraded by microorganisms, improving the nutritional value of okara and producing more desirable aroma compounds, respectively (Vong and Liu, 2016).

Extraction of specific compounds could also represent a possible strategy for okara valorization. This strategy is based on the extraction of target compounds such as fibers, carbohydrates, proteins, and bioactive compounds such as isoflavones. The latter belong to a group of polyphenols believed to be partially responsible for the health benefits of soy (Preece et al., 2017). In this regard, fibers for nanofiber production, antioxidant carbohydrates, β-glucosidase for functional food preparation, and oil fraction for cosmetic and pharmaceutical usage have been extracted from okara (Fung et al., 2010; Mateos-Aparicio et al., 2010; Li et al., 2013; Quintana et al., 2018).

10.6.2.4 Fruit and vegetables

Fruit and vegetable processing wastes are the most widely investigated substrates for the extraction of several types of antioxidants and dietary fibers. This is due to the fact that soft tissues of fruit and vegetable waste are rich in both ingredients, which allow their simultaneous extraction in two separate streams (Laufenberg et al., 2003).

Antioxidant phenols intended for pharmaceutical and food applications are a common target in fruit and vegetable waste valorization strategies since they have been associated with a reduction in the incidence of diseases such as cancer, heart disease, hepatic injury, and neurodegenerative disorders. Their antioxidant activities make them suitable for food applications to prevent rancidity and oxidation instead of chemical antioxidants with documented toxicity, such as BHA and BHT (Peschel et al., 2006).

Similarly, carotenoids, anthocyanins, betanin, and chlorophylls, which are present in large quantities in fruit and vegetable waste, can also be exploited as natural colorants (Bridle and Timberlake, 1997; Rodriguez-Amaya, 2016).

Fruit and vegetable waste also presents high dietary fiber content. In this regard, fruit and vegetable waste can be turned into flour by means of drying and grinding. Fruit and vegetable waste flour has been used as ingredient for the formulation of fiber-enriched foods (Ferreira et al., 2015; Plazzotta et al., 2018c). Drying of fruit and vegetable waste has also been exploited to produce fibrous materials with high contact surface intended as bioadsorbents for the removal of pollutants such as dyes and heavy metals from water and ground and as templates for solvent absorption (Azouaou et al., 2008; Plazzotta et al., 2018b).

Among the different compounds, pectin represents an interesting polysaccharide, which can be extracted from different fruit and vegetable waste, including apple pomace, orange peel, carrot steam peels, green beans cutting waste, leek cutting waste, and celeriac stem peels. In this regard, pectin is primarily known as a gelling agent and is extensively applied in the production of jams and jellies, fruit juice, confectionery products, and bakery fillings (Christiaens et al., 2015; Perussello et al., 2017; Balu et al., 2012).

Citrus waste represents a source of essential oils that can be used in food as flavoring ingredients in drinks, ice creams, and other food products as well as in pharmaceutical industries for its antiinflammatory and antibacterial effect. In addition, substantial quantity of this oil is also used in the preparation of toilet soaps, perfumes, cosmetics, and other home care products or as green solvent (Boukroufa et al., 2015).

Seeds of grapes intended for wine production constitute a valuable source of seed oil, which is produced all over Europe and is highly appreciated due to its rich content of unsaturated fatty acids (particularly linoleic acid) and phenolic compounds (Gowe Chala, 2015).

Water can also be considered a valuable output of a recovery strategy. In this regard, patented or patent-pending systems able to convert organic material into water are already applied in companies, supermarkets, and restaurants. They are based on the hyperacceleration of aerobic decomposition through the activity of naturally occurring microorganisms with enhanced degradation capabilities under tightly controlled environmental conditions (Anon, 2017).

10.7 Development and implementation of food waste valorization strategies

Food waste can be considered a cheap source of energy, water, and valuable ingredients/products. To maximally exploit these potentialities, an integrated approach to waste management should be developed by selecting, and eventually combining, the most efficacious recovery strategies. Such approach results from the application of a rational four-step procedure, including waste characterization, output definition, process design, and feasibility study.

10.7.1 Waste characterization

The first step for developing a rational valorization strategy involves an accurate characterization of the food waste material, in terms of legal classification, amount, and composition. In particular, the reclassification of a processing discard as a by-product or the recognition of its end-of-waste status are possible only if meeting specific requirements of safety, quality, marketability, and sustainability (Dir. 2008/98/CE).

Amount data are often already available to companies, based on the knowledge of company sources flow, transport, and disposal costs.

Secondarily, the identification of process steps mainly involved in waste generation should be carried out. It is likely that in these steps, in fact, waste materials presenting a more homogeneous composition could be available. This would favor and simplify the implementation of a valorization strategy, avoiding or shortening collection and separation processes.

Wastes should be then accurately characterized not only in terms of actual homogeneity and composition but also in terms of long-term variability and perishability. This would allow identifying waste features possibly exploitable in a valorization strategy (e.g., high fiber or protein content). This step would also allow identifying critical features: for example, a high compositional variability would hinder the possibility of standardizing the valorization strategy and a high perishability would pose the need for a quick transformation of the waste.

10.7.2 Output definition

Based on the key properties identified in step “Waste characterization”, possible final products of food waste valorization can be hypothesized. Beside valorization strategies based on the extraction of bioactive compounds, in this step, research and development expertise should be exploited to hypothesize innovative solutions to valorize the waste material. In this regard, it should be underlined that the same waste material could offer a wide range of valorization possibilities. For example, lettuce waste, despite its poor composition, has been shown to be a possible source of phenols but can also be turned into functional flour and innovative porous materials exploitable for solvent loading (Llorach et al., 2004; Plazzotta et al., 2018a,b,c). In this step, a holistic biorefinery approach should be adopted, identifying all the possible outputs, with the final aim of reducing the waste to zero. This can be attained by applying a multiple-step approach. For example, after extracting bioactive molecules from a vegetable matrix, the residual waste could be further exploited to produce flour or serve as water source for company facilities. This step should result in a clear definition of the possible amounts and compositional features of the waste derivatives, as well as in their classification in terms of possible use (ingredients, products, adjuvants, additives, materials) purpose (increase food functionality, material biodegradability, or biocompatibility), and sector (e.g., food, engineering, biomedical, packaging).

10.7.3 Process design

Production processes required to obtain the outputs defined in step "Output definition" are designed. Despite the extremely wide variability in characteristics according to different food waste kinds, Galanakis (2012) developed the 5-Stages Universal Recovery Process, potentially applicable to every kind of food waste. According to this universal approach, food waste recovery could be accomplished in five distinct stages: macroscopic pretreatment (adjustment of the water, solids and lipid content, activation or deactivation of enzymes, reduction of the microbial load, increase in the permeability of the matrix); macro- and micromolecules separation (separation of antioxidants, acids, or ions from biopolymers); extraction (solubilization of free molecules and dissociation of bound ones); purification (clarification of the target compounds from coextracted impurities); and product formation (encapsulation or drying to obtain a stable product).

This recovery strategy has the advantage of being potentially applicable to all kinds of food waste materials, since it can be tailored by omitting some stages. In the simplest case, reuse is possible and thus only pretreatment operations such as cleaning, washing, mincing, and partial dehydration are needed. However, this only applies to traditional recovery strategies such as animal feeding, soil amendment, and composting, which, as already underlined, do not attain a proper valorization of functional compounds present in food waste. In most cases, all steps are required and can be accomplished with different conventional or emerging technologies, both of which present specific advantages and pitfalls that should be accurately considered. Equipment and know-how for the application of traditional technologies are already available and thus they are easy to use and characterized by low or null investment costs. Such technologies include, for example, air-drying, classical solvent-assisted extraction, and alcohol precipitation. However, they are often energy intensive and can damage the treated matrix producing overheating, structural, and functionality modifications. In addition, they usually require huge amounts of solvents, which represent an economic and environmental burden for companies. Novel technologies, such as microwave, ultrasounds, pulsed electric fields, high pressure homogenization, and supercritical drying represent a suitable alternative, since generally reducing thermal effect and matrix damaging, while maintaining or increasing yield efficacy. Such technologies are commonly referred to as "green technologies" because they reduce solvent and energy consumption, due to higher extraction efficacy. By contrast, since their industrial application is still limited, high investment costs for equipment and dedicated expertise are required for process scaling-up from laboratory to industrial plants.

10.7.4 Feasibility study

The final step for the development and implementation of a food waste valorization strategy is the determination of its feasibility from an economic, environmental and social point of view. In other words, the sustainability of the proposed strategy must be assessed. In this regard, different aspects should be taken into consideration, including capital and operating costs, consumer response and acceptance, environmental impact, and adherence to increasingly stringent legal requirements on food and material safety.

The most important issues, possibly hindering the implementation of a food waste valorization strategy, include:

1. Food waste characteristics: the high perishability and inhomogeneity of food waste materials can make their valorization economically unsustainable.
2. Valorization know-how: the lack of information about functional and bioactive compounds present in food waste materials would make necessary a massive investment not only in equipment but also in research and development expertise. In this regard, food science and technology as well as medical expertise would be of crucial importance in defining new possibilities.
3. Consumer response: commercial and marketing knowledge regarding consumer response to food waste derivatives is nowadays still limited. Different attitudes can affect consumer acceptance of such innovative products. Innovations in the food industry suffer a high market failure rate, partly due to a phenomenon known as "neophobia," which is the rejection that some people express towards new or unfamiliar foods (Barrena and Sánchez, 2013). By contrast, consumers are increasingly concerned about food supply chain sustainability and recent surveys have demonstrated a positive reaction to product labels reporting sustainability claims on them, even using specific terms related to food waste. Moreover, issues related to specific food waste should be considered. For instance, consumer fear of contracting BSE, potential allergic reactions to blood proteins, and the belief that products obtained from animals contains harmful microorganisms, toxins, and metabolites, militates against efforts to fully utilize blood proteins as a food and feed source (Ofori and Hsieh, 2014).
4. Possibility to standardize and scale up the process: much of food waste applications are not effective and are only described in the scientific literature. This is due to the massive investment cost often required for scaling-up and validating valorization processes on industrial scale.

5. Fulfillment of regulatory framework: in the process of valorization and of new products development, there is a need for companies to comply with the stipulated governmental environmental regulatory guidelines and legal concerns of the public so that, eventually, all food processing industries contribute directly to sustainable utilization of natural resources and consequent sustainable development of society.

Only by an accurate consideration of all these aspects, the impact of a food waste valorization strategy on economic, environmental and social sustainability can be assessed. This requires the use of a holistic approach, integrating a wide set of expertise in economy and marketing, in social sciences and in Life Cycle Assessment (LCA), which evaluates the environmental impact of a product in all its life stages (Kim and Kim, 2010).

10.8 Conclusions

Valorization of food waste provides a sustainable solution for solving the existing waste disposal problem. In fact, it offers a boon to food processing industries for augmentation of resources available and, with them, for product diversification and innovation to meet increasing consumer demand for novelty. However, most valorization strategies are nowadays only described in the scientific literature and food waste materials are thus mainly unexploited or used as low-value sources of energy, animal feed, and fertilizers. Valorization strategies can be considered the eco-design of an integrated production scheme, involving expertise in food science and technology, economy, marketing, engineering, environmental, and social sciences. Only legislation and integrated studies following well-funded research and development programs will eventually attain the goal of optimized food waste processing, to successfully create a global food waste biorefinery, with the final aim of realizing a zero-waste food supply chain.

References

2008/98/EC, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives. 2008. Offic. J. Eur. Union. 312, 3–30.

Ajila, C.M., et al., 2012. Sustainable solutions for agro processing waste management: an overview. In: Malik, A., Grohmann, E. (Eds.), Environmental Protection Strategies for Sustainable Development. Springer, Netherlands, pp. 65–109.

Al-Weshahy, A., Rao, V., 2012. Potato peel as a source of important phytochemical antioxidant nutraceuticals and their role in human health – a review. In: Rao, V. (Ed.), Phytochemicals as Nutraceuticals. InTech, Rijeka, pp. 207–225.

Amado, I.R., et al., 2014. Optimization of antioxidants extraction from potato peel wastes of *Solanum tuberosum* by surface response methodology. Food Chem. 165 (290–299), 290–299.

Anon, 2017. Waste to water. <http://www.wastetowater.com.au/> (accessed 26.05.18.).

Argun, H., Dao, S., 2017. Biohydrogen production from waste peach pulp by dark fermentation: effect of inoculum addition. Int. J. Hydrogen Energy 42 (4), 2569–2574.

Audic, J., Chaufer, B., Daufin, G., 2003. Non-food applications of milk components and dairy co-products: a review. Lait 83, 417–438.

AWARENET, 2004. Handbook for the prevention and minimization of waste and valorisation of by-products in European agro-food industries, agro-food waste minimization and reduction network – Grow Programme, European Commision.

Azbar, N., et al., 2004. A review of waste management options in olive oil production. Crit. Rev. Environ. Sci. Technol. 34 (3), 209–247.

Azouaou, N., Sadaoui, Z., Mokaddem, H., 2008. Removal of cadmium from aqueous solution by adsorption on vegetable wastes. J. Appl. Sci. 8 (24), 4638–4643.

Balu, A.M., et al., 2012. Valorisation of orange peel residues: waste to biochemicals and nanoporous materials. Chem. Sustain. Energy Mater. 5 (9), 1694–1697.

Barrena, R., Sánchez, M., 2013. Neophobia, personal consumer values and novel food acceptance. Food Qual. Pref. 27 (1), 72–84.

BCFN, 2010. Double Pyramid: healthy food for people, sustainable food for the planet, pp. 1–75. <http://scholar.google.com/scholar?hl = en&btnG = Search&q = intitle: Double + Pyramid + : + healthy + food + for + people + , + sustainable + food + for + the + planet#0> (accessed 26.05.18.).

Boukroufa, M., et al., 2015. Biorefinery of orange peels waste: a new concept based on integrated green and solvent free extraction processes using ultrasound and microwave techniques to obtain essential oil, polyphenols and pectin. Ultrason. Sonochem. 24, 72–79.

Bridle, P., Timberlake, C.F., 1997. Anthocyanins as natural food colours—selected aspects. Food Chem. 58 (1–2), 103–109.

Brundtland, G.H., 1987. Our Common Future. Report of the World Commission on Environment and Development. Oxford University Press, Oxford.

Cahú, T.B., et al., 2012. Recovery of protein, chitin, carotenoids and glycosaminoglycans from Pacific white shrimp (*Litopenaeus vannamei*) processing waste. Process Biochem. 47 (4), 570–577.

Chemat, F., Vian, M.A., Cravotto, G., 2012. Green extraction of natural products: concept and principles. Int. J. Molec. Sci. 13 (7), 8615–8627.

Cherubini, F., Ulgiati, S., 2010. Crop residues as raw materials for biorefinery systems – a LCA case study. Appl. Energy 87 (1), 47–57.

Christiaens, S., et al., 2015. Pectin characterisation in vegetable waste streams: a starting point for waste valorisation in the food industry. LWT – Food Sci. Technol. 61 (2), 275–282.

Clemente, R., et al., 2015. Food byproducts as amendments in trace elements contaminated soils. Food Res. Int. 73, 176–189.

Coffey, R.D., Cromwell, G.L., 2001. Use of spray-dried plasma in diets for weaning pigs. Pig News Info 47N, 22–39.

De Wit, J.N., 1990. Thermal stability and functionality of whey proteins. J. Dairy Sci. 73 (12), 3602–3612.

Del Hoyo, P., et al., 2007. Demineralization of animal blood plasma by ion exchange and ultrafiltration. Meat Sci. 76 (3), 402–410.

Dermeche, S., et al., 2013. Olive mill wastes: biochemical characterizations and valorization strategies. Process Biochem. 48 (10), 1532–1552.

Deydier, E., et al., 2005. Physical and chemical characterisation of crude meat and bone meal combustion residue: "waste or raw material?". J. Hazard. Mater. 121 (1–3), 141–148.

Di Gioia, D., et al., 2007. Production of biovanillin from wheat bran. Enzyme Microb. Technol. 41 (4), 498−505.

Duarte, R.T., Carvalho Simões, M.C., Sgarbieri, V.C., 1999. Bovine blood components: fractionation, composition, and nutritive value. J. Agric. Food Chem. 47 (1), 231−236.

Elkington, J., 1994. Towards the sustainable corporation. Calif. Manage. Rev. Winter 90−100.

Elmekawy, A., et al., 2013. Valorization of cereal based biorefinery byproducts: reality and expectations. Environ. Sci. Technol. 47 (16), 9014−9027.

Evon, P., et al., 2009. Aqueous extraction of residual oil from sunflower press cake using a twin-screw extruder: feasibility study. Industr. Crops Prod. 29 (2−3), 455−465.

FAO, 2009. FAOSTAT. Harvested sheets. FAOSTAT. <http://faostat.fao.org/site/444/DesktopDefault.aspx?PageID¼444#ancor> (accessed 26.0518.).

FAO, 2011. Global food losses and food waste - extent, causes and prevention. <www.fao.org/docrep/014/mb060e/mb060e00.pdf> (accessed 26.05.18.).

FAO, 2013. Climate-smart agriculture sourcebook. Sourcebook on Climate-Smart Agriculture, Forestry and Fisheries. <http://www.fao.org/docrep/018/i3325e/i3325e00.htm> (accessed 26.05.18.).

Feeney, R.E., Yeh, Y., 1998. Antifreeze proteins: current status and possible food uses. Trends Food Sci. Technol. 9 (3), 102−106.

Fernández-Michel, S., Montfort, G.R., Vazquez-Moreno, L., 2006. Physicochemical and microbiological characteristics and sensory analysis of chocolate cakes added with porcine serum proteins. Revista Científica de Veterinaria 16 (4), 420−427.

Ferraro, V., et al., 2010. Valorisation of natural extracts from marine source focused on marine by-products: a review. Food Res. Int. 43 (9), 2221−2233.

Ferreira, M.S., et al., 2015. Formulation and characterization of functional foods based on fruit and vegetable residue flour. J. Food Sci. Technol. 52 (2), 822−830.

Fung, W.Y., Yuen, K.H., Liong, M.T., 2010. Characterization of fibrous residues from agrowastes and the production of nanofibers. J. Agric. Food Chem. 58 (13), 8077−8084.

Galanakis, C.M., 2012. Recovery of high added-value components from food wastes: conventional, emerging technologies and commercialized applications. Trends Food Sci. Technol. 26 (2), 68−87.

Galanakis, C.M., Tornberg, E., Gekas, V., 2010. A study of the recovery of the dietary fibers from olive mill wastewater and the gelling ability of the soluble fiber fraction. LWT Food Sci. Technol. 43 (7), 1009−1017.

Gildberg, A., 2004. Enzymes and bioactive peptides from fish waste related to fish silage, fish feed and fish sauce production. J. Aquat. Food Prod. Technol. 13 (2), 3−11.

Gowe, C., 2015. Review on potential use of fruit and vegetables by-products as a valuable source of natural food additives. Food Sci. Qual. Manage. 45 (November), 47−61.

Grizotto, R.K., et al., 2012. Physical, chemical, technological and sensory characteristics of Frankfurter type sausage containing okara flour. Food Sci. Technol. 32, 538−546.

Guechi, E., Hamdaoui, O., 2016. Biosorption of methylene blue from aqueous solution by potato (*Solanum tuberosum*) peel: equilibrium modelling, kinetic, and thermodynamic studies. Desalin. Water Treatm. 57 (22), 10270−10285.

Halliday, D.A., 1973. Blood − a source of proteins. Process Biochem. 8, 15−17.

Hernández-Ledesma, B., del Mar Contreras, M., Recio, I., 2011. Antihypertensive peptides: production, bioavailability and incorporation into foods. Adv. Colloid Interf. Sci. 165 (1), 23−35.

Hodson, M.E., Valsami-Jones, É., Cotter-Howells, J.D., 2000. Bonemeal additions as a remediation treatment for metal contaminated soil. Environ. Sci. Technol. 34 (16), 3501−3507.

Huang, Y.C., Hsiao, P.C., Chai, H.J., 2011. Hydroxyapatite extracted from fish scale: effects on MG63 osteoblast-like cells. Ceram. Int. 37 (6), 1825−1831.

Jamal, P., et al., 2011. Valorization of cassava peels by the white rot fungus *Panus tigrinus* M609RQY. Austr. J. Basic Appl. Sci. 5 (7), 808−816.

Jayathilakan, K., et al., 2012. Utilization of byproducts and waste materials from meat, poultry and fish processing industries: a review. J. Food Sci. Technol. 49 (3), 278−293.

Ji, Y., et al., 2014. Extraction of keratin with ionic liquids from poultry feather. Separat. Purif. Technol. 132, 577−583.

John, R.P., Madhavan Nampoothiri, K., Pandey, A., 2006. Simultaneous saccharification and fermentation of cassava bagasse for l-(+)-lactic acid production using Lactobacilli. Appl. Biochem. Biotechnol. 134 (3), 263−272.

Kammoun, R., Naili, B., Bejar, S., 2008. Application of a statistical design to the optimization of parameters and culture medium for α-amylase production by *Aspergillus oryzae* CBS 819.72 grown on gruel (wheat grinding by-product). Bioresour. Technol. 99 (13), 5602−5609.

Kang, K., et al., 2009. Optimization of amino acids production from waste fish entrails by hydrolysis in sub and supercritical water. Can. J. Chem. Eng. 79 (1), 65−70.

Kim, I., et al., 2008. Chitosan and its derivatives for tissue engineering applications. Biotechnol. Adv. 26 (1), 1−21.

Kim, M.H., Kim, J.W., 2010. Comparison through a LCA evaluation analysis of food waste disposal options from the perspective of global warming and resource recovery. Sci. Total Environ. 408 (19), 3998−4006.

Kim, S.K., Dewapriya, P., 2014. Enzymes from fish processing waste materials and their commercial applications. In: Kim, S.K. (Ed.), Seafood Processing By-Products. Springer, New York, NY, pp. 183−196.

Korhonen, H., 2009. Milk-derived bioactive peptides: from science to applications. J. Funct. Foods 1 (2), 177−187.

Kothari, R., Tyagi, V.V., Pathak, A., 2010. Waste-to-energy: a way from renewable energy sources to sustainable development. Renew. Sustain. Energy Rev. 14 (9), 3164−3170.

Kowalski, Z., et al., 2008. The possibilities of obtaining hydroxyapatite from meat industry. Molec. Cryst. Liquid Cryst. 486 (1), 282−290.

Kumar, R.M.N.V., 2000. A review of chitin and chitosan applications. React. Funct. Polym. 46 (1), 1−27.

Kurbanoglu, E.B., Kurbanoglu, N.I., 2004. Utilization as peptone for glycerol production of ram horn waste with a new process. Energy Convers. Manage. 45 (2), 225−234.

Laufenberg, G., Kunz, B., Nystroem, M., 2003. Transformation of vegetable waste into value added products: (A) the upgrading concept; (B) practical implementations. Bioresour. Technol. 87 (2), 167−198.

Li, Z., et al., 2006. L-Lactic acid production by *Lactobacillus casei* fermentation with corn steep liquor-supplemented acid-hydrolysate of soybean meal. Biotechnol. J. 1 (12), 1453−1458.

Li, S., et al., 2013. Soybean curd residue: composition, utilization, and related limiting factors. ISRN Industr. Eng. 2013, 1−8.

Liang, S., McDonald, A.G., Coats, E.R., 2014. Lactic acid production from potato peel waste by anaerobic sequencing batch fermentation using undefined mixed culture. Waste Manage. 45, 2022−2027.

Llorach, R., Tomás-Barberán, F.A., Ferreres, F., 2004. Lettuce and chicory byproducts as a source of antioxidant phenolic extracts. J. Agric. Food Chem. 52 (16), 5109−5116.

Mahalaxmi, Y., et al., 2010. Corn husk as a novel substrate for the production of rifamycin B by isolated *Amycolatopsis* sp. RSP 3 under SSF. Process Biochem. 45 (1), 47−53.

Mateos-Aparicio, I., et al., 2010. Multifunctional antioxidant activity of polysaccharide fractions from the soybean byproduct okara. Carbohydr. Polym. 82 (2), 245−250.

Milazzo, M.F., et al., 2013. Sustainable soy biodiesel. Renew. Sustain. Energy Rev. 27, 806−852. Available from: http://www.sciencedirect.com/science/article/pii/S1364032113004760.

Mittal, G.S., 2006. Treatment of wastewater from abattoirs before land application—a review. Bioresour. Technol. 97 (9), 1119−1135.

Mohanty, D.P., et al., 2016. Milk derived bioactive peptides and their impact on human health − a review. Saudi J. Biol. Sci. 23 (5), 577−583.

Mokrejs, P., et al., 2009. Extraction of collagen and gelatine from meat industry by-products for food and non food uses. Waste Manage. Res. 27 (1), 31−37.

Morgan, E., 2009. Fruit and vegetable consumption and waste in Australia, Victoria, Australia. <https://www.vichealth.vic.gov.au/media-and-resources/publications/fruit-and-vegetable-consumption-and-waste-in-australia> (accessed 26.05.18.).

Morr, C.V., Ha, E.Y.W., 1993. Whey protein concentrates and isolates: processing and functional properties. Crit. Rev. Food Sci. Nutr. 33 (6), 431−476.

Muhammad, N., et al., 2016. Extraction of biocompatible hydroxyapatite from fish scales using novel approach of ionic liquid pretreatment. Separat. Purif. Technol. 161, 129−135.

Mussatto, S.I., Roberto, I.C., 2005. Acid hydrolysis and fermentation of brewer's spent grain to produce xylitol. J. Sci. Food Agric. 85 (14), 2453−2460.

Ng, I.S., et al., 2010. High-level production of a thermoacidophilic β-glucosidase from *Penicillium citrinum* YS40-5 by solid-state fermentation with rice bran. Bioresour. Technol. 101 (4), 1310−1317.

Nowak, B., von Mueffling, T., 2006. Porcine blood cell concentrates for food products: hygiene, composition, and preservation. J. Food Protect. 69 (9), 2183−2192.

Ofori, J.A., Hsieh, Y.P., 2014. Issues related to the use of blood in food and animal feed. Crit. Rev. Food Sci. Nutr. 54 (5), 687−697.

Ofuya, C.O., Nwajiuba, C.J., 1990. Fermentation of cassava peels for the production of cellulolytic enzymes. J. Appl. Bacteriol. 68 (2), 171−177.

Olga, R., Etelka, D., 2013. Valorization of wet okara, a value-added functional ingredient, in a coconut-based baked snack. Cereal Chem. 90 (3), 256−262.

Padmaja, G., Jyothi, A.N., 2016. Root and tuber. In: Chandrasekaran, M. (Ed.), Valorization of Food Processing By-Products. Taylor & Francis Group: CRC Press.

Pal, G.K., Suresh, P.V., 2016. Sustainable valorisation of seafood by-products: recovery of collagen and development of collagen-based novel functional food ingredients. Innov. Food Sci. Emerg. Technol. 37 (Part B), 201−215.

Pal, G.K., Nidheesh, T., Suresh, P.V., 2015. Comparative study on characteristics and in vitro fibril formation ability of acid and pepsin soluble collagen from the skin of catla (*Catla catla*) and rohu (*Labeo rohita*). Food Res. Int. 76, 804−812.

Pangestuti, R., Kim, S.K., 2014. Bioactive materials derived from seafood and seafood processing by-products. In: Noomhorm, A., Ahmad, I., Anal, A.K. (Eds.), Functional Foods and Dietary Supplements: Processing Effects and Health Benefits. Wiley-Blackwell, USA, pp. 139−158.

Papargyropoulou, E., et al., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J. Cleaner Product. 76 (August), 106−115.

Park, J., Choi, I., Kim, Y., 2015. Cookies formulated from fresh okara using starch, soy flour and hydroxypropyl methylcellulose have high quality and nutritional value. LWT − Food Sci. Technol. 63 (1), 660−666.

Pathak, P.D., et al., 2018. Valorization of potato peel: a biorefinery approach. Crit. Rev. Biotechnol. 38 (1), 218–230.

Patsioura, A., Galanakis, C.M., Gekas, V., 2011. Ultrafiltration optimization for the recovery of β-glucan from oat mill waste. J. Membr. Sci. 373 (1–2), 53–63.

Pekcan, G., et al., 2006. Household Food Wastage in Turkey. FAO, Rome.

Perussello, C.A., et al., 2017. Valorization of apple pomace by extraction of valuable compounds. Compreh. Rev. Food Sci. Food Safety 16 (5), 776–796.

Peschel, W., et al., 2006. An industrial approach in the search of natural antioxidants from vegetable and fruit wastes. Food Chem. 97 (1), 137–150.

Peters, R.H., 2005. Economic aspects of cheese making as influenced by whey processing options. Int. Dairy J. 15 (6), 537–545.

Pfaltzgraff, L.A., et al., 2013. Food waste biomass: a resource for high-value chemicals. Green Chem. 15 (2), 307–314.

Pickardt, C., et al., 2015. Pilot plant preparation of light-coloured protein isolates from de-oiled sunflower (*Helianthus annuus* L.) press cake by mild-acidic protein extraction and polyphenol adsorption. Food Hydrocol. 44, 208–219.

Plazzotta, S., Manzocco, L., Nicoli, M.C., 2017. Fruit and vegetable waste management and the challenge of fresh-cut salad. Trends Food Sci. Technol. 63, 51–59.

Plazzotta, S., Calligaris, S., Manzocco, L., 2018a. Application of different drying techniques to fresh-cut salad waste to obtain food ingredients rich in antioxidants and with high solvent loading capacity. LWT – Food Sci. Technol. 89 (November 2017), 276–283.

Plazzotta, S., Calligaris, S., Manzocco, L., 2018b. Innovative bioaerogel-like materials from fresh-cut salad waste via supercritical-CO2-drying. Innov. Food Sci. Emerg. Technol. 47, 485–492.

Plazzotta, S., Sillani, S., Manzocco, L., 2018c. Exploitation of lettuce waste flour to increase bread functionality: effect on physical, nutritional, sensory properties and on consumer response. Int. J. Food Sci. Technol. 53 (10), 1–8.

Polo, J., et al., 2005. Functional properties of spray-dried animal plasma in canned pet food. Anim. Feed Sci. Technol. 122 (3), 331–343.

Prazeres, A.R., Carvalho, F., Rivas, J., 2012. Cheese whey management: a review. J. Environ. Manage. 110, 48–68.

Preece, K.E., et al., 2017. Intensified soy protein extraction by ultrasound. Chem. Eng. Process. Process Intensif. 113, 94–101.

Préstamo, G., et al., 2007. The effects of okara on rat growth, cecal fermentation, and serum lipids. Eur. Food Res. Technol. 225 (5), 925–928.

Product Stewardship Institute, 2011. Product Stewardship. <http://productstewardship.us/displaycommon.cfm?an = 1&subarticlenbr = 55> (accessed 30.05.158.).

Prückler, M., et al., 2014. Wheat bran-based biorefinery 1: Composition of wheat bran and strategies of functionalization. LWT – Food Sci. Technol. 56 (2), 211–221.

Quintana, G., Gerbino, E., Gómez-Zavaglia, A., 2018. Valorization of okara oil for the encapsulation of *Lactobacillus plantarum*. Food Res. Int. 106, 81–89.

Radočaj, O., Dimić, E., 2013. Valorization of wet okara, a value-added functional ingredient, in a coconut-based baked snack. Cereal Chem. 90 (3), 256–262.

Ramos, Ó.L., et al., 2012. Edible films and coatings from whey proteins: a review on formulation, and on mechanical and bioactive properties. Crit. Rev. Food Sci. Nutr. 52 (6), 533–552.

Ravindran, R., Jaiswal, A.K., 2016. Exploitation of food industry waste for high-value products. Trends Biotechnol. 34 (1), 58–69.

Rodrigues, I.M., Coelho, J.F.J., Carvalho, M.G.V.S., 2012. Isolation and valorisation of vegetable proteins from oilseed plants: methods, limitations and potential. J. Food Eng. 109 (3), 337−346.

Rodriguez-Amaya, D.B., 2016. Natural food pigments and colorants. Curr. Opin. Food Sci. 7, 20−26.

Russ, W., Meyer-Pittroff, R., 2004. Utilizing waste products from the food production and processing industries. Crit. Rev. Food Sci. Nutr. 44 (1), 57−62.

Sagar, N.A., et al., 2018. Fruit and vegetable waste: bioactive compounds, their extraction, and possible utilization. Compreh. Rev. Food Sci. Food Safety 17, 512−531.

Sahena, F., et al., 2009. PUFAs in fish: extraction, fractionation, importance in health. Compreh. Rev. Food Sci. Food Safety 8 (2), 59−74.

San Martin, D., Ramos, S., Zufía, J., 2016. Valorisation of food waste to produce new raw materials for animal feed. Food Chem. 198, 68−74.

Sánchez-Bastardo, N., Romero, A., Alonso, E., 2017. Extraction of arabinoxylans from wheat bran using hydrothermal processes assisted by heterogeneous catalysts. Carbohydr. Polym. 160, 143−152.

Sánchez-Machado, D.I., Gutiérrez-Coronado, M.A., Ríos-Vázquez, N.J., 2006. Quantification of astaxanthin in shrimp waste hydrolysate by HPLC. Biomed. Chromatogr. 20 (10), 981−984.

Saranya Devi, E., Vijayendra, S.V.N., Shamala, T.R., 2012. Exploration of rice bran, an agro-industry residue, for the production of intra- and extra-cellular polymers by *Sinorhizobium meliloti* MTCC 100. Biocatal. Agric. Biotechnol. 1 (1), 80−84.

Schieber, A., Stintzing, F.C., Carle, R., 2001. By-products of plant food processing as a source of functional compounds—recent developments. Trends Food Sci. Technol. 12 (11), 401−413.

Schingoethe, D.J., 1976. Whey utilization in animal feeding: a summary and evaluation. J. Dairy Sci. 59 (3), 556−570.

Segrè, E.A., Falasconi, L., 2011. Il libro nero dello spreco in Italia: Il cibo. Ambiente Edizioni, Milan.

Servili, M., et al., 2015. New approaches to virgin olive oil quality, technology, and by-products valorization. Eur. J. Lipid Sci. Technol. 117 (11), 1882−1892.

Sharif, M.K., et al., 2014. Rice bran: a novel functional ingredient. Crit. Rev. Food Sci. Nutr. 54 (6), 807−816.

Sharma, V.K., et al., 2000. Inclined-plug-flow type reactor for anaerobic digestion of semi-solid waste. Appl. Energy 65 (1), 173−185.

Sharma, N., Prasad, G.S., Choudhury, A.R., 2013. Utilization of corn steep liquor for biosynthesis of pullulan, an important exopolysaccharide. Carbohydr. Polym. 93 (1), 95−101.

Silva, T.M., et al., 2009. Use of cassava peel as carbon source for production of amylolytic enzymes by *Aspergillus niveus*. Int. J. Food Eng. 5 (5), 1−11.

Siso, M.I.G., 1996. The biotechnological utilization of cheese whey: a review. Bioresour. Technol. 57 (1), 1−11.

Spahis, N., et al., 2008. Purification of water by activated carbon prepared from olive stones. Desalination 222 (1), 519−527.

Stanojevic, S.P., et al., 2013. Bioactive proteins and energy value of okara as a byproduct in hydrothermal processing of soy milk. J. Agric. Food Chem. 61 (38), 9210−9219.

Suresh, P.V., Prabhu, G.N., 2013. Seafood. In: Chandrasekaran, M. (Ed.), Valorization of Food Processing By-Products. CRC Press, New York, pp. 685−736.

Thönissen, R., 2009. Food waste: The Netherlands. FAO, Lund.

Tiwari, D.P., Singh, S.K., Sharma, N., 2015. Sorption of methylene blue on treated agricultural adsorbents: equilibrium and kinetic studies. Appl. Water Sci. 5 (1), 81−88.

Viana, F.R., et al., 2005. Quality of ham pâté containing bovine globin and plasma as fat replacers. Meat Sci. 70 (1), 153−160.

Vong, W.C., Liu, S.Q., 2016. Biovalorisation of okara (soybean residue) for food and nutrition. Trends Food Sci. Technol. 52, 139−147.

Walter, T., et al., 1993. Effect of bovine-hemoglobin-fortified cookies on iron status of schoolchildren: a nationwide program in Chile. Am. J. Clin. Nutr. 57 (2), 190−194.

Wanasundara, J.P.D., Pegg, R.B., Shand, P.J., 2003. Value added applications for plasma proteins from the beef processing industry. Can. Meat Sci. Assoc. 10−15.

Wang, H., et al., 2014. Physical-chemical properties of collagens from skin, scale, and bone of grass carp (*Ctenopharyngodon idellus*). J. Aquatic Food Prod. Technol. 23 (3), 264−277.

Woodard, J.R., et al., 2007. The mechanical properties and osteoconductivity of hydroxyapatite bone scaffolds with multi-scale porosity. Biomaterials 28 (1), 45−54.

WRAP, 2010. A review of waste arisings in the supply of food and drink to UK households. <http://www.wrap.org.uk/sites/files/wrap/Waste arisings in the supply of food and drink toUK households, Nov 2011.pdf> (accessed 26.05.18.).

Yadav, J.S.S., et al., 2015. Cheese whey: a potential resource to transform into bioprotein, functional/nutritional proteins and bioactive peptides. Biotechnol. Adv. 33 (6), 756−774.

Yamamura, H., et al., 2018. Physico-chemical characterization and biocompatibility of hydroxyapatite derived from fish waste. J. Mech. Behav. Biomed. Mater. 80, 137−142.

Yen, G.B., Razak, L.T., 2014. Screening of antioxidant potential from cereal wastes and fruit peels. Int. J. Eng. Res. Technol. 3 (1), 1990−1998.

Young, R.H., Lawrie, R.A., 2007. Utilization of edible protein from meat industry by-products and waste. Int. J. Food Sci. Technol. 10 (4), 453−464.

Yousif, A.M., Cranston, P., Deeth, H.C., 2003. Incorporation of bovine dry blood plasma into biscuit flour for the production of pasta. LWT – Food Sci. Technol. 36 (3), 295−302.

Zhang, Z., Smith, C., Li, W., 2014. Extraction and modification technology of arabinoxylans from cereal by-products: a critical review. Food Res. Int. 65, 423−436.

Zuta, P.C., et al., 2003. Concentrating PUFA from mackerel processing waste. J. Am. Oil Chem. Soc. 80 (9), 933−936.