# Chapter 2
# Food Processing Industries, Food Waste Classification and Handling, Target Compounds

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One of the major moral challenges for modern society is the fact that nearly one in ten people in the world is exposed to severe levels of food insecurity, and an estimated 2 billion people worldwide cannot rely on safe, nutritious and sufficient food (FAO 2020a), whereas industrialized countries are dealing with over-consumption of food, food-related diseases and increasing food waste production; this represents an environmental, economic, and ethical challenge for the modern society.

From a historical perspective, concerns related to food waste (FW) were brought to the scientific community since the 90s (Kroyer 1995).

Figure 2.1 illustrates the food volumes of all commodity groups produced in their primary form, in the regions of the world studied in the last decade.

A decade ago, as per the reports of FAO, about one-third of the food produced in the world for human consumption every year—approximately 1.3 billion tonnes—got lost or wasted during agricultural production (e.g., mechanical damage), post-harvest handling, storage and transportation (e.g., spillage and degradation during storage, damage during transport or non-appropriate transport systems), processing (e.g., degradation during industrial or contamination processing), distribution at the market system (e.g., improper packaging or istorage), and consumption at the household level (Gustavsson et al. 2011). It is rewarding to observe that, nowadays, lost or wasted food represents only 14% of the food produced globally, according to the newly-released FAO 2019 State of Food and Agriculture (SOFA) report. The wastage decrease is significant, and it is a first step towards the end goal of zero hunger, as indicated by the Agenda 2030 Sustainable Development Goal 2. The zero hunger goal can be achieved via Target 12.3 of the Sustainable Development Goals (SDGs), which aims at halving, by 2030, per capita global food waste and reduce food losses (Gustafson, 2019).

The huge generation of FW has been harshly impacting the environment, especially due to the emission of GHG.

Both food loss (FL) and FW are used in scientific literature to identify potential foods that are discharged, lost, degraded, or contaminated, and that will not be used as food. Unfortunately, the definitions of FL and FW often overlap.

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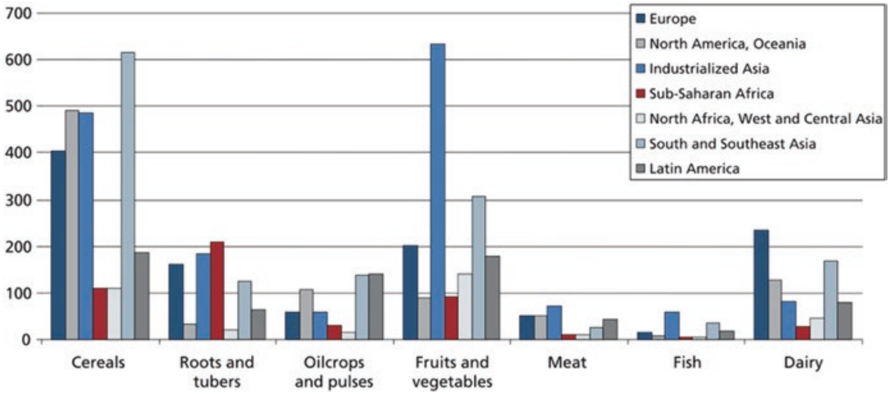

**Fig. 2.1** Production volumes of each commodity group, per region (million tonnes) (Gustavsson et al. 2011). (Source: Food and Agriculture Organization of the United Nations, [2011], [Jenny Gustavsson, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, Alexandre Meybeck], [Global food losses and food waste: extent, causes and prevention], [http://www.fao.org/fileadmin/user_upload/suistainability/pdf/Global_Food_Losses_and_Food_Waste.pdf]. Reproduced with permission)

According to the Food and Agriculture Organisation of the United Nations (FAO) "*food losses refer to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption. Food losses take place at production, post-harvest and processing stages in the food supply chain*" (Gustavsson et al. 2011; Parfitt et al. 2010).

Food waste is the food loss occurring at the end of the food chain, at the retail and final consumption stages, and its generation is related to retailers' and consumers' behavior (Gustavsson et al. 2011; Parfitt et al. 2010).

In the following, we will refer to "food waste" to indicate both food losses and food waste. The fact that these substances are production process undesirable left over defines them as "wastes" (Commission Regulations 442/1975/EEC; 689/1991/EEC).

FW can be classified into avoidable FW (edible) and unavoidable FW (non-edible). The avoidable FW generation (due to leftover food, improper storage, unnecessary purchase) can be decreased by taking preventive measures at each level from its production to consumption. For unavoidable FW (such as shells, stones, bones, peels), there is an extreme necessity to have proper waste management and reuse practices. Unfortunately, the word "waste" does not account for the potentiality of re-utilizing it. The term "food byproducts" would be more appropriate to notify that "food wastes" are precious substrates for the extraction of functional compounds and the synthesis of marketable products.

Figure 2.2 illustrates the per capita food loss and waste. Per capita waste by consumers was between 95 and 115 kg a year in Europe and North America, while consumers in developing countries each throw away only 6–11 kg a year.

In developing countries, 40% of losses occured in the supply chain: improved infrastructures, better transportation, and the expansion of the packaging industry could help to reduce the amount of food loss and waste. On the converse, in industrialized countries, FW at retail and consumer levels due to quality standards that

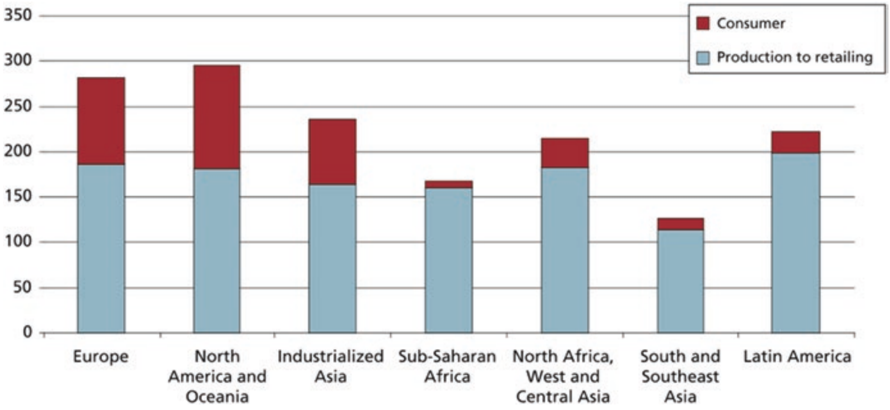

**Fig. 2.2** Per capita food losses and waste (kg/year), at consumption and pre-consumptions stages, in different regions (Gustavsson et al. 2011). (Source: Food and Agriculture Organization of the United Nations, [2011], [Jenny Gustavsson, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, Alexandre Meybeck], [Global food losses and food waste: extent, causes and prevention], [http://www.fao.org/fileadmin/user_upload/suistainability/pdf/Global_Food_Losses_and_Food_Waste.pdf]. Reproduced with permission)

over-emphasize appearance and consumption habits at the household level were impressive. FW at the consumer level in developed countries is almost as high as the total net food production in sub-Saharan Africa: this is an unethical and paradoxical absurdity (Gustavsson et al. 2011). The graph of the seven commodity groups below shows the percentage food losses and waste of the edible parts of food products that were produced for human consumption.

In 2016, plant-based food, such as fruits, vegetables, roots, and tubers had the highest wastage rates of any food (ca. 45%), followed by fish (35%), cereal (30%), oilseeds, meat, and dairy products (20%) as graphically depicted in Fig. 2.3.

Figure 2.4 depicts the percentages of FW derived from a specific food industry sector (Baiano 2014). It is surprising to observe that circa one-fourth of the global waste comes from the drink industry.

Due to the notorious problem of land competition between food and biomass feedstock dedicated crops, residues represent a highly eligible biorefineries feedstock for reducing the burden on virgin raw materials. The first step for applying the industrial symbiosis concept in the food chain sector is their identification, quantification, and characterization followed by the study of the regional availability of FW producers and of potential users. This is a crucial starting point for deciding their best market positioning.

As regards the valorization of FW, it is easier to focus on the recovery of functional compounds derived from byproducts from the early stages of the food processing sector since these sources are abundant and concentrated in production or processing locations and less susceptible to deterioration compared to the wastes, produced across a broad range of retailers and households, that need to be subsequently accumulated. This collection stage complicates their valorization as sources for valuable components since the biological stability might be dramatically reduced due to the growth of pathogens.

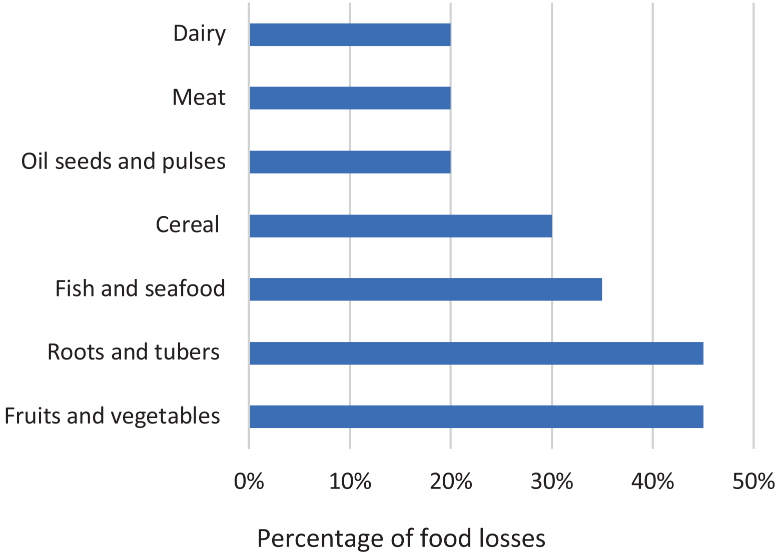

**Fig. 2.3** Percentage of food losses and waste of the seven commodity groups (FAO 2016)

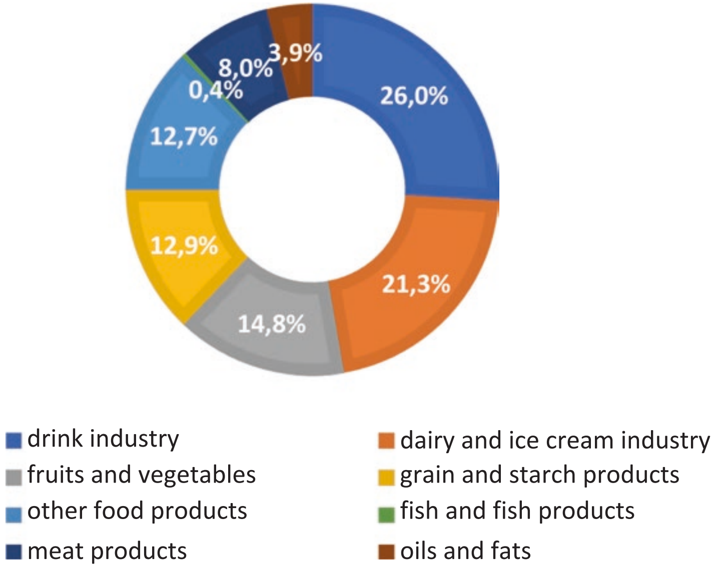

**Fig. 2.4** Food waste generation; percentages of FW derived from a specific food industry sector (Baiano 2014).

Functional foods meet strengthening consumer demand for foods that enhance health and wellbeing providing a specific health benefit over and above their nutritional value. Modern science has unraveled the secrets of many FW components and established a sound basis for their nutritional and functional value.

In parallel, technology developments and cost-effectiveness have been the main drivers for a range of functional isolates. Generally speaking, the potential of the valorization of target compounds in specific FW has to be supported by evidence-based information on their valuable content promoting health. In parallel, the time between waste generation and valorization activities has a direct impact on the final concentration and quality of bioactive compounds. Isolation, purification, and recovery procedures to improve and standardize target compounds profile are needed and will be dealt with in Chap. 4.

In the following, we will detail the main FW sources and the high-value target compounds that can be obtained from them.

## 2.1 Fruits and Vegetables

Fruits and vegetables are high energy food items; soluble carbohydrates (glucose, fructose), vitamins, minerals, fibers, polyphenols and other bioactive compounds make their nutritive profile very rich (Schieber 2017). Fruit and vegetable spoilage is very common, and it is often indicated by discoloration, biochemical reactions, and oxidation, thermal treatments, rotting, microbial proliferation, and over-ripening. Wastes from the fruit and vegetable sectors mainly consist of hydrocarbons and relatively small amounts of proteins and fat, with an impressive moisture content of 80–90%. The wastewaters contain large amounts of suspended solids (SS), that result in high biochemical (BOD) and chemical oxygen demand (COD); among dissolved compounds, pesticides, herbicides, and cleaning chemicals can be found (Kosseva 2011). In general, fruits and vegetable byproducts can be profitably used as animal feedstuff (Angulo et al. 2012). Common disposal methods, such as composting, land filling, and incineration, give rise to environmental concerns because of toxic and greenhouse gas emissions, microbial proliferation, and landfill leachate (Dessie et al. 2018). Since wastes from the fruit and vegetable sectors are well renowned as one of the best waste source of polyphenols, dietary fiber, pigments, enzymes (cellulase, amylase, protease, phytase, etc.), fragrances and flavors (vanillin), essential oils, biopesticides, plant growth regulators, and other precious bioactive compounds (Balasundram et al. 2006; Sharma et al. 2020) their valorization is mandatory.

Fruit and vegetable waste can also be a cheap source of starch, cellulose and/or hemicelluloses; they can be hydrolyzed to soluble sugars and further fermented to produce biohydrogen, bioethanol, and biogas (Díaz et al. 2017). Microbial processing of fruits and vegetable waste has paved the way for their valorization as fermented beverages (fenny, vineger), single-cell proteins (*Saccharomyces* sp., *Candida utilis*, *Endomycopsis fibuligera* and *Pichia burtonii*), single-cell oils (Sharma et al. 2020). Acidogenic fermentation of fruit and vegetable wastes, via the bifidus pathway by *Bifidobacterium,* resulted in lactic acid production (Wu et al. 2015).

Fruit and vegetable wastes were also used to produce succinic acid: firstly, they were hydrolyzed; the fungal hydrolysis by *Aspergillus niger* and *Rhizopus oryzae* produced glucose and fructose; *Actinobacillus succinogenes* used fruit and vegetable wastes hydrolysate as the sole feedstock to produce succinic acid with high yield (Dessie et al. 2018).

In Chap. 6, the importance of this platform chemical, which has considerable potential economics and environmental meaning for the bioplastics sector, will be detailed.

Many different kinds of fruit and vegetable waste were exploited as biosorbents for heavy metal removal (Sud et al. 2008). Compared to conventional treatment methods, biosorption advantages includes: low cost, high efficiency, minimization of sludge, and good metal recovery. Biosorption is discussed in Chap. 5 (Sect. 5.8).

Tables 2.1 and 2.2 detail, for fruit and vegetable wastes, respectively, the specific source and the target molecules which can be upcycled.

In the following, we will detail a classical gamut of source byproducts and associated target compounds.

**Table 2.1** Fruit waste: specific source and target molecules for recovery

| Source | Target compound | References |
|---|---|---|
| Apple pomace | Pectin, polyphenols, fiber, lactic acid, citric acid, aroma compounds, pectinases | Galanakis (2012), Ravindran and Jaiswal (2016), Wolfe and Liu (2003), Huber and Rupasinghe (2009), Henríquez et al. (2010), Schieber (2017), Kiran et al. (2014), Dhillon et al. (2011, 2012), Liu et al. (2011), and Vorobiev and Lebovka (2010) |
| Apple skin | Phenols | Galanakis (2012) and Huber and Rupasinghe (2009) |
| Apple, black currant, chokeberry, pear, cherry and carrot pomace | Dietary fiber | Nawirska and Kwaśniewska (2005) |
| Chokeberry and apple pomace | Hemicellulose and pectin as sorbents for heavy metals | Nawirska and Kwaśniewska (2005) |
| Apple, golden rod and artichoke | Polyphenol | Peschel et al. (2006) |
| Berries residuals | Phytochemicals, polyphenols, pectin, dietary fiber | Górecka et al. (2010), Rohm et al. (2015), Paes et al. (2014), and Kryževičiute et al. (2016) |
| Black currant seeds | Essential fatty acids, tocopherols, phytosterols | Bakowska-Barczak et al. (2009) |
| Lingonberry (*Vaccinium vitis-idaea L.*) Pomace | Linolenic and linoleic fatty acids | Kitrytė et al. (2020) |
| Peach pomace | Pectin | Galanakis (2012) |
| Peach | Antioxidants | Plazzotta et al. (2020) |

(continued)

**Table 2.1** (continued)

| Source | Target compound | References |
|---|---|---|
| Jackfruit waste (peel). | Pectin | Naik et al. (2020) |
| Apricot kernel | Protein isolate | Galanakis (2012) and Ravindran and Jaiswal (2016) |
| Kalahari melon seed | Phytosterol | Ravindran and Jaiswal (2016) |
| Grape pomace | Dietary fiber | Galanakis (2012) |
| Grape skin | Phenols, fragrance compounds, anthocyanins | Galanakis (2012) and Ghafoor et al. (2010) |
| Grape processing industry | Ethanol, dietary fibre, grape seed oil, pomace oil, oleanolic acid, catechin, epicatechin, and proanthocyanidins (flavanols), gallic acid (phenolic acid), resveratrol (stilbene), enocyanin (anthocyanin), procyanidins, tartates, malates, citric acid, single cell protein, short-chain fatty acids from vinasse | Schieber (2017), Galanakis (2017), Makris (2018), Luo et al. (2019), Barba et al. (2016), Santamaría et al. (2002), Löf et al. (2011), Spigno et al. (2015), Dahmoune et al. (2013), Vergara-Salinas et al. (2015) Pedras et al. (2017), Duba et al. (2015), Drosou et al. (2015), Casazza et al. (2010), Dang et al. (2014), González-Centeno et al. (2015), Bonfigli et al. (2017), Caldas et al. (2018), Boussetta et al. (2009), Liu et al. (2011), Mouratoglou et al. (2016), Patsea et al. (2017), and Bosiljkov et al. (2017) |
| Wine lees | Calcium tartrate, enocyanin | Galanakis (2012) |
| Pomace of six fruits (*Fragaria ananassa* (strawberry), *Prunus cerasus* (sourcherry), *Ribes nigrum* (black currant), *Ribes rubrum* (red currant), *Rubus fruticosus* (blackberry) and *Rubus idaeus* (raspberry) | Natural antioxidants, preservatives, antimicrobial compounds | Krisch et al. (2009) |
| Fresh cut fruit peels, seeds, and unused flesh | Bioactive compounds, (phenolic compounds, carotenoids, vitamins) endowed with antioxidant anti-microbial activity | Ayala-Zavala et al. (2010) |
| Cold hardy mandarin peel | Narirutin | Galanakis (2012) |
| Orange peel and other byproducts | Hesperidin, apocarotenoid, limonene, cellulose, fiber | Galanakis (2012), Ravindran and Jaiswal (2016), Bicu and Mustata (2011), and de Moraes Crizel et al. (2013) |
| Lemon by-product | Pectin | Galanakis (2012) |

(continued)

**Table 2.1** (continued)

| Source | Target compound | References |
|---|---|---|
| Citrus by-product | Essential oil (limonene), phenolics, pectin, antioxidants, ethanol, organic acids (citric, malic, malonic, and oxalic acids), and flavonoids, fibers, amino acids and proteins, minerals, lipids, vitamins, carotenoids, xanthan gum | Matharu et al. (2016), Fernández-López et al. (2004), Scordino et al. (2007), Satari and Karimi (2018), Farhat et al. (2011), Ferhat et al. (2006), Yang et al. (2009), Fishman et al. (1999), and Liu et al. (2006) |
| Clementine | Antioxidants and natural preservatives polyphenols and carotenoids, flavonoids and anthocyanins, proanthocyanidins ascorbic acid | Pfukwa et al. (2019) |
| Rejected and processed kiwifruits | Soluble and insoluble dietary fiber | Galanakis (2012) |
| Banana waste | Cyanidin-3-rutinoside | Galanakis (2012) |
| | Lignin, pectin, cellulose, hemicellulose, phenolic compounds (prodelphinidins, flavonol glycosides), procyanidins, flavanols | Schieber (2017), Kiran et al. (2014), and Maneerat et al. (2017) |
| Mango peels and byproducts | Starch, fiber, sterols, tocopherols, tannins, polyphenols, flavonols, xanthones, anthocyanins, alkylresorcinols, unsaponifiable matter, essential amino acids, antioxidant, carotenoids, vitamins, enzymes, dietary fibers, pectin | Schieber (2017), Abdalla et al. (2007), Ajila et al. (2010), and Berardini et al. (2005). |
| Passion fruit peels | Pectin | Canteri et al. (2010) and Seixas et al. (2014) |
| Papaya processing wastes | Pectin production<br>Bioactive compounds such as benzyl isothiocyanate | Boonrod et al. (2006) and Hall et al. (2018) |
| Pineapple | Pectin, phenolic compounds, carotenoids and bromelain, dietary fibre | Schieber (2017), Kiran et al. (2014), Upadhyay et al. (2012), da Silva et al. (2010), and Martins et al. (2014) |
| Brazilian tropical fruits | Total phenols, anthocyanins, yellow flavonoids, flavonoids, resveratrol, coumarin, other bioactives | Da Silva et al. (2014) |
| Watermelon fruit rinds | Pectin | Prakash Maran et al. (2014) |

**Table 2.2** Vegetables waste: specific source and target molecules for recovery

| Source | Target compound | References |
|---|---|---|
| Various vegetable and fruits water extracts | Soluble sugars and organic acids for yeast cultivation without nutrient addition | Stabnikova et al. (2005) |
| Tomatoes byproducts | Carotenoids (lycopene, β-carotene) and pectin | Schieber (2017), Kiran et al. (2014), Grabowska et al. (2019), Riggi and Avola (2008), Zuorro et al. (2011), Strati and Oreopoulou (2011), Ishida and Chapman (2009), MacHmudah et al. (2012), Baysal et al. (2000), Sarkar and Kaul (2014), and Kehili et al. (2017). |
| Tomato pomace | Lycopene | Galanakis (2012) and Ravindran and Jaiswal (2016) |
| Tomato skin | Carotenoids, fibers | Galanakis (2012), Ravindran and Jaiswal (2016), Urbonaviciene et al. (2012), and García Herrera et al. (2010) |
| Carrot peel | α-carotene, β-carotene, phenols | Galanakis (2012) and Schieber (2017) |
| Onion | Pectin, fructans, phenolic compounds and dietary fiber myricetin, quercetin, quercetin, luteolin and kaempferol | Kiran et al. (2014), Corell et al. (2018), Nile et al. (2017),<br>Choi et al. (2015), and Zill-E-Huma et al. (2011) |
| Leeks | Myricetin, quercetin, luteolin and kaempferol<br>Pectins | Corell et al. (2018)<br>Christiaens et al. (2015) |
| Cauliflower floret curd | Pectin | Galanakis (2012) |
| Cauliflower | Dietary fiber with high water absorption index, suitable for functional food production | Stojceska et al. (2008) |
| Cabbage (white) | Sulforaphane<br>Pectin | Tanongkankit et al. (2013)<br>Westereng et al. (2008) |
| Cabbage (red) | Di-acylated cyanidin Anthocyanins | Valencia-Arredondo et al. (2020) and Ravanfar et al. (2018) |
| Cabbage (black) | Flavonoids | Romani et al. (2003) |
| Cabbage, watermelon husk and peach peels | Carotene production, using blakeslea trispora, a heterothallic fungus | Papaioannou and Liakopoulou-Kyriakides (2012) |
| Verza | Sulforaphane (a biologically active phytochemical) | Sivakumar et al. (2007) |

(continued)

**Table 2.2** (continued)

| Source | Target compound | References |
|---|---|---|
| Broccoli | Bioactive compounds (glucosinolates, phenolic acids, and flavonoids) and nutrients (vitamin c, minerals, and trace elements) with antioxidant activity | Dominguez-Perles et al. (2011) and Aires et al. (2017) |
| Chicory roots, citrus peel, cauliflower florets and leaves, endive, and sugar beet pulps | Pectic oligosaccharides and pectin using proteases and cellulases enzymes | Zykwinska et al. (2008) |
| Chicory | Antioxidants<br>Fructan and sugars for the production of 5-hydroxymethylfurfural<br>Hydrochar | Lante et al. (2011)<br>Stökle and Kruse (2019)<br>Stökle et al. (2019) |
| Horse chestnut (from gardening activities) | Quercetin and kaempferol glycosides, saponins of oleane type, flavonoids used in pharmacy and cosmetic industries | Kapusta et al. (2007) |
| Asparagus | Phenols (flavonoids and hydroxycinnamic acids) and saponins useful as functional ingredients | Fuentes-Alventosa et al. (2013) |
| Carob pulp aqueous extracts | Carbon source for the production of the biocontrol agent *Pantoea agglomerans* PBC-1, usable as biopesticide | Manso et al. (2010) |
| Turnip greens | Organic acids, fatty acids, and tocopherols.<br>Phenolic compounds | Chihoub et al. (2019) |
| Field herbs | Tannin | Kardel et al. (2013) |
| Thistle | Antioxidant and Anti-aging Flavonolignans<br>Cynaropicrin and Cnicin<br>Silymarin<br>Total flavonoids and total polyphenols<br>Silybin A and silybin B<br>Organic acids, fatty acids, and tocopherols.<br>Phenolic compounds with antioxidant, antibacterial | Drouet et al. (2019)<br>Mizuno and Usuki (2018)<br>Saleh et al. (2017)<br>Lee et al. (2017)<br>Çelik and Gürü (2015)<br>Chihoub et al. (2019) |
| Swiss chard | Polyphenols | Santos et al. (2014) |

(continued)

**Table 2.2** (continued)

| Source | Target compound | References |
|---|---|---|
| Lettuce | Bioaerogel-like materials antioxidants | Plazzotta et al. (2018a) |
| | Functional flour or natural adsorbents | Plazzotta et al. (2018b) |
| | Bitter and gelling compounds, poly-phenols | Plazzotta et al. (2017) |
| | Cellulose nanofibers for biocomposite | Zhang et al. (2019) |
| | Polyphenols | Santos et al. (2014) |
| | Antioxidants | Lafarga et al. (2019) |
| Rocket salad | Phenolic and glucosinolate | Solana et al. (2016) |
| Radicchio | Bioplastics with antioxidant capacity | Perotto et al. (2018) |
| | Polyphenols | Cefola et al. (2016) |
| Spinach | Polyphenols | Santos et al. (2014) |
| | Protein complexes associated with oxygenic photosynthesis from thylakoid membranes. | Korotych et al. (2019) |
| | Lutein and chlorophyll | Derrien et al. (2018) |
| | Flavonoids | Singh et al. (2018) |
| | Chlorophylls | Leite et al. (2018) |
| | Carotenoids and polyphenols | Jaime et al. (2015) |
| Garlic | Organosulfur compounds | Ferioli et al. (2020) |
| | Polyphenols | Ciric et al. (2020) |
| | Polyphenols | Noda et al. (2019) |
| Artichokes | Inositols and caffeoylquinic acids | Mena-García et al. (2020) |
| | Inulin-Type Fructans | Zeaiter et al. (2019) |
| | Pentacyclic Triterpenes | Dai et al. (2019) |
| | Caffeoylquinic acids and flavone glycosides (antioxidants) | Pagano et al. (2018) |
| | Phenolic acids and flavonoids | Stumpf et al. (2020) |
| | Cynaropicrin and Cnicin | Conidi et al. (2014) |
| | Inulin and functional protein (from the tuber Jerusalem Artichoke) | Mizuno and Usuki (2018)<br>Maumela et al. (2020) |
| Fennel | Anisole, Estragole, Fenchone, and Limonene | Eyvazkhani et al. (2020) |
| | Sterols, phenols from seed oil | Bettaieb Rebey et al. (2019) |
| Cucumbers | Antioxidant polysaccharide | Chen et al. (2019b) |
| Beans | Tannins, flavonoids, cardiac glycosides, anthocyanins, terpenoids, carotenoids, ascorbic acid and reducing compounds | Nawaz et al. (2020) |
| | Quercetin | Aghajanian et al. (2020) |
| | Antioxidant with anticancer activity | Yang et al. (2019) |

(continued)

**Table 2.2** (continued)

| Source | Target compound | References |
|---|---|---|
| Green beans | Flavonoids | Gbashi et al. (2017) |
| | Antioxidant phenolic acids and flavonoids | Aires et al. (2017) |
| | Pectin | Christiaens et al. (2015) |
| Legumes | Proteins, lipids, fatty acids, vitamins, minerals and phenolic compounds | Kiran et al. (2014) and Parate and Talib (2015) |
| Pea peel waste | Carbon source to produce cellulase enzymes | Verma et al. (2011) |
| Pea pod, broad bean pod and okara | Dietary fiber, potassium, iron<br>Fats rich in linoleic and oleic acid. | Mateos-Aparicio et al. (2010) |
| Soybean wastewater | Albumin, isoflavone aglycone | Galanakis (2012) and Ravindran and Jaiswal (2016) |
| Soybean vinasse | L(+)-lactic acid | Karp et al. (2011) |
| Eggplant | Anthocyanins (nasunin) polyphenols (5-O-caffeoylquinic acid) and steroidal glycoalkaloids (alpha-solasonine and alpha-solamargine) | Mauro et al. (2020) |
| | Phenolics, pectin, pullulan for starch replacement and edible coatings | Kazemi et al. (2019) |
| Sweet Peppers | Polyphenols, carotenoids | Nath et al. (2015) |
| | Capsinoids | Oğuzkan (2019) |
| | Capsaicin and dihydrocapsaicin | Martinez-Sena et al. (2017) |
| Celery | Flavonoids polyphenols | He et al. (2016) |
| | Luteolin and apigenin (bioactive flavonoids) | Han and Row (2011) and Zhang et al. (2011) |
| Pumpkin | Pumpkin polysaccharide | Chen et al. (2020) |
| | Vanillic acid | Mitić et al. (2020) |
| | Linoleic and oleic acids, beta-carotene and tocopherols, phytosterols and phenolic compounds | Cuco et al. (2019) |
| | Polyphenols and fatty acids | Ferreira et al. (2019) |
| | Polyphenols and fatty acids | Massa et al. (2019) |
| | Carotenoids | Lima et al. (2019) |
| | Beta-carotene, tocopherols and phytosterol | Cuco et al. (2019) |
| | Squalene | Hataminia et al. (2018) |
| | Antioxidants | Kulczyński et al. (2020) |
| Zucchini | Antioxidants | Lafarga et al. (2019) |
| | Flavonols and flavones for cosmeceutical valorization | Piccolella et al. (2019) |
| Mushroom waste | Ergosterol and vitamin d2 | Papoutsis et al. (2020) |

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**Table 2.2** (continued)

| Source | Target compound | References |
|---|---|---|
| Coffee | Antioxidants, vitamins, enzymes, cellulose, starch, lipids, proteins, pigments, citric acid, gibberellic acid, ethanol, dyes, and dietary fibres (cellulose, hemicelluloses, lignin, pectin, gums) | Murthy and Madhava Naidu (2012) and Kiran et al. (2014) |
| Spent coffee grounds | Lipids | Ahangari and Sargolzaei (2013) |
| Spent filter coffee | Polyphenols | Pavlović et al. (2013) |
| Tea | Caffeine, polyphenols, triacontanol, and saponins | Sui et al. (2019) |
| Filter-tea by-product (yarrow–Rose Hip Mixtures) | Chlorophylls and Carotenoids | Pavlić et al. (2016) |
| Cocoa husks | Pectin | Mollea et al. (2008) |

### *2.1.1 Apple*

Apple juice industry produces a million pounds a year of wastes with high costs of disposal and threat to the environment (Wolfe and Liu 2003). Up to 25% of the processed apples turn into by-product (Shalini and Gupta 2010), which is largely available during harvesting season. This FW refers to a variable mixture of peels, pomace and seed, with a high content of water, simple sugars (glucose, fructose, and sucrose) and insoluble carbohydrates, such as hemicellulose, cellulose and lignin, and pectin; it has a great biotechnological potential.

Apple pomace was used as a carbon source in the propionic-acetic fermentation via wild strain *Propionibacterium freudenreichii* T82 bacteria. After 120 hours of cultivation, propionic acid biosynthesis reached its maximum (1.771 g/L) while the content of the acetic acid reached the level of 7.049 g/L (Piwowarek et al. 2016).

High concentrations of phenolic compounds in apple peels may support the prevention of chronic diseases, such as cardiovascular diseases and cancer. Besides, several microorganisms can use apple residues as a substrate for growth (Kosseva 2011). This by-product can be used as fuel or cattle feed, but it is also a source of food ingredients, pectin, fibers; moreover, it can be used in biotransformation (Shalini and Gupta 2010).

Valuable food ingredients could be made using the waste peels, dried, and ground to a powder, without large losses of phytochemicals. Blanching treatments for 10 s and freeze-drying represented the best processing condition to keep the total phenolic and flavonoid contents similar to those of the fresh apple peels. The phenolic, flavonoid, and anthocyanin contents in 100 g of dried peels were, respectively, 3342 ± 12 mg gallic acid equivalents, 2299 ± 52 mg catechin equivalents, and 169.7 ± 1.6 mg cyanidin 3-glucoside equivalents. The apple peel powder had a total antioxidant activity of

220 mg vitamin C equivalents/g: it also had a strong antiproliferative effect on HepG 2 liver cancer cells. Apple peel powder may be used in a range of healthy food products to add phytochemicals and promote the antioxidant activity of foods (Wolfe and Liu 2003).

Huber and Rupasinghe (2009) demonstrated that apple peel extracts are natural antioxidants and effective inhibitors of oxidation of polyunsaturated fatty. Indeed, lipid oxidation is a major concern in the food industry, impacting both the food quality and health of consumers, and new natural food antioxidants would be highly eligible candidates to solve the problem.

Henríquez et al. (2010) optimized a pilot scale extraction procedure using a double drum-dryer as drying technology and maneuvered temperature and extraction time in order to maximize the retention of phenolic compounds and dietary fiber.

### 2.1.2 Berries

High amounts of wastes from currant, raspberries, and blackberries released during juices, jams, and jellies preparations manufacturing are extremely rich in antioxidants, phenolic acids, flavonoids, polyphenols, and fibers, which are eligible to be recovered for different industrial purposes.

Bakowska-Barczak et al. (2009) focused on residues of seeds from five black currant (*Ribes nigrum L.*) cultivars. Canadian black currant seed oil can be profitably upcycled for the recovery of essential fatty acids, tocopherols, and phytosterols. Extraction of polyphenols from the seed residues remaining after the oil extraction even allowed the recovery of additional valuable phenolic antioxidants.

Pap et al. (2004) studied waste production prevention and minimization in berry juice processing. Less process waste and effluent resulted from the eco-innovative practices. Supercritical fluid extraction with natural carbon dioxide ($CO_2$) was deemed the most environmentally friendly solvent-free extraction method for the recovery of value-added compounds.

The amount of fibers in berries residuals makes them as replacement of flour in cookies at the level 25 and 50% (Górecka et al. 2010). The added raspberry pomace in a dried form resulted in a functional product with high fiber content and with a palatable taste whose organoleptic characteristics were positively accepted by consumers.

### 2.1.3 Citrus Fruits

In contrast with other types of fruits, citrus fruits processing results in large amounts of waste materials, such as peels and seeds, usually discarded during juice manufacturing. These residues are a precious source of a gamut of compounds, including soluble sugars, fiber, organic acids, amino acids and proteins, minerals, lipids, flavonoids and vitamins (Fernández-López et al. 2004).

Different concentrations of lemon albedo and orange dietary fiber powder (including that obtained from the orange juice wastewater) were added to cooked and dry-cured sausages to increase their dietary fiber content (Fernández-López et al. 2004).

Viuda-Martos et al. (2011) studied the microbiological properties of the orange juice wastewater and their physico-chemical characteristics, including pH, phenolic compounds and antioxidant activity, organic acids, sugars, soluble solids, and color. Narirutin and hesperidin were the most concentrated phenolic compounds, whereas the main sugar and organic acid were, respectively, glucose and succinic acid. De Moraes Crizel et al. (2013) suggested that orange juice fibers byproducts can be used as a fat replacer in ice cream because they have an ideal ratio between soluble and insoluble fiber and high water and oil retention capacity. Their use as a substitute of fat in ice cream led to a 70% reduction of fat without causing significant changes in attributes such as color, odor, and texture while providing a high content of phenolic compounds and carotenoids.

The residue of pigmented orange pulp wash (Scordino et al. 2007) was stabilized by removal of enzymes and microorganisms via ultra-filtration; 80% of the water was eliminated by a reverse osmosis treatment to obtain a purified transparent liquid of slight amber color that is a sugar concentrate (28 Brix) containing about 250 g/L of sugars (glucose, fructose, and sucrose), 9 g/L of citric acid and 1 g/L of pectin. It could be easily used as a natural sweetener in the food and beverage industries.

Citrus fruits byproducts were also effectively used as cattle feed, especially for ruminants. Bampidis and Robinson (2006) studied the physical and nutrient composition, digestibility, and effects on ruminants (weight and lactating production) according to the size of the rations of these feeds to support growth and lactation in ruminants.

Citrus waste was also used for xanthan gum production (see Sect. 5.1.4) using the plant pathogen using *Xanthomonas campestris* (Murad et al. 2019).

Cellulose extraction from orange peels is a promising upcycling of these byproducts. Bicu and Mustata (2011) studied sodium sulfite and sodium metabisulfite as pulping reagents and optimized the main process parameters (reagent dosage and reaction time), to maximize cellulose yield. Recovered cellulose was characterized by good purity, whiteness, and water retention, low crystallinities, and moderate molecular weight. It can be used as filler, water-absorbent, or as raw material to produce cellulose derivatives.

### *2.1.4 Exotic Fruits*

The exotic fruits processing industry also produces a large percentage of waste byproducts very rich in bioactive compounds, phenols, carotenoids, vitamins, fibers that are precious as antioxidants, antimicrobials, flavoring, colorants, and texturizer additives (Ayala-Zavala et al. 2010).

New uses for these types of waste are continuously envisioned because fruit byproducts presented higher bioactive compound contents than their respective fruit pulps.

Passion fruit peels, treated with nitric acid, are a major source of pectin, a dietary fiber that is a gelling agent and stabilizer (Canteri et al. 2010) due to its rheological properties.

Pineapple stem, a typical pineapple processing waste, was extensively used for bromelain extraction (Upadhyay et al. 2012). The waste obtained during this process is a nutraceutical resource of antioxidants, antimicrobials, and inhibitors against 15-lipoxygenase and advanced glycation end products. The anti fungal activity is probably due to high amounts of benzoic acid present in the waste. The bioactivities in all the performed assays indicate that pineapple stem waste could be utilized as an economical source of preventive or therapeutic phytochemicals that have a promising usage in functional food based industries.

Mango "waste mining" seems to be one of the most promising FW upcycling. Abdalla et al. (2007) studied mango seed kernel extract and oil. Their combination had synergistic antioxidant potency and could be used as natural antioxidant and antimicrobial in different kinds of food. Phenolic compounds, unsaponifiable matter, and crude protein rich in all essential amino acids are typical of this waste. Mango peels powders rich in bioactive compounds, such as antioxidant polyphenols, carotenoids, vitamins, enzymes, and dietary fibers, were incorporated into macaroni (up to 7.5%) to enhance its nutritional quality without affecting its cooking, textural and sensory properties (Ajila et al. 2010). Polyphenolics were extracted from Mango peel while pectin was recovered by alcohol precipitation (Berardini et al. 2005).

Virgin coconut oil byproducts, namely coconut skim milk and insoluble protein, can be used to obtain coconut protein powder, with good emulsifying properties that can be used in emulsified foods (Naik et al. 2012).

Besides, coconut and peanuts shell powder could be upcycled as filler in natural rubber (Sareena et al. 2012).

Papaya processing wastes served as a substrate for yeast (*Saccharomyces cerevisiae*) growth as well as a feed supplement for shrimp (Kang et al. 2010) but it is also used for pectin production (Boonrod et al. 2006).

Ueno et al. (2003) proposed to use pineapple and grapes processing wastes as substrate and enzyme for successful lactic acid production.

Da Silva et al. (2014) quantified the levels of total phenols, anthocyanins, yellow flavonoids, flavonoids, resveratrol, coumarin, and other bioactives in pulps and byproducts of twelve typical tropical fruits from Brazil (pineapple, acerola, cashew apple, guava, soursop, papaya, mango, passion fruit, surinam cherry, sapodilla, and tamarind). They are interesting functional food ingredients.

### *2.1.5 Tomatoes*

Tomato is the second most important global vegetable crop next to potato, with a yearly production of 100 million tons fresh fruit in 144 countries (Kalogeropoulos et al. 2012). Tomatoes are rich in bioactive and valuable phytochemicals (Dumas et al. 2003), such as carotenoids, vitamin C and E and various phenolic compounds. The strong correlations between carotenoid consumption and a reduced risk of cancer and coronary and cardiovascular diseases, probably because of the carotenoids antioxidant activity, made tomato processing byproducts very interesting as a potential and inexpensive source of these bioactive compounds (Urbonaviciene et al. 2012). Actually a huge amount of carotenoids are discarded along with the peels during the processing of tomatoes into pastes or sauces. Lycopene is the most abundant and the most antioxidant carotenoid in tomatoes, but β-carotene is the major dietary precursor of vitamin A.

Kalogeropoulos et al. (2012) pointed out that antioxidants from tomatoes byproducts could be used for the formulation of functional foods or serve as additives in food systems to extend their shelf-life.

Ćetković et al. (2012) confirmed the importance of tomato wastes as a potential source of phenolic antioxidants and anticancer agents, identifying and quantifying some individual phenolic compounds, including phenolic acids and flavonoids and their antioxidant activity.

For the commercial exploitation of these wastes as nutraceutical resources, it is necessary to consider both environmental and extraction profitability.

The majority of the studies published in the literature focus on two target carotenoids: lycopene and β-carotene (Grabowska et al. 2019). Riggi and Avola (2008) studied the dependence of carotenoids content in tomato wastes on their source and the month in which they were produced. The highest lycopene and β-carotene contents were recorded in summer due to the higher proportion of red fruits that is statistically correlated with the lycopene content. Zuorro et al. (2011) indicated that the recovery of lycopene could be greatly enhanced by using cellulolytic and pectinolytic enzymes. Thermal processing of tomatoes (for example, the blanching process) increases carotenoid bioavailability in tomato peels. It was also found that the best source for purified lycopene was tomato peel with lycopene and β-carotene concentrations higher in the blanched tomatoes than in the non-blanched tomatoes (Urbonaviciene et al. 2012).

As regards the extraction of carotenoids, it is clear that the use of a food-friendly and nontoxic solvent is mandatory. Ethyl lactate gave the highest carotenoid yield, compared to other organic solvents, after optimizing the extraction parameters (time, temperature and steps) (Strati and Oreopoulou 2011; Ishida and Chapman 2009). MacHmudah et al. 2012) discussed the use of supercritical carbon dioxide to extract lycopene from tomato peel by-product containing tomato seeds which exerted a synergistic effect on extraction yield. Baysal et al. (2000) assessed various parameters for lycopene extraction by supercritical carbon dioxide such as temperature, pressure, time, $CO_2$ flow rate, and co-solvent addition.

García Herrera et al. (2010) demonstrated that peels are mainly composed of carbohydrates, with an average value of 80% of total dietary fiber; insoluble fiber is the major component. Tomatoes peel fiber can be used as a food ingredient of new functional foods.

### 2.1.6 Pulses

Pulses represent an excellent source of high-quality dietary proteins, dietary fiber, micronutrients, and phytochemicals.

Pulses are prone to serious damage due to insect pests which cause serious losses; fumigation is the current way to prevent crop damage, but the use of an anti-metabolic protein from wild pulses, involved in plant defense mechanism, such as arcelin, is promising (Karuppiah et al. 2018).

Horse gram is an underutilized pulse crop that has been used as a food item for millennia. It grows in a wide assortment of adverse climatic conditions. Besides its importance for human nutrition, its non-nutritive bioactive substances, such as phytic acid, phenolic acid, fiber, enzymatic/proteinase inhibitors, flavonoids, and high molecular tannins, have significant metabolic and/or physiological effects and might be responsible for its use in ethnic and traditional medicine as a potential therapeutic agent to treat kidney stones, urinary diseases, respiratory infections etc. The use of antioxidants from legumes decreases the risk of intestinal diseases, diabetes, coronary heart disease, and dental caries; hence the seed coat fractions and other waste can be profitably used (Prasad and Singh 2015).

Tannins, flavonoids, cardiac glycosides, anthocyanins, terpenoids, carotenoids, ascorbic acid, and reducing compounds (Nawaz et al. 2020), antioxidants with anti-cancer activity (Yang et al. 2019), and quercetin (Aghajanian et al. 2020) are important bioactives that can be recovered from beans waste. Flavonoids (Gbashi et al. 2017), antioxidant phenolic acids (Aires et al. 2017), and pectin (Christiaens et al. 2015) are specific target compounds that can be recovered from green beans waste.

Peel pea waste was used as a carbon source for cellulase production under solid-state cultivation by *Tricoderma reesei*. Cellulase (Sect. 5.7.2) is a crucial enzyme for lignocellulosic biomass waste bioconversion (Verma et al. 2011). Dietary fiber, potassium, iron, and fats rich in linoleic and oleic acid can be recovered from pea pod and broad bean pod (Mateos-Aparicio et al. 2010).

## 2.2 Winemaking Industries

According to FAO statistics (FAO 2020b), grapes are one of the largest and highest value crops grown worldwide in order to produce wine. In the Mediterranean area, Italy, France and Spain are the three main wine producers. The annual production worldwide can reach almost 80 million tons, but 20% of processed grapes remain as a by-product.

The waste from the winemaking process mainly consists of pomace, which is the solid waste that remains after the grape pressing and the fermentation processes, and lees, which are clarification sediment.

Grape pomace consists of the seedless fraction (pulp, skin and stem) and the grape seed itself. Wine lees mainly contain ethanol, tartaric acid, and yeast cells with phenolic compounds (Kalli et al. 2018). The traditional disposal of large amounts of pomace in the environment or its incineration may be detrimental because the high polyphenols content decreases the pH and increases the resistance to biodegradation.

The winemaking byproducts generated after grape exploitation constitute a very cheap source of high-value ingredients, including hydrocolloids, dietary fibers, lipids, proteins, and natural antioxidants, which can be used as dietary supplements and nutraceuticals in functional foods, or in the production of phytochemicals, medical remedies, antimicrobial components, and cosmetics (Yu and Ahmedna 2013). The winery waste biomass contains an unparalleled amount and assortment of polyphenols, a broad class of secondary plant metabolites. Target compound content obviously depends on the grape variety, pedo-climatological conditions, and agricultural conditions. In red skins the polyphenol content is usually higher than for corresponding white skins. Specific polyphenols are contained in stems and seeds, and their apportionment is significant. Given the importance of polyphenols as target compounds in wine and fruit industry byproducts Fig. 2.5 illustrates the principal polyphenolic subclasses.

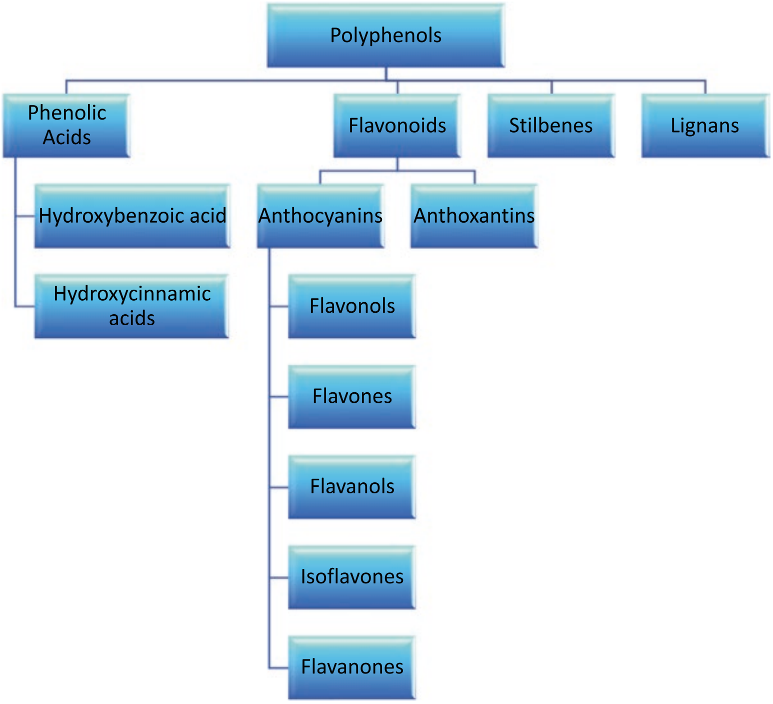

**Fig. 2.5** Principal polyphenolic subclasses

Growing evidence suggests that polyphenolic molecules are endowed with a gamut of beneficial bioactivities and have the potential to exert antioxidant, free radical scavenging, anti-inflammatory, antimicrobial, cardioprotective, anticancer, anti-aging, metal chelating, antithrombotic, and antidepressant activity (Rabiei et al. 2017). These multifunctional compounds are capable of interfering with the progression of diabetes, cardiovascular, carcinogenic, neurodegenerative diseases and inhibiting allergic reactions.

The effective recovery of polyphenols from vinification waste is the focus of interest of many laboratory-scale research studies; the use of organic solvents is unsuitable in terms of safety and poses environmental concerns. Green, nontoxic solvents and eco-compatible technologies represent a hot research field with respect to health-related and environmental risks. In this context, an aqueous bioethanol mixture is a green and effective solution for extraction of polyphenols from pomace (skins and seeds), from seeds, and for the extraction of trans-resveratrol from grape stems. Glycerol is a good bio-solvent competitor. Acidity was an important parameter to maximize the extraction yield; lactic acid was successfully used for flavonoid extraction, while acetic acid was shown to perform better for flavanol recovery. Along with conventional green solvent extraction, additional specific techniques, such as pressurized-liquid extraction, microwave-assisted extraction, ultrasound-assisted extraction, supercritical fluid extraction, accelerated solvent extraction, and subcritical water, and deep eutectic solvent extraction (that will be dealt with in Chap. 4) were successfully used (Makris 2018; Aliakbarian et al. 2012; Kalli et al. 2018).

Novel applications of winery by-product will be detailed in the following.

### *2.2.1 Winery By-Product for the Food Industry*

First of all, within a circular economy approach, grape pomace finds application in the wine industry itself. It was exploited as a fining agent for red wines to remove tannins (Gil et al. 2018), and to improve the antioxidant potential of red wines, as indicated by total phenolic and flavonoid content (Jara-Palacios et al. 2016). Dehydrated waste grape skins were able to release significant amounts of pigments, bioactive compounds, and aromas into white wines (Pedroza et al. 2011), and positive sensory repercussion from grape seed flour usage was also reported (Rosales Soto et al. 2012). Fermentation of grape pomace resulted in hydrolytic enzymes such as xylanase, and exo-polygalacturonase, and cellulase commonly used in the clarification processes in wine cellars and juices industries as well as in paper and pulp industries (Walia et al. 2017; Díaz et al. 2012).

Grape waste was also used as a functional ingredient to produce cheese (Marchiani et al. 2016), ice creams (Sagdic et al. 2012), and fermented milk (Frumento et al. 2013) with improved antioxidant activity. Cereal bars, pancakes, and noodles were enriched with phenols from Merlot grape seed flour to provide these food products with high antioxidant activity (Rosales Soto et al. 2012), and, similarly, grape pomace was used in bakery products and cookies for the same reason (Acun and Gül 2014).

Grape byproducts are a source of natural antioxidants that can replace synthetic antioxidants such as butylated hydroxyanisole and butylated hydroxytoluene, studied for potential toxicities, including hazard for carcinogenicity and genotoxicity (Kalli et al. 2018).

As polyphenols delay lipid peroxidation, grape pomace and its extracts have the potential to protect foods from oxidative damage. In this context, grape byproducts were used for lipid oxidation protection in yoghurt and salad dressings (Tseng and Zhao 2013), cooked beef, and pork patties (Rojas and Brewer 2007; Lorenzo et al. 2014). lamb meat (Guerra-Rivas et al. 2016), pork burgers (Garrido et al. 2011), minced fish muscle during frozen storage (Sánchez-Alonso et al. 2007), cooked and uncooked chicken meat (Selani et al. 2011). Extracts of grape pomace were incorporated into chitosan edible films providing antioxidant properties and promising shelf-life extension (Ferreira et al. 2014).

Along with the antioxidant activity, different components of grape pomace show antimicrobial activity against food spoilage microorganisms and pathogens, limiting the color deterioration, acidification, slime forming bacteria, and gas production. The most active compounds were reported to be gallic acid, hydroxybenzoic, and vanillic acid (Tesaki et al. 1999; Kalli et al. 2018).

In the fruit processing industry, white grape skin extract improved the antioxidant activity and color stability of a model fruit juice and retained the stability of probiotic strains, during storage (Shah et al. 2010).

Grape byproducts provided protection from potentially hazardous substances, such as acrylamide, classified as "a probably carcinogenic agent to humans", in heat-processed foods: polyphenols from skin extracts and grape seeds blocked its formation during frying (Xu et al. 2015). Grape seeds proved to be able to reduce residuals of nitrite after ripening of dry-cured sausages thereby inhibiting the formation of N-nitrosodimethylamine, identified as a mutagenic and a carcinogenic agent in all species examined (Li et al. 2013; Wang et al. 2015).

Grape pomace is a potential substrate for the production of microbial proteins (single-cell protein) with a high concentration of essential amino acids like lysine and valine for livestock feed or human nutrition (Kalli et al. 2018).

Tartaric acid from lees may serve as a natural preservative, as an emulsifier in the bread-making industry, as an acidifier in the winemaking industry, and as an ingredient of many food products and beverages. Similarly, enocyanin, known as E163 in the food sector, is a natural pigment derived from the anthocyanins in grape skin, approved by EFSA (European Food Safety Authority) as food dyes and in pharmaceutical products (Smith and Hong-Shum 2011).

Target compounds that can be extracted from winery waste are outlined in Table 2.1.

### 2.2.2 Winery By-Product for Cosmetics and Pharmaceutical Industry

Natural formulations are the focus of interest of the anti-aging market to avoid health risks of allergies from long-term exposure to synthetic preservatives, colorants, aromas, and stabilizers.

Anti-ageing properties of polyphenols from grape pomace make them a cost-effective source for the cosmetic industry also because they are endowed with antibacterial and antifungal properties that are crucial in cosmetic formulations (Baydar et al. 2006). Special care during encapsulation and delivery is needed to prevent the degradation of bioactive compounds (Davidov-Pardo and McClements 2015).

Many dietary supplements include grape seed, grape extract, and red wine powder for therapeutic purposes due to their antioxidant, hypoglycemic and hypolipidemic effects (Weseler and Bast 2017; Sun et al. 2016). The addition of grape seed extract and freeze-dried skin pomace to white bread was reported to reduce the postprandial glycemic response and cholesterol levels (Coe and Ryan 2016; Mildner-Szkudlarz and Bajerska 2013). The grape seed extract was shown to reduce *Campylobacter* induced pro-inflammatory cytokines secretion in human intestinal epithelial cells HT-29 in a dose-dependent manner (Silvan et al. 2017).

Grape pomace was also exploited as a drug delivery vehicle to create microemulsions (Kumar et al. 2014).

### 2.2.3 Winery By-Product for the Environment, Agriculture, and Animal Feeding

Removal of heavy metals from wastewater is a hot research topic; conventional methods such as chemical precipitation, ion exchange, membrane separation, reverse osmosis, and electro dialysis, are costly and not very effective. Plant wastes, including grape stalks, rice husk, black gram, waste tea, coffee, and walnut shell proved to be potent adsorbents for heavy metal removal (Tripathi and Rawat Ranjan 2015). Winery wastes adsorb heavy metals from aqueous solutions thanks to an ion-exchange mechanism with a significant release of $Ca^{2+}$, $Mg^{2+}$, $K^{+}$ and $H^{+}$ from grape stalks and uptake of $Cu^{2+}$ and $Ni^{2+}$. In addition, grape stalk wastes can be reused for the decontamination of metal-containing effluents (Villaescusa et al. 2004).

Grape pomace can be composted at first and then can be used as a soil conditioner with a low content in phosphoric acids and nitrogen (Ferrer et al. 2001).

Grape seed can be used in animal feeding (Brenes et al. 2016) with beneficial effects on animal health (Moate et al. 2014; Sehm et al. 2011; Hao et al. 2015; Ebrahimzadeh et al. 2018).

### 2.2.4 Winery By-Product as Biorefinery Feedstock

Following the biorefinery idea, grape marc, pomace, vinasses, wine lees, and winery wastewater have been used as raw materials to produce lactic acid, biofuels including ethanol, carboxylic acids (butyric acid, acetic acid), butanol, acetone, enzymes, high-value chemicals and energy via enzymatic or chemical hydrolysis and anaerobic digestion and pyrolysis (Luguel et al. 2011). Factors that may affect the revenue generation of winery waste biorefinery include harvesting, transport, treatment, storage, and distribution (Zacharof 2017).

Anaerobic digestion of grape marc waste was performed under mesophilic conditions at a laboratory scale to produce methane with a coefficient of 252 ± 31 mL of $CH_4$ per gram of added volatile solids at a temperature of 0 °C, and pressure of 1 atm. The volatile fatty acids concentration increased, and the pH and alkalinity slightly declined over the experimental time. The biomethanization can be implemented for waste management, reducing the large volume of waste generated (Javier et al. 2019).

High-quality short-chain fatty acids can be recovered from the anaerobic fermentation of wine vinasse and waste activated sludge mixtures. The diversity and abundance of fermentative bacteria resulted in the rapid hydrolysis and acidification of bioavailable substrates for short-chain fatty acids generation. Moreover, the presence of wine vinasses enhanced the dewaterability of fermentation residues (Luo et al. 2019).

## 2.3 Cereals and Tubers

Globally, cereal grains obtained from seeds of *Gramineae* family (such as wheat, rice, barley, maize, sorghum, millet, oat, and rye) fill a significant proportion of the human diet. Wheat is the dominant crop supply in high-income countries, while in South Asia rice is more prevalent (Gustavsson et al. 2011). Cereals processing is a key point of supply chains for important products as bread, pasta, and sweets. Cereal processing produces various byproducts like bran and germ (Sharma et al. 2020). Quantifying and correctly qualifying byproducts are an important starting point for deciding their best market positioning. Traditionally, straw, husk, and dried leaves of crops like wheat, corn, rice, and barley are used for making thatching roofs, broom, hand fans, baskets, and other commodities. Husks is actually a thermal insulator in the structures of environmentally friendly buildings (Hỳsek et al. 2019) and can be used in construction materials like lightweight bricks (Kumar and Mor 2013). Cereals products often undergo pretreatments to produce semi-finished products for various agri-food manufacturing. The typical example is represented by the milling-industry for the production of flours. These semi-finished products are used, in turn, as raw materials for various food productions. Pretreatments are generally characterized by low production yields with significant production of byproducts. Their quantification seems, therefore, to be important for both economic and environmental reasons. In addition to cereals residues from the early steps of the manufacturing process, bakeries, confectioneries, and pasta factories generate additional very variegate cereal-based FW. The complexity of data collection does not enable satisfactory official data assessments. Table 2.3 details, for cereal and tubers waste, specific sources, and target molecules for recovery.

### *2.3.1 Soft and Durum Wheat Processing*

In addition to flours suitable for the production of bread, pasta, and other products for the human diet, wheat milling provides a series of byproducts that are mainly used for feed preparation.

Processing soft and durum wheat aims to the maximum separation between the flour containing endosperm from the germ and outer layers (bran). Notably, the milling process is represented by a sequence of physical operations like cleaning, conditioning, breaking, sifting, and grinding.

This last step aims at breaking seeds, opening caryopsis, and detaching, as much as possible, endosperm from the outermost seed parts, leaving them as flat flakes. Further grinding processes aim to reduce particles size. The flour yield is about 75%; hence we have 25% of other byproducts such as bran (10%) which contains outer integument fragments and other seed parts almost entirely deprived by the floury nucleus and other cereal residues (15%), namely outer skins fragments and seed parts deprived of wheat bran (Riva 2013). The grinding of wheat produces byproducts, rich in high nutritional proteins, dietary fibers, and glucuronoarabinoxylans, that represent a form of hemicellulose found in the cell walls of grasses (Hollmann et al. 2009).

For production of refined flour, bran and germ are removed as they adversely affect the processing properties (Sharma et al. 2020). Wheat bran was used as a bread nutritional improver after an integrated biotechnological approach, combining xylanase treatment and lactic acid bacteria fermentation with a relevant decrease of the predicted glycemic index of the fortified bread (Pontonio et al. 2020). Water insoluble fibers (i.e., hemicelluloses) are able to regulate intestinal function and are used in supplement food products or ready meals (Rodríguez et al. 2006).

Wheat bran is an agroindustrial residual which represents an eligible feedstock in biorefinery processes. In line with the need to better utilize underutilized agricultural fractions, a sequential processing for extraction of starch, lipids, and proteins from wheat brans leaving a rest-material enriched in dietary fiber was

**Table 2.3** Cereal, roots and tubers waste: specific source and target molecules for recovery

| Source | Target compound | References |
|---|---|---|
| Wheat byproducts | Arabinoxylans | Galanakis (2012) and Hollmann et al. (2009) |
| Wheat straw | Hemicellulose | Galanakis (2012) |
| Wheat bran | Glucuronoarabinoxylans, fructans, nonstarch carbohydrates and oligosaccharides, phenolic compounds, lipid soluble vitamins and folic acid, and phytosterols, arabinose and xylose | Galanakis (2012), Ravindran and Jaiswal (2016), Schieber (2017), Sardari et al. (2019), and Bedő et al. (2019) |
| Straw | Lignin nanoparticles with (applications in the biomedical and environmental fields, such as tissue engineering or regeneration, artificial muscles, and strong underwater antifouling materials) | Lou et al. (2020) and Iravani and Varma (2020) |
| | Furfural | Brandenburg et al. (2018) |
| | Cellulose and Methylcellulose | Kumar and Kumar Walia (2017) |
| Rice bran | Albumin, globulin, hemicellulose b, insoluble dietary fiber, lipids, minerals, and antioxidants (vitamin e and oryzanol) | Galanakis (2012), Ravindran and Jaiswal (2016), Kiran et al. (2014), and Schieber (2017) |
| Rice husk | Silicon, silica | Kong et al. (2019) and Chen et al. (2019a) |
| Sesame husk | Insoluble dietary fiber | Ravindran and Jaiswal (2016) |
| Oat mill waste | β-Glucan, antioxidants | Galanakis (2012), Ravindran and Jaiswal (2016), and Kock et al. (2018). |
| Malt dust | Glucose, arabinose & galactose | Galanakis (2012), |
| Brewery's spent grains | Arabinoxylans, ferulic acid, fermentable sugars, bio-oil, bio-char, bioactive peptides (Connolly et al. 2019) | Galanakis (2012), Ravindran and Jaiswal (2016), Luft et al. (2019), López-Linares et al. (2019), Lorente et al. (2019), Connolly et al. (2019), and Ferrentino et al. (2019) |
| Brewery spent liquid | Brewery spent liquid as fermentation substrate for citric acid production or microalgae production. | Dhillon et al. (2012) and Amenorfenyo et al. (2019). |
| | Antioxidants | Barbosa-Pereira et al. (2013) |
| Potato peel | Phenols, antioxidants, flavonoids and flavonols | Galanakis (2012), Mohdaly et al. (2010), Sabeena Farvin et al. (2012), Kanatt et al. (2005), Okuno et al. (2002), and Amado et al. (2014) |
| Potatoes | Lysine, protein (patatin), steroidal alkaloids, cellulolytic enzymes, adsorption dyes, and biopolymer films | Kiran et al. (2014), Matharu et al. (2016), and Schieber (2017) |
| Sugar beet molasses | Organic acids | Galanakis (2012) |
| Sugar beet pulp | Phenols, antioxidants, flavonoid and flavonol | Mohdaly et al. (2010) |
| Cassava | Sugars | Ona et al. (2019) |

designed and developed. After a mild water-based extraction of starch, supercritical fluid extraction of lipids, and alkaline extraction of proteins, the remaining material had a fiber content that on average corresponded to 73±3% (Sardari et al. 2019).

A microbial saccharification of wheat bran was the first step for bioethanol fermentation (Farkas et al. 2019). A biotechnological approach was also used, via an integrated biorefinery process, for arabinose and xylitol production from wheat bran; a dilute-sulphuric-acid fractionation process resulted in xylose-rich and arabinose-enriched hydrolysates, separately. Arabinose biopurification of the hydrolysates by *Ogataea zsoltii* gave pure arabinose solutions. Xylitol fermentation by *Ogataea zsoltii* on the xylose-rich hydrolysate under the best pH and aeration conditions resulted in a xylitol yield of 53% in the bioreactor (Bedő et al. 2019).

Bioconversion of wheat bran into high value-added products, such as ethanol, lactic acid, and inulinase, was optimized, and mathematical modeling of fermentations from acid-pretreated and non-detoxified wheat bran predicted the experimental production data. Ethanol and lactic acid yields were up to 30.44% and 66.68%, respectively, when the free *Scheffersomyces stipitis* (ATCC 58,784) and the immobilized *Lactobacillus casei* were used. The feasibility of the process was clearly demonstrated (Germec et al. 2019).

### 2.3.2 ByProducts from Rice Processing (*Oryza sativa* L.)

The processing needed to transform raw rice into edible rice aims at improving the quality of the edible product consisting of cleaning, husking, bleaching, and optical separation.

During the cleaning process impurities like straw, stones, soil, and foreign seeds are eliminated. Husking is the second step in which peeling machines remove husk (the outer shell that covers the grain) by rubbing; this way, brown or whole-rice is obtained. Husking of rice produces byproducts, which are rich in high nutritional proteins, dietary fibers, and glucuronoarabinoxylans (Hollmann et al. 2009).

The bleaching aims at removing chaff and other residues. The product obtained must be further separated by broken seeds with a separator machine. By using the optical separation, a further refinement of rice is carried out on the basis of seed color. Staining defects are often produced during processing operations.

Thus, the yield of refined rice is around 60–65%, while different byproducts could reach 40%.

Byproducts can vary due to a gamut of rice varieties, but a common classification can be summarized as follow:

- Rice husk (ca. 20%) is the main brown-beige by-product obtained by rice processing. It is the coating on a grain of rice, made of hard materials, including silica and lignin. It is available in large quantities continuously. Its average humidity is around 10%, and the gross energy (or higher heat value) of its dry matter can be up to 15–16 MJ/kg. It is much more resistant than wheat husk. Its low density ranges from 132 to 140 kg/m$^3$, and it is biologically very stable. The ashes are made almost entirely of silicon oxide and are around 17% (Riva 2013; Kumar et al. 2016).

- Rice bud and bran (ca. 10%). Rice germ essentially consists of embryos and small rice fragments. It is generated during the whitening process. Its humidity is around 12%; the gross energy of its dry matter is about 22.3 MJ/kg, while ashes represent 8.7%; Bran contains dietary fibers (β-glucan, pectin, and gum) various antioxidants, rice bran oil, and unsaponifiable components including tocotrienols, γ-oryzanol, and β-sitosterol; all these components may be healthy as regards the plasma lipid profile (Riva 2013; Watson et al. 2014).
- Rice broken grains (ca.10%) with smaller dimensions. They have a humidity value of 12%; the gross energy of its dry matter is about 18.6 MJ/kg, while ashes are around 0.8% (Riva 2013).

Rice husk is useful as pet feed fiber, fertilizer and it is also a substrate for vermicomposting technique (Kumar and Mor 2013) or in fermentation processes to adjust moisture, maintain the porosity of fermentative material for gaseous exchange (Sharma et al. 2020).

Recycling of carbonized rice husk was used for producing high purity silicon (the purity of the silicon can reach up to 99.9) by the combination of electric arc smelting and slag refining (Kong et al. 2019). A zinc silicate glass system (ZnO-SiO2) synthesized using the melt and quench method and derived from white rice husk ash was doped with various europium ion concentrations; the luminescent properties are useful for optical devices such as white light-emitting diodes (Khaidir et al. 2019). Rice-husk-derived porous silica (Kumar et al. 2016), modified with recycled copper from industrial wastewater and cerium, was found to be useful to remove mercury and NO from simulated flue gases (Chen et al. 2019a). Rice husk ash was also profitably mixed with some cementitious structural materials (Shimamoto and Suzuki 2019) or to produce silica fertilizer for rice plants (Sekifuji and Tateda 2019), steel fiber-reinforced concrete (Koushkbaghi et al. 2019), and for pavement base material (Poltue et al. 2019).

### *2.3.3 Potatoes*

Potato is the largest crop worldwide since it is a quantitatively important energy source due to the high content of carbohydrates, especially starch. Processing of potatoes mainly for the production of chips or French fries generates peels or cull potatoes as byproducts. The use of byproducts from potatoes industry as cattle feed is very common (Nelson 2010). The upcycling of their peel waste would solve a potentially massive disposal problem. Potatoes processing byproducts are very interesting since they also contain vitamins, minerals, and phytochemicals, such as carotenoids and natural phenols. Sabeena Farvin et al. (2012) demonstrated that the ethanol extract of potato peel is a natural antioxidant for retarding lipid and protein oxidation in minced mackerel via comparison to a control with no added extracts. Radiation processing is very effective for sterilization but may impair the sensory quality of meat. Kanatt et al. (2005) exploited the antioxidant activity of potatoes peel to reduce lipid peroxidation of radiation-processed meat without affecting its flavor.

Starch can be recovered from wastewater produced during potato washing for chips, snacks, or fries, thereby avoiding starch sedimentation in drainage pipelines (Catarino et al. 2007).

Okuno et al. (2002) extracted antioxidants from waste powder derived from sweet-potatoes with orange flesh, using supercritical carbon dioxide extraction with no toxic solvent residue.

Among the several roots and tubers, cassava is very popular in South Asia and America; its peel can be enzymatically hydrolyzed to simple sugars as a useful feedstock from a cheap non-food biomass waste (Ona et al. 2019).

## 2.4 Breweries

Brewer’s spent grain is the typical waste produced in large amounts by the brewing industry. Its high potential in obtaining fermentable sugars through enzymatic hydrolysis makes it an eligible source of sugars for bioprocesses. The optimization of operational variables such as mechanical stirring, temperature, enzyme and substrate concentrations, and ultrasound (pulse factor and amplitude) were analyzed. The best sugar yield (370.9 g /kg) was obtained using direct sonication that performed better than mechanical stirring and indirect sonication processes. Besides, direct sonication decreased the treatment time, confirming that it is a promising technology for improving the yields of fermentable sugars from brewer’s spent grain (Luft et al. 2019).

A microwave-assisted hydrothermal pretreatment technology was similarly developed to recover fermentable sugars from brewer’s spent grain without acid or alkali catalysts. These sugars were fermented, yielding 46 kg of butanol per ton of brewer’s spent grain (López-Linares et al. 2019).

An integral valorization of brewers’ spent grains within the biorefinery framework relied on a microwave-assisted, hydrothermal process catalyzed by Ni-Co/Al-Mg. Using a temperature of 250 °C and a pressure of 125 bar for 2 h, it is possible to convert the original material into (i) 8% high-energy bio-oil made up a complex mixture of phenols, ketones, aldehydes, carboxylic acids, and nitrogen compounds with a higher heating value of 26 MJ/kg; (ii) 35% bio-char (spent solid) with a higher heating value of 32 MJ/kg; (iii) a saccharide-rich (31%) aqueous solution (Lorente et al. 2019).

Brewer's spent grain was used to generate a range of bioactive peptides with antioxidant activity via direct enzymatic hydrolysis without the prior use of an alkali protein extraction step (Connolly et al. 2019).

Supercritical fluid extraction was successfully used to extract oils from brewer's spent grain without and with ethanol as co-solvent in percentages, and this procedure was compared to the Soxhlet using hexane as solvent. The fatty acid composition, the yield, the recovery, and the antioxidant activity were similar, but supercritical carbon dioxide is obviously a greener procedure with no health hazard (Ferrentino et al. 2019).

Alternative use of spent brewer's yeast, which is both biologically and nutritionally rich, exploits its angiotensin converting enzyme inhibitory activity (ACE-I), after autolysis and subsequent hydrolysis via an extract of *Cynara cardunculus.* Nanofiltration produced a fraction with <3 kDa, stable in the gastrointestinal system and in vitro, exhibiting the highest inhibitory activity. This ingredient can be useful to deal with hypertension (Amorim et al. 2019).

Brewer's spent grain and yeast are not the only byproducts of the brewing process. In fact, brewery industries release about 70% of the production water as wastewater into water bodies. Brewery effluents contain huge amounts of organic compounds such as sugars, soluble starch, ethanol, volatile fatty acids, and nitrogen and phosphorous compounds; its discharge raises environmental concerns, including excessive growth of undesirable microbes that causes loss of aquatic lifeforms. Physical wastewater treatment to reduce suspended solids through sedimentation by gravitational force, chemical treatments such as pH adjustment or coagulation/flocculation and final aerobic (activated sludge) or anaerobic digestion are usually applied for the sake of environmental safety and to comply with strict regulations. Membrane filtration is considered environmentally friendly and safe. Nanofiltration can subtract COD, $Na^+$, and $Cl^-$ with an average removal rate of 100%, 55%, and 70%, respectively but fouling and high energy consumption are major challenges for this process. Microbial fuel cells (see Sect. 4.3.4) are able to convert organic pollutants into electricity, but this technology is still in its infancy. The microalgae wastewater treatment method is an emerging environmentally friendly biotechnological process to turn nutrient-rich wastewaters into useful biomass; this process is interesting for the $CO_2$ sequestration involved in biomass production. Microalgae such as *Chlorella* sp., *Scenedesmus dimorphus*, and *Scenedesmus obliquus* are actually able to absorb organic nutrients, and efficiently reduce the organic pollutants, but light and temperature are limiting factors of the process; removal of salt, odor and color is not efficient. The harvested algal biomass from the wastewater may be processed into plant fertilizers, animal feed, or biofuel production (Amenorfenyo et al. 2019).

*Aspergillus niger* NRRL-567 was used to ferment several food industry wastes, including brewery spent liquid, lactoserum, and starch industry water sludge to produced citric acid. The production was optimized by manipulating several parameters, such as temperature (25–35 °C), pH (3–5), presence of inducers, incubation time, and supplementation with different proportions of apple pomace ultrafiltration sludge (Dhillon et al. 2012).

Target compounds that can be extracted from brewery waste are outlined in Table 2.3.

## 2.5 Olive Oil and Edible Oil Industry

Virgin olive oil is valuable vegetable oil, extracted from olive fruits (*Olea europaea* L.) by mechanical and other physical methods since ancient times. This agroindustrial activity is of crucial economic significance for many Mediterranean countries (Cecchi et al. 2010a, 2011). Nowadays, it is well-known that regular dietary consumption of virgin olive oil manifests in health benefits associated with a Mediterranean diet (Cecchi and Alfei 2013).

Olive oil production results in the generation of large quantities of solid wastes (Lozano-Sánchez et al. 2011) and wastewaters (Federici et al. 2009; Cardinali et al. 2012; Bertin et al. 2011) rich in antioxidant phenolic compounds (Cecchi et al. 2010b) (phenolic acids and alcohols, secoiridoids, lignans, and flavones) with a great nutraceutical and pharmaceutical interest (Cecchi et al. 2011; Ghanbari et al. 2012). The traditional release of effluents from the oil processing industry into the soil and groundwater results in oily film formation on the aquatic surface that endangers aquatic animals and may block sewage and drains due to emulsification of organic matter (Okino-Delgado et al. 2017).

Waste valorization from olive industry processing regards the recovery of bioactive compounds from wastewaters and the reduction of water pollution problems. To exploit the potential of olive mill wastewaters, Federici et al. (2009) evaluated various challenging technologies for extraction of fine chemicals and for different biotechnological applications such as the production of important metabolites; technology costs are the major concern for these procedures. Again, antioxidants are the main target compounds in olive mill wastewater with many promising applications in foods, cosmetics, and pharmaceuticals. Among them, oleuropein and hydroxytyrosol (Bouaziz et al. 2008) are the most exhaustively studied due to their presence in all olive byproducts and their outstanding biological activities. Cardinali et al. used a membrane technology coupled to low-pressure gel filtration chromatography and focused on polyphenols recovery and structural characterization (Cardinali et al. 2012). For the same purpose, Bertin et al. (2011) applied a solid-phase extraction procedure.

A biotechnological degradation of the organic matter from oil industry effluents or kitchen waste oil with the concomitant production of high value-added bio-based microbial biosurfactants can be an attractive valorization alternative. For example, *Pseudomonas aeruginosa* synthesized biosurfactants such as rhamnolipids and glycolipids using lipase (Chen et al. 2018), (Henkel et al. 2012). Edible oil industry waste was reported to be a cheap source for bioactives such as tocopherols, sterols, and squalene which represents important target compounds of the pharmaceutical and cosmetics industry (Sherazi et al. 2016). Solid byproducts include olive mill pomace or olive press cake containing fragments of skin, pulp, pieces of kernels, and some oil. The oil industry annually produces about 350.9 million tonnes of the de-oiled cake; they are a good source of protein and they are commonly further utilized for preparing animal feed and fertilizer (Chang et al. 2018). Their water and methanol/water derived extracts are reported to have antioxidant and breast cancer antiproliferative activities due to the phenolic compounds (hydroxytyrosol in particular) and can be useful for nutraceutical applications, as food supplements (Ramos et al. 2013). Polar lipids able to protect against cardiovascular diseases were extracted, fractionated, and tested for their bioactivity; the presence of platelet-activating factor antagonists in the polar lipid extract from olive oil waste makes it a value-added materials for the functional food industry (Karantonis et al. 2008).

Accelerated solvent extraction of polyphenols from the solid residue of olive cake could be proposed as a simple and rapid extraction procedure (Suárez et al. 2009); the phenolic extract characterized by a strong antioxidant activity is a putative natural antioxidant also for the development of supplemented olive oil. Convective dehydration of olive cakes resulted in a dried olive cake that could be upcycled in many food and cosmetic applications or animal feed (Uribe et al. 2013).

Along with polyphenols and polar lipids, there are other important target compounds, including carbohydrates, proteins, fatty acids, polyalcohols, and pigments. A hydrothermal treatment and an autohydrolysis of the olive cake, gave a water-soluble fraction comprising monosaccharides, oligosaccharides, and mannitol (Fernández-Bolaños et al. 2004).

Application of olive cake to soil was proposed as a simple disposal strategy due to its high content in organic matter, able to adsorb triazine herbicides and to reduce desorption of the most hydrophobic terbuthylazine and prometryn (Delgado-Moreno et al. 2007). Actually, olive mill wastes could be used as a source of carbon for soil carbon sequestration strategy (Sánchez-Monedero et al. 2008).

Waste cooking oil is the residue of the deep fat frying process, and it is unsuitable for human consumption due to the formation of polar compounds like free short-chain fatty acids, mono- and di-glycerides, aldehydes, ketones, polymers, cyclic and aromatic compounds; cooking oil wastes were bioremediated using lipases extracted from orange wastes through transesterification reactions that decreased the toxicity of the waste cooking oil (Okino-Delgado et al. 2017).

Olive oil wastewaters were also used for xanthan gum production (see Sect. 5.1.4) using the plant pathogen using *Xanthomonas campestris* (Murad et al. 2019).

Target compounds that can be extracted from oil crops waste are outlined in Table 2.4.

**Table 2.4** Oil crops waste: specific source and target molecules for recovery

| Source | Target compound | References |
|---|---|---|
| Sunflower seed | Phytosterols | Galanakis (2012) |
| Sunflower | Proteins and chlorogenic acid<br>Polyphenols and flavonoids | Albe Slabi et al. (2020)<br>Rodríguez et al. (2019)<br>Daraee et al. (2019) |
| Rapeseed meal | Isothiocyanate and Glucosinolates | Ishikawa et al. (2014) |
| Rapeseed oil waste | Phytosterols and tocopherols | Jafarian Asl et al. (2020) |
| Soybean seed | Phytosterols | Galanakis (2012) |
| Soybean oil waste | Phytosterols | Galanakis (2012) |
| Olive mill waste and wastewater, olive pomace | Phenols, pectin, substrate for biosurfactants (rhamnolipids and glycolipids), and biodiesel production, tocopherols, sterols, squalene, and single cell protein, phenolic acids (ferulic, cinnamic, gallic etc.) and alcohols, secoiridoids, lignans, and flavones, oleuropein and hydroxytyrosol, xanthan gum | Galanakis (2012), Ravindran and Jaiswal (2016), Kiran et al. (2014), Henkel et al. (2012), Ghanbari et al. (2012), Suárez et al. (2009), Bouaziz et al. (2008), Federici et al. (2009), Bouaziz et al. (2008), Murad et al. (2019), Cassano et al. (2013), Rahmanian et al. (2014), Crea (2002), Caballero et al. (2020), Di Mauro et al. (1999) and Ferri et al. (2011). |
| Olives processing byproducts | Phenolic compounds, polyphenols, carotenoids, phytosterols, squalene, and dietary fiber | Schieber (2017), Karantonis et al. (2008), Suárez et al. (2009), Cardinali et al. (2012) and Bertin et al. (2011) |
| Winter oil seed rape waste | Phytosterol | Ravindran and Jaiswal (2016) |
| Sesame cake | Antioxidants, phenolics, flavonoid and flavonol | Mohdaly et al. (2010) and Sarkis et al. (2014) |

## 2.6 Meat Products

Globally, meat consumption has been continuously increasing, and the meat processing industry is a huge segment of the food industry chain system. Animal originated wastes are rich in proteins that are too valuable to be discharged into the environment.

Meat industry discards large quantities of slaughterhouse byproducts, such as blood, entrails, and some muscles (widely consumed in the past due to poverty needs) and non-edible parts such as skin, bones, deboning residues, tendons, skull, hooves, feathers, and detergent residues.

Nearly 40% and 20% of the slaughtered carcass are made of edible and inedible byproducts, respectively (Bhaskar et al. 2007). The former can obviously be used as human food or animal feed (Toldrá et al. 2012).

Due to microbiological hazard, the recovery of meat industry byproducts is bound by severe hygiene limitations. For example, the European Union promulgated legislative measures in order to avoid the spread of the bovine spongiform encephalopathy (BSE) (Regulation 999/2001and 853/2004). In this respect, combustion of bone byproducts (Deydier et al. 2005) is a safe procedure that produces residues rich in calcium (30.7%) and phosphate (56.3%), with significant levels of sodium (2.7%), potassium (2.5%) and magnesium (0.8%), and with no heavy metal content. Almost 90% of ash particles are smaller than 1 mm.

Anyhow the recovery of protein from meat byproducts is the focus of interest of many studies.

Selmane et al. investigated the operating conditions of the extraction, purification, and concentration of proteins from meat byproducts in order to maximize their recovery (ca. 50%) and to enhance their functional properties, namely gelling, emulsifying, and foaming properties if used as food ingredients (Selmane et al. 2008).

Rendering industries are the oldest recycling industries; they convert waste animal tissue into stable bone meal, hydrolyzed feather meal, blood meal, fish meal, and purified animal fats (lard and tallow) (Yaakob et al. 2019).

Poultry slaughterhouse waste mixed with molasses were fermented to eliminate pathogens and to produce lactic acid bacteria that can be used as probiotics (Ashayerizadeh et al. 2017). Chicken slaughterhouse wastewater was used for green algae (*Scenedesmus* sp.) biomass generation to be used as fish feed (Yaakob et al. 2019). Apart from food applications such as blood sausage, blood cake, blood pudding, and blood curd, blood can also be used as a fertilizer or a binder (Adhikari et al. 2018).

The use of a fungal protease for the enzymatic treatment of sheep visceral mass (including stomach, large and small intestines) resulted in a protein hydrolysate rich in some of the essential amino acids that can be used as a flavor enhancer, functional ingredient in foods of low protein quality (Bhaskar et al. 2007). Tahergorabi et al. used isoelectric solubilization/precipitation to recover functional proteins, useful for novel food preparations, from chicken meat processing byproducts. The authors recommended the addition of $TiO_2$ during the extraction process to increase the gel strength (Tahergorabi et al. 2012).

Krasnoshtanova developed methods for increasing the efficiency of enzymatic hydrolysis of meat byproducts. A kinetic models of the processes enabled the determination of the optimal conditions ensuring a degree of substrate conversion of at least 95%; the presence of alkyl hydroxy benzenes improved the efficiency of enzymatic processes. Increased temperatures (55–65 °C) made it superfluous to maintain aseptic conditions (Krasnoshtanova 2010).

Gomez-Guillen et al. focused on collagen and gelatin extraction from non-mammalian species (fish and poultry). They can be easily be upcycled as emulsifiers, foaming agents, and colloid stabilizers (Gomez-Guillen et al. 2011).

Cellulosic spent casing from frankfurter/sausage production was found to be an excellent source of cellulose that can be hydrolyzed into simple sugars or used as a substrate for the production of cellulase (Cumba and Bellmer 2005).

Target compounds that can be extracted from meat waste are outlined in Table 2.5.

**Table 2.5** Animal food waste origin, specific source and target molecules for recovery

| Origin | Source | Target compound | References |
|---|---|---|---|
| Meat | Chicken byproducts | Protein | Galanakis (2012), Ravindran and Jaiswal (2016), Tahergorabi et al. (2012) and Gomez-Guillen et al. (2011) |
| | Slaughterhouse byproducts | Protein, bone meal, hydrolyzed feather meal, blood meal, animal fats (lard and tallow); substrate for lactic acid bacteria and biomass generation as fish feed | Galanakis (2012), Ravindran and Jaiswal (2016), Selmane et al. (2008), Yaakob et al. (2019), Ashayerizadeh et al. (2017) and Yaakob et al. (2019). |
| | Bovine blood | Protein | Galanakis (2012) |
| | Beef lung | Protein | Galanakis (2012) |
| | Sheep visceral mass | Protein hydrolisate | Galanakis (2012) and Bhaskar et al. (2007) |
| | Bone byproducts | Calcium, phosphate, sodium, potassium, magnesium, with no heavy metal content | Deydier et al. (2005) |
| Fish and seafood | Fish leftovers (skin, head, bones) | Protein, lipids, gelatin, chitosan, glycosaminoglycans | Galanakis (2012), Ravindran and Jaiswal (2016), Gehring et al. (2011), Aspevik et al. (2017), Gomez-Guillen et al. (2011), Sousa et al. (2017), and Prameela et al. (2017) |
| | Shrimp and crab shells | Chitosan, chitin, chitinase, glycosaminoglycans; astaxanthin, calcium carbonate | Galanakis (2012), Ravindran and Jaiswal (2016), Kiran et al. (2014), Yan and Chen (2015), Prameela et al. (2017), Kumar et al. (2018), and Valcarcel et al. (2017) |
| | Lobster | Chitin | Yan and Chen (2015) |
| | Surimi wastewater | Proteins | Galanakis (2012) |
| | Sea products waste | Lipids and pigments from algae, and oils from fish-processing plant waste streams | Kerton et al. (2013) |
| | Tuna by-product hydrolysate | Antioxidant bioactive peptides. | Saidi et al. (2018) |
| | Fish cartilage | Chondroitin sulfate | Kim et al. (2012), Gargiulo et al. (2009), and Murado et al. (2010). |

(continued)

**Table 2.5** (continued)

| Origin | Source | Target compound | References |
|---|---|---|---|
| Dairy products | Whey | Lactose, whey protein concentrate and isolate, β-lactoglobulin, α-lactalbumin, probiotics, antibacterials, immunoglobulins, whey peptides, whey permeate, fermentation products, single cell protein, and probiotics, xanthan gum, bioactive peptides. | Smithers (2008), Yadav et al. (2015), Cheirsilp and Radchabut (2011), Nguyen et al. (2003), Santos et al. (2019), Borad et al. (2019) Yadav et al. (2015), Barba et al. (2001), Pereira et al. (2002), Cheirsilp and Radchabut (2011), Minhalma et al. (2007), Nguyen et al. (2003), Jeantet et al. (2000), Rektor and Vatai (2004), Kelly et al. (2000), DeSilva et al. (2003), Borad et al. (2019), Alonso et al. (2010), Maragkoudakis et al. (2010), Koutinas et al. (2009), Murad et al. (2019), Patel and Murthy (2010), Sánchez-García et al. (2018), and Monti et al. (2018) |
| | Milk | Biodiesel, ethanol, whey protein, Lactose, baker's yeast, and minerals | Parashar et al. (2016), Matharu et al. (2016), and Kiran et al. (2014) |
| | Dairy wastes and wastewaters | Lactose, proteins, peptides, salts, fatty substances, and cleaning chemicals | Kosseva (2011). |

## 2.7 Fishery

Fishery supplies around 20% of the world's food to humans. The utilizable mass of marine animal is unfortunately quite low: for example crabs only yield 40% meat, and in tuna fish only 75% of the fillet is available (Sharma et al. 2020).

Processing of fish and seafood results in appreciable amounts of wastes (i.e., 9–15% and 6–8% of marine catches in industrialized and developing countries, respectively) rich in proteins and lipids from fish skin, head frames, and viscera (Gehring et al. 2011). After industrial filleting, fish processing byproducts are *ca.* 60–70% of the total fish weight (Tahergorabi and Jaczynski 2014).

These residuals contain potentially bioactive compounds, which can be made use of as food or feed. Optimal utilization of proteins in such residual raw materials makes use of advanced technologies such as freezing/cooling, acid preservation, salting, rendering and protein hydrolysis (Aspevik et al. 2017).

Upcycling fish byproducts is a crucial practice for marine resources conservation. Different added-value products can be recovered, thereby avoiding the costs associated with the management of wastes.

Strict legislation regulates the upcycling of various animal-based residuals Fish skins constitute an important fraction of the huge amount of fish byproducts. Fish skins can be valorized through the extraction of gelatins. The gel-forming properties of gelatins are profitably used in food, photographic, cosmetic, and pharmaceutical applications. Gelatins are gummy when moist; hence they are natural biodegradable emulsifiers, foaming agents, and colloid stabilizers. Gelatins are also endowed with diverse antimicrobial, antioxidant or antihypertensive activities (Gomez-Guillen et al. 2011).

Extraction of gelatin from fish skin can be optimized manipulating the extraction parameters, such as reagents concentration, water consumption, and time of processing, while maintaining the highest extraction yield. Characterization of the chemical composition, rheology, structure, texture, and molecular weight, enable the introduction in the market of gelatins with unique properties for specific applications (Sousa et al. 2017).

A strictly pharmaceutical compound (i.e., chondroitin sulfate) used for osteoarthritis, can be recovered from scapular cartilage of Shortfin mako shark (Kim et al. 2012), waste of *Scyliorhinus canicula*, (Gargiulo et al. 2009), and skate cartilage (Murado et al. 2010).

Shells of aquatic animals such as shrimps, lobsters, crabs, prawns, fish scales, and endoskeletons harbor useful chemicals such as protein, chitin, and calcium carbonate. Crustaceans are a large, diverse arthropod taxon. Their processing results in important byproducts; seafood waste is chitinaceous in nature. Actually, the shell of crabs, lobsters, shrimps, and prawns all contain chitin from which chitosan can be extracted (Galanakis 2012; Ravindran and Jaiswal 2016; Kiran et al. 2014; Yan and Chen 2015; Prameela et al. 2017; Kumar et al. 2018). Chitin is insoluble in water and inert to most chemical agents; hence its common disposal (ocean dumping, incineration, landfilling) leads to environmental pollution, eutrophication, and biofouling. Its recovery would eradicate the environmental issue along with revenue generation (Yan and Chen 2015; Kumar et al. 2018). Dried shrimps and crabs contain about 50% of chitin on a dried basis (Yan and Chen 2015), and even if it can be used as an animal feed supplement, bait, or fertilizer, it is the main source of chitosan, an important biopolymer which exhibits antibacterial activity against *Enterococcus faecalis*, *Escherichia coli*, *Staphylococcus aureus*, and *Candida albicans* (Hussein et al. 2013). The importance of chitosan will be clearly detailed in Sect. 5.9. Seafood waste is also a potential source for functional and bioactive compounds: for example, glycosaminoglycans extracted from marine animal waste are better than those obtained from terrestrial organisms (Valcarcel et al. 2017); shrimp waste was used to produce nutraceutical compound such as astaxanthin (3,3′-dihydroxy-ß-carotene-4,4′-Dione), a xanthophyll carotenoid present in crustacean waste that was extracted through oxidative transformations of ingested β-carotene or zeaxanthin by feed microalgae (Prameela et al. 2017).

Target compounds that can be extracted from fish waste are outlined in Table 2.5.

## 2.8 Dairy Products

The dairy industry is an important food industry sector; dairy waste is derived from the processing industry, microbial spoilage of the dairy products, and inappropriate storage or handling. Dairy wastes and wastewaters are a significant source of lactose, proteins, peptides, salts, fatty substances, and cleaning chemicals used for maintaining proper hygiene during processing (Kosseva 2011). During the processing of raw milk, up to 3.0 L of wastewater are generated per liter of processed milk; the high content of the nutrients poses serious environmental concerns and demands wastewater conversion methods such as activated sludge, sequencing batch reactor, trickling filter, anaerobic sludge blanket, and aerated lagoons (Sharma et al. 2020).

Cheese whey was discovered about 3000 years ago when calves' stomachs were used as milk containers, and the naturally occurring enzyme chymosin (rennet) coagulated the milk and spawned the start of the cheese-making activity. The manufacturing of cheese generates 9 kg of whey per kg of cheese produced (Parashar et al. 2016).

After milk is coagulated during cheese production when pH is dropped to 4.6, 50% of the milk total solids remain in the whey; interestingly, all the lactose (ca. 5%, w/v) and all the typical whey protein (ca. 0.7% w/v) such as β-lactoglobulin, α-lactalbumin, glycomacropeptide, minor protein/peptide components including immunoglobulins, lactoferrin (a whey globular glycoprotein of the immune system, involved in the binding and transport of iron ions, with strong antibacterial, antiviral, antiparasitic, anticancer, and anti-allergic functions, with bone growth enhancement properties), lactoperoxidase (a whey enzyme that catalyzes the oxidation of substrates by hydrogen peroxide, endowed with natural antibacterial activity), serum albumin, lysozyme, and growth factors can be found in whey since they are not involved in curd formation. Whey also include 1.0% (w/v) salts, and 0.1%±0.8% (w/v) lactic acid (Lee et al. 2000). Whey proteins are the most important target compounds in whey because of their exceptional biological value (15% better than egg protein). This means that the body can well and quickly exploit this kind of proteins; for this reason, whey protein is the protein of choice for bodybuilders, athletes, and debilitated people. Whey proteins are a rich source of the essential and branched amino acids that represent metabolic regulators in protein, glucose and lipid metabolism, thereby playing a role in weight control (Smilowitz et al. 2005). Whey proteins are also a balanced source of the sulfur amino acids (methionine, cysteine), precursors to the potent intracellular antioxidant glutathione (Shoveller et al. 2005). By this scenario, nowadays, the bioactivity of whey is receiving considerable scientific scrutiny around the world even if whey medicinal applications during the seventeenth and eighteenth centuries were already well renowned (Smithers 2008).

Many recent studies established a sound basis for its nutritional and functional value and this underpinning knowledge paved the way to technology developments for its valorization. It was found that the bioactivity of whey also includes (i) physical fitness, (ii) satiety and weight control, (iii) cardiovascular health, (iv) anticancer activity on in vitro cell culture, in vivo animal studies, and some epidemiological investigations (v) growth factor activity and wound healing (vi) antimicrobial effects of lactoferrin for the management of infections and for enhancing the safety of meat (vii) infant nutrition (viii) potent bone growth enhancement properties of lactoferrin for the prevention and treatment of osteoporosis (ix) antimicrobial effects of lactoperoxidase again oral infection and halitosis (Smithers 2008).

Historically, the first management method of the dairy activity was whey disposal via its spraying onto fields, although the smell and salt content were major problems. Discharging the whey into rivers, lakes, sea, or municipal sewage system was also exploited; however environmental concerns progressively restricted and banned this disposal approach. Actually, whey emission into river systems is an environmental hazard due to its high organic content (Biochemical oxygen demand (BOD) >35,000 ppm; chemical oxygen demand (COD) >60,000 ppm) (Smithers 2008).

Transformation of whey from a nuisance into a valuable dairy raw material and valuable feedstock has been facilitated by environmental considerations and legislative restrictions on whey disposal, knowledge about target bioactive compounds in whey, and technology advances in whey-processing technologies (concentration, transformation, fractionation, and dehydration of whey, and modern biochemical techniques).

Whey was also used for xanthan gum production (see Sect. 5.1.4) using the plant pathogen using *Xanthomonas campestris* (Murad et al. 2019).

Whey can be simply concentrated and dried as whey powder, or it can be used as substrate for ethanol production; technological advancements have enhanced whey utilization up to 50% of the total produced whey to produce lactose, whey protein, whey permeate, but also fermentation products such as bioethanol, hydrogen, methane, whey peptides, and probiotics (Yadav et al. 2015). The recovery of protein and lactose is of utmost importance: no whey utilization strategy is feasible without suitable attention being paid to lactose, which represents more than 75% of whey solids. Whey proteins, containing all 20 amino acids, are widely used to prepare drinks and bars, which are the most popular dietary supplements for athletes; anyhow, whey-based ingredients successfully compete for a share of the burgeoning functional foods market. There are two types of whey protein useful for dietary supplements: whey concentrate and whey isolate. The latter undergoes more processing, which results in higher protein content with fewer carbohydrates, lactose, and fat.

The processes and techniques for the full valorization of target compounds from whey will be described in Chap. 4, they include microfiltration, ultrafiltration, nanofiltration, reverse osmosis, electrodialysis, and ion exchange, anyhow we will detail in the following whey target compounds.

Microfiltration of whey (to remove fat, bacteria, and residual casein micelles) is the first step of the process.

Whey protein concentrates (up to 80% protein) are then obtained by ultrafiltration, a membrane technique that lowers the fat and lactose content and limits protein denaturation (Barba et al. 2001). Pereira et al. valorized ovine cheese whey, by means of a thermo-calcic precipitation and microfiltration before ultrafiltration. The clarification step improved the next ultrafiltration treatments. The chemical composition of retentate powders was comparable to that of conventional ultrafiltration powders (Pereira et al. 2002).

The membrane ultrapermeate usually contains lactose, salts, nonprotein nitrogen, and water. If it is subsequently nanofiltrated, lactose can be recovered because it is retained by the nanomembrane, while salts and water constitute the permeate. The salt depleted lactose concentrate can be used as a raw material in the pharmaceutical, food, and paper industries; it is a lowcost carbon source for the biotechnological production of kefiran, a water-soluble exopolysaccharide that comprises equal amounts of glucose and galactose, by *Lactobacillus kefiranofaciens* (Cheirsilp and Radchabut 2011). The valorization of this dairy sugar may involve the use of crystallization, fermentation, hydrolysis, and transformation (into various valuable derivatives).

The salt-enriched permeate from nanofiltration, almost free from organic matter, could be reused in the process: nanofiltration, using the optimal operating conditions, could therefore minimize the wastewater environmental impact with a maximum water recovery of approximately 80% (Minhalma et al. 2007).

Nguyen et al. used nanofiltration to obtain a four-fold concentration of solids from cottage cheese whey, while removing about three-quarters of the sodium and potassium salts and some acids. The desalted nanoconcentrate could be considered an ingredient in dairy and other food products (Nguyen et al. 2003). Anyhow, other techniques such as electrodialysis and chromatography are also used for demineralisation of whey and separation of whey protein from the abundant lactose and residual fat (Jeantet et al. 2000; Rektor and Vatai 2004) to produce functional whey ingredients for athletes and debilitated people.

At variance with whey protein concentrate, whey protein isolate contains up to 90% protein without fat and lactose (Kelly et al. 2000); it can be obtained by ionic exchange chromatography that is able to selectivity adsorb and subsequently desorb proteins even if it might trigger their denaturation.

Given the high value of specific proteins, it would be highly desirable to fractionate whey proteins.

Procedures usually based on selective ion exchange have been developed for selective manufacture of β-lactoglobulin and α-lactalbumin isolates via precipitation of α-lactalbumin from sweet whey concentrated by ultrafiltration, under specified conditions of pH and temperature, leaving β-lactoglobulin in solution and unaffected by the pH/temperature treatment (Smithers 2008). Alternatively, fractionation can be obtained via liquid chromatography as well as continuous chromatographic separation technology and ultra-high pressure processing aiming at maintaining the functional and nutritional traits of the wide array of whey bioactive compounds (DeSilva et al. 2003).

Apart from the major whey proteins (β-lactoglobulin, α-lactalbumin, and glycomacropeptide) whey contains a number of minor proteins. Among them immunoglobulins represent the most abundant. Colostrum is a precious ingredient for the manufacture of immunoglobulin-enriched milk products that are gaining significance in the global nutraceutical market as dietary supplements. These immunoglobulin-rich isolates might be important because they contain an abundance of immune components that can be exploited to address the poor immune status of immuno-compromised people and enhance gut health. High-pressure processing enables the preservation of the colostrum immunoglobulins (Borad et al. 2019).

Whey peptides have additional and often varied bioactivity compared to that of the parent molecule (Herrera-Ponce et al. 2019). A number of these bioactive whey peptides, together with the parent protein source, have been the focus of interest of in vitro and in vivo studies to investigate their positive influence on cardiovascular, endocrine, and immune systems. Desolvation and internal gelation have been so far employed for bioactive peptides particulation (Yadav et al. 2015). Commercially, the most promising of these peptides is the potent antimicrobial lactoferricin and closely related peptides, derived by peptic or chymosin digestion of lactoferrin (Herrera-Ponce et al. 2019).

Engineering developments have led to a number of innovations and improvements in the drying of whey, whey concentrates, isolate, and permeates: spray drying, freeze-drying, and filtermat drying have different advantages and disadvantages (Písecký 2005), and also influence on the organoleptic outcomes (Vincenzetti et al. 2018).

Lactic acid is widely used in food and pharmaceutical sectors and recently for biopolymers production, as illustrated in Chap. 6. To obtain lactic acid from whey, Vasala et al. (2005) used *Lactobacillus salivarius,* an ideal microorganism for lactic acid fermentation in high-salt high lactose conditions, typical of whey. Yoghurt whey from expired products could be used for lactic acid production by *Lactobacillus casei* (Alonso et al. 2010).

Raw whey permeate can serve as a natural sanitizing agent in the washing of vegetables (Martin-Diana et al. 2006). The possibility to obtain lactic acid from whey fermentation led to the production of a whey-based food disinfectant. A scalable fermentation protocol to produce a disinfectant, with the highest lactic acid concentration and the lowest lactose levels, made use of a specific mesophilic-lactic acid bacteria starter mix over 120 h. Antibacterial activity against food pathogenic and spoilage strains was successfully tested. This fermented whey represents an effective and environmentally-safe alternative to the use of chlorine as a disinfectant for shredded lettuce on the basis of microbial quality and other quality indicators such as texture, color, and sensory perception, pH, $O_2$ and $CO_2$ determinations (Santos et al. 2019).

Whey permeate, obtained from ultrafiltration, containing lactose, salts, nonprotein nitrogen, and water, is a dairy effluent usually dealt with via land spreading or incorporation into animal feed. It was recently demonstrated that it could be hydrolyzed using enzymes to release fermentable sugars and then integrated into wheat fermentation as a co-substrate or to partially replace process water for ethanol production using *Saccharomyces cerevisiae* (Parashar et al. 2016).

Edible filamentous fungi such as *Aspergillus oryzae* and *Neurospora intermedia,* were profitably used to enzymatically convert dairy waste into high-quality biomass for animal feed or human consumption, and chemicals, such as ethanol and glycerol (Mahboubi et al. 2017).

Whey was also used for the production of probiotics. The whey by-product from Ricotta cheese manufacturing, called “Scotta” presented favorable characteristics as a potential growth substrate for the production of a probiotic fermented drink (Maragkoudakis et al. 2010). The manufacture of novel dairy starter cultures for better cheese ripening and extended shelf life, using whey as raw material, was also proposed. The developed technology involved biomass production from whey followed by thermal drying of cultures. Authors found that the most suitable culture in lactose and milk whey fermentation was kefir due to its technological properties (Koutinas et al. 2009).

Target compounds that can be extracted from dairy waste are outlined in Table 2.5.

## 2.9 Kitchen Waste

Kitchen waste from public catering rooms, restaurants, households, and canteens broadly consists of fruits, vegetables, staple food, shells, bones, pits, and meat (Zhao et al. 2017). It is compostable. It contains high organic matter and particularly carbohydrates (cellulose, hemicellulose, pectin and starch), protein, lignin, fats, organic acids, inorganic salts, and others (Chen et al. 2017). Traditional disposal of kitchen waste such as land-filling, incineration, and direct or indirect discharge into the environment is detrimental to the ecosystem and human health (Sharma et al. 2020). The high moisture content and a pool of nutrients facilitate the growth of pathogens, rotting, breeding of flies, emission of toxic volatiles, including ammonia and greenhouse gases.

Interestingly, kitchen waste could be used as a substrate to generate of a huge array of value-added products. Xanthan gum was produced via chemical and enzymatic treatments of kitchen waste (Li et al. 2017); volatile fatty acids were obtained using anaerobic fermentation, using activated sludge to inoculate FW (Wang et al. 2014); short-chain fatty acids were similarly obtained by co-fermentation of kitchen waste with waste activated sludge under alkaline conditions and the fermentation liquid was successfully used in microbial fuel cells (Chen et al. 2013) described in Sect. 4.3.4; kitchen waste was investigated as a nutrient resource for L(+)-lactic acid production by *Lactobacillus manihotivorans* LMG18011 (Ohkouchi and Inoue 2006), and for cellulase manufacture via *Aspergillus niger* in solid-state fermentation (Bansal et al. 2012); glucoamylase is another interesting target compound in kitchen waste valorization, it was produced by *Aspergillus niger* UV-60 under submerged fermentation (Wang et al. 2008).

Carbohydrate from kitchen waste after mild acid pretreatment of hydrochloric acid and glucoamylase gave fermentable sugars (93.25g/L glucose, 0.542g/L sucrose, 0.348g/L maltose, and 0.321g/L fructose) as the feedstock for bioethanol production (Hafid et al. 2015). Ethanol production from kitchen waste was studied using successive liquefaction, pre-saccharification, and simultaneous saccharification and fermentation (Nishimura et al. 2017), while biobutanol is the product of enzymatic hydrolysis and *Clostridium acetobutylicum* fermentation of kitchen waste (Chen et al. 2017); methane and hydrogen can also be obtained by anaerobic fermentation (Campuzano and González-Martínez 2016; Parthiba Karthikeyan et al. 2018).

*Bacillus agaradhaerens* C9 degrading enzymes (amylase, protease, lipase, cellulase, xylanase, and pectinase) promoted the hydrolysis of kitchen waste and strong alkaline fermentation conditions induced the production of an environment-friendly and biodegradable macromolecular bioflocculant, using unsterilized kitchen waste. The bioflocculant was characterized by a high flocculation efficiency, and it was applied to treat mineral mining processing wastewater comprising heavy metal ions, thereby enabling its recycling (Liu et al. 2019).

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