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Review

Current options for the valorization of food manufacturing waste: a review

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ABSTRACT

The production of food waste covers all the food life cycle: from agriculture, up to industrial manufacturing and processing, retail and household consumption. In developed countries, 42% of food waste is produced by households, while 39% losses occur in the food manufacturing industry, 14% in food service sector and remaining 5% in retail and distribution. Increasingly, industrial ecology concepts such as cradle to cradle and circular economy are considered leading principle for eco-innovation, aiming at "zero waste economy" in which waste are used as raw material for new products and applications. The large amount of waste produced by the food industry, in addition to being a great loss of valuable materials, also raises serious management problems, both from the economic and environmental point of view. Many of these residues, however, have the potential to be reused into other production systems, trough e.g. biorefineries. The present work focuses on the use of food waste coming from food manufacturing (FWm). Through extensive literature review, the authors present feasibility and constraints of applying industrial symbiosis in recovering waste from food processing, focusing on recycling (excluding energy recovery) of the solid and liquid waste from food processing industry. The main uses of functional ingredients derived from this transformation are presented and discussed, highlighting mainstream sectors of application, e.g. in the nutraceutical and pharmaceutical industry.

1. Introduction

In the era of paradoxes, about 15% of population in developing countries, is starving (FAO, 2012) whereas a growing number of countries is dealing with over-consumption of food, food related diseases and increasing food waste (hereinafter FW) production. FW is a topic of concern worldwide as substantial amount of food that should have been eaten ends up as waste along the food value chain. This represents not only a resource problem but also an environmental and economic one, on top of being a moral challenge for the modern society. Concerns related to food waste were brought to the scientific community since 90's (e.g. Kroyer, 1995).

The production of FW covers all the food life cycle: from agriculture phase, up to industrial manufacturing and processing, retail and household. Notwithstanding specific statistics on FW's quantity are quite difficult to be collected, the best available estimates (European Commission, 2010) account for a total food loss in the EU 27 of about 89Mt, or 179 kg per capita, in 2006. Up to 42% of food waste is produced by households, 39% losses occur in the food manufacturing industry, 14% pertains to food sector (ready to eat food, catering and restaurants), while 5% is lost along distribution chain (agricultural food loss is not included in this estimation). In addition, FW is expected to rise to about 126 Mt by 2020 if additional prevention policy or activities are not undertaken. In Italy, food wastes can be generated along several stages of supply chain: 3.3% of agri-food products (17 Mt/yr) and 2.6% (1,7 Mt/yr) of final products from food industry are discarded before selling, while the loss in food retailers amounts to 250.000 t/yr (of which 40% are fruits and vegetables) (Segré & Falasconi, 2011). This implies an increasing environmental burden due to associated resource consumption and pollutant emission. E.g., it has been estimating that for each ton of FW there is an emission of about 2 tons of CO_2 (European Commission, 2010).

In Europe, integrated product policy (EC, 2003), resource efficiency flagship initiative (EC, 2011) and the bio-economy communication (EC, 2012) are promoting the prevention of FW in all the life stages. Moreover, industrial ecology concepts such as cradle to cradle and circular economy have been considered leading principle for eco-innovation, aiming at "zero waste" society and economy where wastes are used as raw material for new products and

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applications. In fact, closed systems are the basis of so-called industrial symbiosis, in which the goal is to use wastes from one sector as an input for other sectors. The large amount of waste produced by the food industry, in addition to being a great loss of valuable materials, also raises serious management problems, both from the economic and environmental point of view. Many of these residues, however, have the potential to be reused into other production systems, trough e.g. bio-refineries.

There are several studies in the literature, which deal with the bio-refinery concept, i.e. with the use of biomass feedstock in substitution of fossil ones. Due to the well-known problem of land competition between food and biomass feedstock dedicated crops, a growing number of studies investigate specifically the use of residues as a secondary source of energy or raw material. Food industry (both agriculture and food processing sectors is considered a relevant sector for bio-refineries (Ghatak, 2011; B. Kamm and M. Kamm, 2004), especially due to the potential use of food industry residues (e.g. (Mahro and Timm, 2007). The first step for applying industrial symbiosis concept in the food processing sector is the identification, quantification and characterization of residues (Rosentrater, 2004). Afterwards, FW sources and high-added value ingredients should be classified, exploring the recovery stages, and the conventional and emerging technologies applied for processing them (Galanakis, 2012). The feasibility of industrial symbiosis relies also on regional specificity, namely the availability of FW producers and of potential users, as presented in the case of the food chain in Finland (Niutanen and Korhonen, 2003).

In order to systematize most recent research on the topic, the present study focus on the potential use of food waste coming from food manufacturing (hereinafter FWm). The aim of this study is twofold:

1. Reviewing the literature concerning the possible use of FWm for producing new products, reducing burden on virgin raw materials
2. Assessing main constraints and limitation in a large scale implementation of FWm reuse/recycling

The authors performed an extensive review of possible use of FWm in order to transform food waste in resource for production of new products, applying industrial ecology and eco-innovative approaches.

The study is organized as follows: in Section 2 the methods applied in the review are presented, whereas in Section 3 the selected studies are reported by food waste typology (plant based food waste, such as vegetables and fruit; animal base food waste, such as dairy products and meat and derivatives; and miscellaneous). In Section 4, the review results are discussed, providing the reader with a summary of the valuable compounds and products derivable from the reviewed studies. The main uses of functional ingredients derived from this transformation are presented and discussed, with a focus on mainstream sectors of application, e.g. in the nutraceutical and pharmaceutical industry.

2. Methods

The methodological approach for the literature review is briefly described.

Several keywords were chosen to obtain a large range of papers to be analyzed. The keywords selected were: food waste; industrial ecology food; byproducts food waste; byproducts food industry; food processing waste; meat processing byproduct; biorefinery food waste; meat waste byproduct; dairy waste byproduct. No geographical restrictions were applied, and the search was limited to papers published from 2000 to 2012. The keywords were introduced with boolean operator "AND" into the most important databases of scientific journals, such as Scopus, Cilea and SciDirect. Titles and abstracts from more than 1500 publications were screened and examined, and then relevant papers were selected based on a number of criteria and were used for this review.

The selection criteria chosen to identify the relevant articles were related to the objectives of this review. We selected studies: (1) focusing on target products related to the processing and preserving of fruit and vegetables, the dairy industry and the production of meat products and derivatives; (2) dealing with recycling (excluding energy recovery) of the solid and liquid waste from food processing industry; (3) providing suggestion for possible recoveries strategy; (4) addressing relevant commodities. In most of the articles analyzed the food waste is not used as it is, but only after a transformation that allows to extract active ingredients with high added value.

Papers coming from fifty scientific journals were finally selected, plus two conference proceedings and one PhD thesis, for a total number of 111 papers reviewed (Table 1). The journals mainly belong to food research, biotechnology, chemistry and waste management field. The 111 articles selected were classified into the following categories: fruits and vegetables; dairy products; meat and derivatives. Within the first category, the following subcategories were defined: apples; berries; citrus fruits; exotic fruits; potatoes; tomatoes; olives; other vegetables; and miscellaneous.

3. Food wastes from agro-industry and its potential recovery

3.1. Vegetable and fruits

Food industries produce large amount of vegetable and fruit waste. This affects municipal landfills because of FW high biodegradability, leachate and methane emissions (Misi and Forster, 2002).

These wastes from fruit-and vegetables processing generally contain large amounts of suspended solids (SS), and present high biochemical (BOD) and chemical oxygen demand (COD), which influence possible recovery solutions and costs treatment. According to UNIDO (2013), BOD range from 3.2 g/l for bakery products to 0.53 g/l for meat specialties, while COD range from 7 g/l to 0.9 g/l. Waste organic composition includes about 75% sugars and hemicellulose, 9% cellulose and 5% lignin (Kosseva, 2011). Wastes mainly consist of hydrocarbons and relatively small amounts of proteins and fat, with moisture content of 80–90%. Finally, the wastewaters contain dissolved compounds, pesticides, herbicides and cleaning chemicals (Kosseva, 2011).

3.1.1. Apples

Pomace and its extracts, the most important wastes of apples manufacturing industry, have a great potential for biotechnology industry. The waste generally refers to a heterogeneous mixture of peels, pomace and seed, with high content of water and insoluble carbohydrates, such as hemicellulose, 9% cellulose and 5% lignin. This waste is largely available, especially during harvesting season.

In large scale apple juice industry a large amount of wastes is produced, indeed about 75% of apple is utilized for juice and the remaining 25% is the by-product, apple pomace (Shalini and Gupta, 2010). Apple pomace is constituted by simple sugars (glucose, fructose, and sucrose) and is a rich source of carbohydrate, pectin, crude fiber, proteins, vitamins and minerals, and as such is a good source of nutrients, worth to be recovered. Furthermore, several microorganisms can use apple residues as a substrate for growth (Kosseva, 2011). Shalini and Gupta (2010) analyzed different uses of this by-product: i) fuel purposes; ii) food products; iii) pectin extraction; iv) cattle feed; v) biotransformation; vi) source of fibers;

Table 1
List of the journals selected and related articles reviewed.

Journal	No. papers
ACTA Biochimica Polonica	2
ACTA Scientiarum Polonorum Technologia Alimentaria	1
African Journal of Biotechnology	1
Animal Feed Science and Technology	1
Annals of the Faculty of Engineering Hunedoara – Journal of Engineering	1
Applied Biochemistry and Biotechnology	1
Biomass and bioenergy	1
Bioresource Technology	7
BioResources	1
Biotechnology Letters	1
Catalysis in Industry	1
Chemical Engineering Journal	1
Chemical Industry & Chemical Engineering Quarterly	1
Desalination	1
Electronic Journal of Environmental, Agricultural and Food Chemistry	1
Environmental Chemistry Letters	1
Enzyme and Microbial Technology	1
Food and Bioprocess Technology	2
Food and Bioproduct Processing	1
Food Chemistry	9
Food Hydrocolloids	2
Food Microbiology	1
Food Research International	1
Food Science and Technology Resource	1
HortScience	1
Industrial Crops and Products	1
Innovative Food Science and Emerging Technologies	4
International Dairy Journal	4
International Journal of Food Science and Technology	2
International Journal of Molecular Sciences	1
Journal of Agriculture and Food Chemistry	12
Journal of Animal Science	1
Journal of Applied Polymer Science	1
Journal of Biotechnology	2
Journal of Chemical Technology & Biotechnology	1
Journal of Cleaner Production	1
Journal of Environmental Management	3
Journal of Food Biochemistry	1
Journal of Food Composition and Analysis	1
Journal of Food Engineering	2
Journal of Food Microbiology	1
Journal of Food Processing and Preservation	1
Journal of Food Science	5
Journal of Food Science and Technology	1
Journal of Food, Agriculture & Environment	1
Journal of Hazardous Materials	1
Journal of Industrial Microbiology and Biotechnology	1
Journal of Polymers and the Environment	1
Journal of Reinforced Plastics and Composites	1
Journal of the Science of Food and Agriculture	1
LWT – Food Science and Technology	3
Meat Science	2
New Biotechnology	1
Resources, Conservation and Recycling	1
Science of the Total Environment	1
Trends in Biotechnology	1
Trends in Food Science & Technology	1
Waste Management	1
World Journal of Dairy & Food Sciences	1
Other	
Total Food 2004, Conference Proceedings, Institute of Food Research Norwich	1
PhD Thesis	1
Proceedings of the Waste Minimization and Resources Use Optimization Conference	1
Total	111

vii) miscellaneous use. Due to large quantity of produced apple pomace, the preparation of single product would not be economically feasible and production of alternative products should be explored.

Million pounds of waste apple peels are also generated in apples industry each year (Wolfe and Liu, 2003), with high costs of disposal and threat to the environment. Several studies focused on apple peel properties, due its high content of phenolic compounds and antioxidants. High concentrations of phenolic compounds in apple peels may support the prevention of chronic diseases, such as cardiovascular diseases and cancer. In their review, Wolfe and Liu (2003), stated that valuable food ingredient could be made using the waste peels, trough drying and grounding processes without large losses of phytochemicals. Rome Beauty apple peels were treated with citric acid dips, ascorbic acid dips, and blanches and dried under various conditions. On a fresh weight basis, the total phenolic and flavonoid contents of these samples were similar to those of the fresh apple peels. Results showed that the optimal processing conditions for the ingredient are blanching for 10s and freeze-drying. Apple peel powder ingredient developed could be a valuable and attractive addition to healthy food products, since a small amount could greatly increase the phytochemical content and antioxidant activity of foods.

Huber and Rupasinghe (2009) studied apple peels properties as natural antioxidants. Indeed, lipid oxidation, especially the oxidation of polyunsaturated fatty acids, is a significant issue in the food industry impacting both food quality and health of consumers and the use of apple skin is investigated to solve the problem. The authors evaluated the phenolic compound composition and antioxidant properties of 21 selected apple genotypes. The apple skin extracts, specifically the crab apple varieties such as “Dolgo,” were revealed to be effective inhibitors of oxidation of polyunsaturated fatty acid in a model system and thus could be considered to develop new natural food antioxidants.

Henríquez et al. (2010) developed an ingredient from Granny Smith apple peel, using a pilot scale double drum-dryer, as drying technology. All steps to maximize the retention of phenolic compounds and dietary fiber and operational conditions, such as drying temperature and time, were determined. Furthermore, they analyzed the physical–chemical characteristics, mineral and sugar content, and technological functional properties such as water retention capacity, solubility index, and dispersability among others. The obtained powder ingredient resulted to be suitable for use in food preparation and a source of phenolic compounds and dietary fiber.

3.1.2. Berries

Ribes, raspberries and blackberries are greatly used in food manufacturing, for juices, jams and jellies preparations, etc. Due to their high content of antioxidants, phenolic acids, flavonoids, polyphenols and fibers, as well as the high amount of wastes released during industry manufacturing, these by-products could be successfully recovered and for different industry purposes.

Bakowska-Barczak et al. (2009) evaluated the seeds from five black currant (*Ribes nigrum* L.) cultivars grown in western Canada for their oil content, fatty acid and triacylglycerol composition, and tocopherol and phytosterol profiles and contents. Moreover, they determined polyphenolic compounds and antioxidant activity in the seed extracts remaining after oil extraction. Canadian black currant seed oil was proven as a good source of essential fatty acids, tocopherols, and phytosterols. Extraction of phenolic antioxidants from the seed residues even allowed the recovery of additional valuable components.

Pap et al. (2004) focused on waste minimization and best eco-innovative practices in berry juice processing. The optimisation included the reduced utilization of raw materials, less energy and water use, while, as a result, less process waste and effluent was generated. Supercritical fluid extraction (SFE) with natural CO_2 was deemed the most promising technology for the recovery of valuable compounds in light of being the least expensive and more environmentally friendly solvent-free extraction method.

The functional properties and palatable taste makes berries adapt to be used also in sweets and snacks preparation, in order to obtain functional foods enriched by the valuable compounds of berries. For this purpose, Górecka et al. (2010) added raspberry pomace in a dried form as replacement of flour in cookies at the level 25 and 50%. The use of raspberry pomace in cookies resulted in fiber contents increase and the addition of raspberry pomace did not have negative influence on organoleptic characteristics of the product and was accepted by consumers.

3.1.3. Citrus fruits

In contrast with other types of fruits, citrus fruits have a small edible portion. Hence, large amounts of waste material, such as peels and seeds, are discarded during juice and food processing. Residues of citrus juice production are a source of several compounds, principally by water, soluble sugars, fiber, organic acids, amino acids and proteins, minerals, oils and lipids, and also contains flavonoids and vitamins (Fernández-López et al., 2004). Two types of citrus by-products (lemon albedo and orange dietary fiber powder), at different concentrations, were added to cooked and dry-cured sausages to increase their dietary fibers content (Fernández-López et al., 2004). Authors found promising results and potential applications to produce healthier products.

The orange juice wastewater generated in the process is an interesting source of citrus fiber too.

Viuda-Martos et al. (2011) characterized the physic-chemical and microbiological properties of the orange juice wastewater of a citrus by-product by determining the pH, soluble solids, color, reduction of residual nitrite and total antioxidant activity, along with the content of phenolic compounds, organic acids and sugars.

Crizel de Moraes et al. (2013) characterized orange juice fibers by-products to study their application as a fat replacer in ice cream. The authors analysed two different samples of orange fiber: F1 (peel, pulp and seeds) and F2 (peel). According to results, both samples showed high levels of total dietary fiber and an ideal ratio between soluble and insoluble fiber. The fibers showed a high water and oil retention capacity and a high content of phenolic compounds and carotenoids. Authors concluded that orange fiber proved to be a promising alternative as a fat replacer in ice cream since it led to a 70% reduction of fat without causing significant changes in products attributes such as color, odor and texture.

The residue of pigmented orange pulp wash was investigated to obtain a purified sugar concentrate applying a series of resin adsorptions and membrane techniques (Scordino et al., 2007). Final products and intermediates were characterized: anthocyanins, limonoids, flavanones and hydroxycinnamates were absent; ultrafiltration (UF) process stabilized the product by removal of enzymes and microorganisms; low acidity content was found. 80% of the water was eliminated by a reverse osmosis (RO) treatment, increasing the sugar concentration by four times. The final product (28 Brix) contained about 250 g/l of sugars (glucose, fructose and sucrose), 9 g/l of citric acid and 1 g/l of pectin. This concentrate was a transparent liquid of slight amber color with a very low microbial count and could easily find application as a natural sweetener in food and beverage industries.

Another interesting application of citrus fruits by-products is as cattle feed, especially for ruminants. The most important by-products that can be used are fresh or dried pulp, citrus silage, citrus meal and fines, citrus molasses, citrus peel liquor, and citrus activated sludge. Bampidis and Robinson (2006) characterized physical and nutrient composition, digestibility, fermentation and effects on ruminants (weight and lactating production) of these feeds. Authors stated that these wastes could be effectively used as feedstuff in rations that support growth and lactation in ruminants. Bicu and Mustata (2011) focused on orange peels recovery for cellulose extraction. Two different pulping reagents were used, sodium sulphite and sodium metabisulfite and the effect of the main process parameters, sulphite agent dosage and reaction duration, on cellulose yield was investigated. The physic-chemical characterization data indicated good levels of purity, low crystallinities, good whiteness, good water retention and moderate molecular weights. Fillers, water absorbents, or as raw materials for cellulose derivatives could be subsequent applications of the recovered cellulose materials. A different and emerging application was presented by Kato-noguchi and Tanaka (2006), who assessed the potential of *Citrus junos* -one of the most consumed citrus fruits in Japan-to be used as weed inhibitor and as soil amendment.

3.1.4. Exotic fruits

The exotic fruits processing industry also produces a large percentage of waste by-products, such as peels, seeds and flesh. Exotic fruits are rich in bioactive compounds, phenols, carotenoids, vitamins and fibers and in most cases these components can be found in the waste by-products, with the same or even higher quantity. Several researches focused on recovery technologies and new uses for these types of waste.

Ayala-Zavala et al. (2010) reviewed the possible integral exploitation of by-products rich in bioactive compounds and the different extraction techniques. Authors identified several applications, such as: antioxidants, antimicrobials, flavoring, colorants and texturizer additives.

Considering the high amount of passion fruit consumed and used by food industry in Brazil, Canteri et al. (2010) studied the potential of waste peels as pectin source, a dietary fiber that is widely used in the food industry as a gelling agent and stabilizer. The pectin extraction was carried out using nitric acid and the chemical and rheological properties of the extracted pectin were similar to those of industrial pectin.

Even if pineapple is not produced in Italy, it is widely used by Italian food processing industry for juices, canned fruit in syrup and dessert preparations. Pineapple stem is a typical waste during pineapple processing and has been extensively used for bromelain extraction; however, almost no attention has been given to the waste obtained during bromelain manufacturing. (Upadhyay et al., 2012) studied antioxidant, antimicrobial, inhibitions against 15-lipoxygenase and advanced glycation end product formations by pineapple stem waste. Some important phytochemicals with considerable bioactivities were found in these wastes, suggesting a promising usage as a cheap source of one of the ingredients in functional food based industries.

Abdalla et al. (2007) studied mango seed kernels, their composition: amino acids; phenolic compounds; the characteristics of the extracted oil including unsaponifable matter constituents, lipid classes and fatty acid composition. Moreover, antioxidant and antimicrobial activities of mango seed kernel extract and oil were investigated. Results show that mango seed kernels contained a considerable amount of total phenolic compounds, total lipid, unsaponifiable matter, and a low amount of crude protein, but the quality of protein was good because it was rich in all essential amino acids. The combination of both mango seed kernel extract and oil had optimum antioxidant potency higher than each one alone, and could be used as natural antioxidant and antimicrobial in different kind of food.

Ajila et al. (2010) found that mango peels are a good source of bioactive compounds such as polyphenols, carotenoids, vitamins, enzymes and dietary fibers; its extracts have also good antioxidant properties. Therefore, mango peel powder was incorporated into macaroni at three different percentages (2.5, 5.0, 7.5%) and its effect on the cooking properties, firmness, nutraceutical and sensory characteristics of macaroni was studied. Results showed that mango peel powder enhance the nutritional quality of macaroni without affecting its cooking, textural and sensory properties.

Ashoush and Gadallah (2011) replaced mango peels powders at different levels (5, 10, 15 and 20%) and mango kernels powders at (20, 30, 40 and 50%) in biscuits preparation evaluating the rheological, physical, sensory and antioxidant properties of the final product. Biscuits with an acceptable mango flavor were obtained by incorporating up to 10% of peels powders and with mango kernel powders up to 40%. A use as potential source for functional food ingredients could be encouraged for these two byproducts.

Two interesting applications were found for byproducts of coconut food industry. Naik et al. (2012) evaluated the byproducts of virgin coconut oil processing industry, such as coconut skim milk and insoluble protein, to obtain a value-added product, namely, coconut protein powder. This had shown to have good emulsifying properties and hence had potential to find applications in emulsified foods and could be a useful food ingredient. Moreover, coconut and peanuts shell powder could be used as filler in natural rubber (Sareena et al., 2012a, 2012b).

Papaya processing wastes showed new and interesting potential applications compared to those of previous studies. Papaya processing waste served as substrate for yeast (Saccharomyces cerevisiae) growth (Kang et al., 2010). The research focused on: (1) nutrition analysis of the bioprocessed waste products, (2) results of shrimp feeding trail using papaya waste products as feed supplement, and (3) economic analysis of the bioprocess system. The product contained an average of 45% crude protein and nutrients of fat, fiber, lignin, cellulose, and minerals. The inclusion of these byproducts into shrimp diets leads the authors to infer that 50% papaya processing wastes diets are comparable to commercial feed. A last recovery option of exotic fruits processing wastes was proposed (Ueno et al., 2003), who suggested to use pineapple and grapes processing wastes as enzymes substrate for lactic acid production.

Morais Ribeiro da Silva et al. (2014) quantified the levels of resveratrol, coumarin, and other bioactives in pulps and by-products of twelve tropical fruits from Brazil (pineapple, acerola, monbin, cashew apple, guava, soursop, papaya, mango, passion fruit, surinam cherry, sapodilla, and tamarind pulps, as well as their by-products peel, pulp's leftovers, and seed) for future application in food industry. Total phenolic, anthocyanins, yellow flavonoids, flavonoids, low flavonoids, s their by-products peel, Authors stated that fruit by-products presented higher bioactive content than their respective fruit pulps.

3.1.5. *Potatoes*

Potatoes are one of the most commonly consumed vegetables throughout the world. Potatoes mainly contain carbohydrates, especially starch, vitamins, minerals and phytochemicals, such as carotenoids and natural phenols. Peels are the major by-product of potato processing industries and contain the same amount of valuable compounds of edible vegetable. Sabeena Farvin et al. (2012) examined the utilization of potato peel as a source of natural antioxidants for retarding lipid and protein oxidation in minced mackerel. Mackerel mince with two different concentrations (2.4 or 4.8 g/kg) of water or ethanol extracts of potato peel and a control with no added extracts were prepared and compared. Results suggested that ethanol extracts of potato peel can be employed as natural antioxidant to prevent lipid and protein.

Kanatt et al. (2005) used potato peel waste as a source of natural antioxidants and test its effectiveness in reducing lipid peroxidation of radiation-processed meat. Radiation processing is one of the most effective technologies for sterilization in raw meat and meat products. However, meat on irradiation may undergo oxidative changes that influence the sensory quality of meat. Potato peel extracts retard lipid peroxidation of radiation-processed meat without affecting its flavor.

Nelson (2010) proposed to use byproducts of potatoes industry processing as cattle feed. Potato waste was a quantitatively important energy source in beef cattle diets and solved a potentially massive disposal problem; limitation to use is mostly economic, not due to quality concerns. Okuno et al. (2002) utilized supercritical carbon dioxide (SC-CO_2) extraction to waste powder derived from sweet-potatoes roots with orange flesh, highlighting the possibility of extracting antioxidants from waste materials with SC-CO_2. Furthermore, the compounds extracted have no toxic solvent residue because this extraction does not require organic solvents and it is itself non-toxic.

3.1.6. *Tomatoes*

Tomato is the second most important vegetable crop next to potato worldwide, with annual production at 100 million tons fresh fruit produced in 144 countries (Kalogeropoulos et al., 2012).

Tomatoes are rich in bioactive and valuable compounds, such as carotenoids, mainly lycopene (80–90%) e β-carotene, plus vitamin C, vitamin E and various phenolic compounds (Dumas et al., 2003).

Kalogeropoulos et al. (2012) compared tomato processing byproducts and unprocessed tomatoes for several bioactive phytochemicals, like sterols, tocopherols, carotenes, terpenes, total and simple polyphenols. The results showed that industrial tomato byproducts contain significant amounts of bioactive phytochemicals, known to exert antioxidant activities. Therefore, these value adding constituents could be either isolated from the wastes to be used as natural antioxidants for the formulation of functional foods, or to serve as additives in food systems to elongate their shelf-life.

García Herrera et al. (2010) characterized tomato waste peels in terms of fiber and macronutrients (proteins, ash, total available carbohydrates and soluble sugars), demonstrating that peels were mainly composed by carbohydrates, with an average value of 80% of total dietary fiber, being insoluble fiber the major component and suggesting their use as a food ingredient of new functional foods. Tomato wastes were subjected also to evaluation as potential source of phenolic antioxidants and anticancer agents (Ćetkovi et al., 2012), identifying and quantifying some individual phenolic compounds, including phenolic acids and flavonoids. The tomato extracts analyzed contained considerable amount of phenolic antioxidants and exhibited good antioxidant properties. However, before considering these wastes as nutraceutical resource, commercially exploited, it is necessary to consider both environmental and economic aspects (extraction profitability).

The majority of the studies published in literature focus on carotenoids characterization, especially for Lycopene and β-carotene. Riggi and Avola (2008) characterized the tomato wastes for content of carotenoids and waste composition in relation to their source and to the month in which they were produced. Source and month both affected the characteristics of the wastes, since in summer the highest proportion of red fruits and the highest lycopene and β-carotene contents were recorded. A statistical analysis proved that the proportion of red fruits was significantly correlated with the lycopene content ($R = 0.839$, $P < 0.001$). Zuorro et al. (2011) studied the enzyme-assisted extraction of lycopene from the peel fraction of tomato processing waste. The results of this study indicated that the recovery of lycopene could be greatly enhanced by the use of mixed enzyme preparations with cellulolytic and pectinolytic activities and the comparatively low cost of commercial food-grade enzyme preparations, having possible implementation on industrial scale. Other recovery possibilities imply the use of enzymes and surfactants, to enhance the extraction potential. Papaioannou and Karabelas (2012) and Urbonaviciene et al. (2012) found that the best source for purified lycopenes was tomato peel and determined the concentration and stability of lycopene and β-carotene subjected to blanched and non-blanched tomatoes. The results showed that the mean lycopene and β-carotene concentrations were higher in the blanched tomatoes than in the non-blanched tomatoes.

The extraction potential of various organic solvents was investigated optimizing the extraction parameters (type of solvent, extraction time, temperature and extraction steps) for maximum yield (Strati and Oreopoulou, 2011). Among other solvents, the authors tested a new environmentally friendly one, ethyl lactate, which gave the highest carotenoid yield. It was found also that carotenoids concentration increased with time, approaching a quasi-saturated condition at approximately 30 min of extraction. Ishida and Chapman (2009) confirmed that ethyl lactate is an excellent solvent to extract carotenoids. Machmudah et al. (2012) discussed the extraction of lycopene from tomato peel by-product containing tomato seed using supercritical carbon dioxide and proved that the presence of tomato seed in the peel by-product improved the yield of extracted lycopene.

Baysal et al. (2000) evaluated various operative conditions for lycopene extraction by supercritical CO_2, varying temperature, pressure, time, CO_2 flow rate and co-solvent addition.

3.1.7. Olives

Olive oil production, an agro-industrial activity of vital economic significance for many Mediterranean countries, is associated with the generation of large quantities of wastes (Lozano-Sánchez et al., 2011). These wastes are rich in phenolic compounds with a great biological and pharmaceutical interest, due their antioxidant properties. Olive pomace is one of the main by-product of olive food industry processing. It is a solid residue containing fragments of skin, pulp, pieces of kernels and some oil. Its major ingredients are sugars mainly in the form of polysaccharides, proteins, fatty acids like oleic acid and other C2–C7 fatty acids, polyalcohols, polyphenols, and other pigments (Karantonis et al., 2007).

Lozano-Sánchez et al. (2011) evaluated the phenolic compounds of wastes generated during the storage of extra origin olive oil. These wastes contain polyphenols belonging to different classes such as phenolic acids and alcohols, secoiridoids, lignans, and flavones.

Qualitative and quantitative characterizations of these solid and aqueous wastes suggested that these byproducts could be considered an important natural source of phenolic compounds, which, after suitable purification, could be used as food antioxidants or as ingredients in nutraceutical products due to their interesting technological and pharmaceutical properties.

Fernández-Bolaños et al. (2004) suggested a process for the value addition of solid waste from two-phase olive oil extraction includes a hydrothermal treatment, leading to the production of different mixtures of soluble oligosaccharides. Ghanbari et al. (2012) focuses on the nutrients and high-value bioactive profile as well as medicinal and functional aspects of different parts of olives and its byproducts.

Waste valorization from olive industry processing concerns also the recovery of bioactive compounds from wastewaters. (Federici et al., 2009) evaluated various technologies for extraction of fine chemicals and enzyme production. The research suggested that these effluents could be regarded as a useful resource for the recovery of fine chemicals and for different biotechnological applications such as the production of important metabolites; however there are several key points of technical and scientific difficulty and technology costs are still too high. Another research (Cardinali et al., 2012) focused on the recovery and structural characterization of antioxidant compounds from olive mill wastewater, using a membrane technology coupled to low-pressure gel filtration chromatography.

Ramos et al. (2013) studied the phenolic composition, antioxidant and breast cancer antiproliferative activities of water and methanol/water derived extracts from olive pomace (OP) and dry olive mill residue (DOR), from Portuguese industries. DOR water extracts showed the highest extraction yield; as well as the highest total phenolic content and hydroxytyrosol. Authors extracts showed that DORW extracts have antioxidant and breast cancer antiproliferative activities proving its potential as source of phenolic compounds for nutraceutical applications, as food supplements. Finally, olive mill wastes could be used as a source of C for soil C sequestration strategy (Sánchez-Monedero et al., 2008). The authors calculated the C balance during the whole life cycle of two different two-phase olive mill wastes; C losses were calculated during the composting process and after soil application of the composting mixtures under laboratory conditions. The total C losses showed lower losses compared to composts prepared with organic residues of different origin.

In order to recover high-added value compounds and to reduce water pollution problems related to wastewaters, Bertin et al. (2011) applied a solid phase extraction procedure for the recovery of olive mill wastewaters phenolic compounds.

Among various extraction procedures, most of them focused on maximizing the recovery of two compounds, oleuropein and hydroxytyrosol (Bouaziz et al., 2008). These compounds were found to be the most exhaustively studied due to their presence in all olive by-products and their superior and diverse biological activities, with many promising applications in foods, cosmetics, and medicine.

An important by-product of the olive oil industry, the olive cake, was characterized through a drying process, where the influence of air drying temperature on physicochemical properties and antioxidant activity was investigated (Uribe et al., 2012). According to authors' results, convective dehydration could lead not only to a dried olive cake that could be used as a material for many processing industries (e.g. food and cosmetic) or animal feed, but also could contribute to minimize the environmental impacts of this agro-industrial waste. Olive cake was used also to obtain phenolic extracts from its vegetative water and solid residue, to maximize the extraction of all phenolic compounds (Suárez et al., 2009). The authors studied different extraction procedures, a simple and a rapid one, and they found that the phenolic extract obtained by accelerated solvent extraction from the solid residue of olive cake could be proposed as a simple and rapid extraction procedure as an alternative to solid–liquid extraction. Furthermore, this procedure permitted a phenolic extract to be obtained containing the main components of the virgin olive oil phenolic fraction with a potent antioxidant activity and potential future applications as a natural antioxidant and as an ingredient in the development of supplemented olive oil. Delgado-Moreno et al. (2007) proposed to apply olive cake to soil as disposal strategy, due its high content in organic matter, increasing also sorption of all triazine herbicides tested and reducing desorption of the most hydrophobic ones, terbuthylazine and prometryn. The total polar lipids contained in olive oil and its by-products are of great interest due their potential to protect against cardiovascular diseases. Karantonis et al. (2007) extracted total polar lipids from olive oil, pomace, pomace oil and waste byproducts; they fractionated by thin layer chromatography and tested for their bioactivity.

3.1.8. Other vegetables

This section considers the studies related to other food wastes (e.g. soybean, palm, cauliflower etc.) that cannot be included in previous categories.

Karp et al. (2011) developed a bioprocess to produce L(+)-lactic acid, a product with various applications in food, cosmetic, pharmaceutical and chemical industry, using soybean vinasse as substrate, without supplementation with inorganic nitrogen sources and yeast extract.

Sago residues (a palm specie native to tropical southeastern Asia) could be a promising source to produce several products such as fermentable sugar, enzyme, compost for mushroom, animal feed and adsorbent, through biotechnological means Awg-Adeni et al. (2010). Sago bark (peelings from initial processing), sago 'hampas' (fibrous byproducts from crushing and sieving) and its wastewaters are the most promising resources and sago starch can be successfully employed in food, polymer, pharmaceutical and textile industry.

Cauliflower is a vegetable rich in bioactive compounds and nutrients, with a high rate of wastes during its industry processing. For this reason, Stojceska et al. (2008) incorporated cauliflower trimmings into ready-to-eat products and evaluated their effect on the textural and functional properties of extrudes. The results showed that the cauliflower to levels of 5–20% increased dietary fiber in the finished product by over 100%, it increased protein content and the water absorption index, making these wastes suitable for functional food production.

Domínguez-Perles et al. (2010) focused on broccoli by-products analyzing their content in bioactive compounds (glucosinolates, phenolic acids, and flavonoids) and nutrients (vitamin C, minerals, and trace elements). Broccoli byproducts may be used as a source of bioactive ingredients to design novel beverages- using organic green tea as a food matrix- presenting improved physical quality, phytochemical composition and antioxidant capacity (Dominguez-Perles et al., 2011). Carob pulp aqueous extracts were used as carbon source in the production of the biocontrol agent *Pantoea agglomerans* PBC-1, usable as bio-pesticide (Manso et al., 2010). Tests proved that the aqueous extracts exhibit a high potential of this by-product as a carbon source to produce high amounts of biomass of the biocontrol agent at low cost.

Lante et al. (2011) evaluated red chicory leaf residue as a natural substitute for synthetic antioxidants for the food and feed industry. Horse chestnut extracts are widely used in pharmacy and cosmetic industries and their main active constituents are saponins of oleane type, but seeds also contain flavonoids. Kapusta et al. (2007) isolated the main flavonoids from horse chestnut seeds and established their structures with spectral methods. Flavonoids were present in relatively high amount contributing to the overall activity of these extracts. Industrial horse chestnut wastewater could be used to obtain quercetine and kaempferol glycosides for cosmetic, nutraceutical, and food supplement industries.

Verma et al. (2011) studied pea peel waste performing batch experiments and using industry processing wastes as carbon source to produce cellulase enzymes.

The by-products of asparagus are also rich in many of the phytochemicals, such as phenols (flavonoids and hydroxycinnamic acids) and saponins, located in the edible part of the spears. Fuentes-Alventosa et al. (2013) developed a process for obtaining added-value compounds from asparagus by-products by the hydrothermal treatment of the samples. The preliminary results showed that the distinct products obtained from asparagus by-products are of interest for their biological activity and are suitable for being used as functional ingredients.

3.1.9. Miscellaneous

Some studies investigated the possibility of recovery and/or reuse of the food industry wastes from matrices composed by different types of vegetables. A review article (Sud et al., 2008) provided the available information on various aspects of utilization of the agricultural waste materials for heavy metal removal. According to the authors, the major advantages of biosorption over conventional treatment methods included: low cost, high efficiency, minimization of chemical or biological sludge, regeneration of biosorbents and possibility of metal recovery.

Aqueous and methanol extracts made from the pomace of six fruits (*Fragaria x ananassa, Prunus cerasus*, *R. nigrum*, *R. rubrum*, *Rubus idaeus*, *R. fruticosus*) were tested for antimicrobial activity by broth dilution assay (Krisch et al., 2009). Pomace resulted to be rich in extractable bioactive compounds, and could be used in various ways in the food industry as source of natural antioxidants, preservatives and antimicrobial agent.

Mohdaly et al. (2010) examined the antioxidant properties and total phenolic, flavonoid and flavonol contents of three industrial by-products, sugar beet pulp, sesame cake and potato peel, extracted with various solvents The antioxidant activity observed encouraged the use of these wastes as natural antioxidants in the pharmaceutical and food industries.

Stabnikova (2005) used water extracts of cabbage, watermelon, a mixture of residual biomass of green salads and tropical fruits for yeast cultivation. Indeed, vegetable and fruit processing wastes contained soluble sugars and organic acids, which could be utilized by some microorganisms, mainly yeast, to produce biomass with high protein content and, according to authors' results, with no addition of nutrients. Moreover, it is possible to increase nutrient and economic values of yeast by adding in the medium 5 μg/ml of selenium.

Nawirska and Kwaśniewska (2005) determined the amounts of particular dietary fiber fractions in samples containing apple, black currant, chokeberry, pear, cherry and carrot pomace. In the samples, pectin occurred in the smallest amounts, while the content of lignin was very high (black currant and cherry pomace) or comparatively high (pear, chokeberry, apple and carrot pomace). The proportion of other fibers varied from one sample group to another. Authors proposed chokeberry and apple pomace as sorbents for heavy metals, due their content of hemicellulose and pectin.

The process that produces Liege syrup (apple butter-like) results in high amounts of residues from cooked apples, pears and sun-dried dates Aguedo et al. (2012). These unusual fruit by-products were studied by the authors for their composition in total proteins and fats, dietary fiber and their content in total and free monosaccharides and were finally compared with raw no cooked fruits. The polyphenolic content and the antioxidant activity of the three products were also assessed and the values showed that their antioxidant characteristics were comparable to that of various raw fruits.

Lignocellulosic agricultural byproducts are a copious and cheap source for cellulose fibers (Reddy and Yang, 2005). These biofibers can be used for several purposes, from producing chemicals to enzymes. Reddy and Yang (2005) analyses the production processes, structure, properties and suitability of these bio-fibers for various industrial applications.

Fresh-cut fruit consumption is increasing due to the rising public demand for convenience and awareness of fresh-cut fruit's health benefits (Ayala-Zavala et al., 2010). These fruits and vegetables are rich in. Fresh cut fruit industry discards large percentages of byproducts, such as peels, seeds, and unused flesh that can present similar or even higher contents of bioactive compounds, such as phenolic compounds, carotenoids, and vitamins than the final product. This support the antioxidant enrichment and antimicrobial protection of fresh-cut fruits, provided by the fruit's own byproducts.

A research by Do Espírito Santo et al. (2012) evaluated the effect of the supplementation of total dietary fiber from apple, banana or passion fruit processing by-products on the post-acidification, total treatable acidity, bacteria counts and fatty acid profiles in skim milk yoghurts, producing a new high nutritional value-added dairy product.

Djilas et al. (2009) discussed in a review the potential of the most important by-products of apple, grape and citrus fruits processing as a source of valuable compounds.

Papaioannou and Liakopoulou-Kyriakides (2012) examined solid agro-food wastes such as cabbage, watermelon husk and peach peels as main carbon source for-carotene production, using Blakeslea trispora, a heterothallic fungus. B. trispora was able to utilize, almost equivalently, different origin agro-food wastes for carotenoids production, with a yield of over 76% in all examined cases.

Peschel et al. (2006) screened eleven fruit and vegetable byproducts and two minor crops for industrial polyphenol exploitation potential by determination of their extraction yield, total phenolic content and antioxidant activity. The extracts obtained from apple, golden rod and artichoke byproducts resulted to have the highest activity and phenolic content.

Zykwinska et al. (2008) extracted pectin using proteases and cellulases enzymes. Pectins were isolated from different plant byproducts, i.e., chicory roots, citrus peel, cauliflower florets and leaves, endive, and sugar beet pulps. The results proved that the enzymatic method proposed by the authors could convert vegetable byproducts into high-added value compounds, such as pectins and pectic oligosaccharides, and thus considerably reduce the amount of these residues generated by food industries.

According to Mateos-Aparicio et al. (2010) the legume by-products, pea pod, broad bean pod and okara, could be considered a source of dietary fiber, because it is the major constituent, more than 50% for pea pod and okara and 40% for broad bean pod. Furthermore these by-products contained also high amount of vegetable protein and a remarkable concentration of potassium, fats rich in linoleic and oleic acid.

Considering the nutritional value found for fruit and vegetable waste, it was proved that this product might be considered as a potential alternative for animal feeding. Angulo et al. (2012) evaluated the use of fruit and vegetable waste from market place as feedstuff for diets of lactating Holstein cows with an emphasis on milk yield and quality. The wastes mixture was included in 0, 6, 8, 12, and 18% of the concentrate and these wastes could be a good alternative feedstuff, without detriment in the milk yield and with improvement in the milk quality.

3.2. Dairy products

The dairy industry is a major and important part of the food industry, with a great contribution of liquid wastes (Kosseva, 2011). Dairy wastes and wastewaters can contain proteins, salts, fatty substances, lactose and cleaning chemicals (Kosseva, 2011). The waste that has received considerable attention as a source of value added products is cheese whey. It is estimated that approximately 9 million ton of cheese per annum is produced within EU, for an annual whey production figure of 50 million m^3 (Kosseva, 2011). A comprehensive review on cheese whey management Prazeres et al. (2012) compared different options: (1) biological treatments without valorization; (2) biological treatments with valorization; (3) physic-chemical treatments and direct land application. The authors described the main reactors used, the influence of the main operating variables, the microorganisms or reagents employed and the characterizations of the final effluent principally in terms of chemical oxygen demand.

Smithers (2008) traced the history of the use of whey, analyzing process key points (treatments, technologies, environmental considerations, etc.), highlighting issues related to wastes disposal, source of valuable compounds (proteins, peptides) and future applications.

Pereira et al. (2002) valorized ovine cheese whey and deproteinized whey, by means of thermo calcic precipitation and microfiltration (TP/MF) followed by ultrafiltration – diafiltration (UF/DF). Afterwards, the chemical composition of microfiltration and UF/DF retentate powders was studied and compared with that of conventional ultrafiltration powders, in view of further applications. The clarification of the two cheese by-products widely improves the next filtration treatments. Diaz et al. (2004) evaluated the functional characteristics of ovine cheese whey and deproteinized whey, adding the liophilization step to previous procedure. The by-products of the clarification procedure, showed similar solubility and higher emulsifying activity than conventional whey protein concentrate, although their emulsion stability was lower. Authors envisaged the potential use of these protein concentrates in food industry. Nguyen et al. (2003) applied nanofiltration to cottage cheese whey in order to concentrate its solids content four fold, while removing about three-quarters of the sodium and potassium salts and some acid. The desalted nanoconcentrate could be considered as a recovered by-product for use as an ingredient in dairy and other food products. Nanofiltration technology was used also by Minhalma et al. (2007) to recovery second cheese whey organic nutrients, that is a rich lactose in the concentrate and a process water with a high salt content in the permeate. The authors tested two different membranes and found a maximum water recovery of approximately 80%, concentrating the nutrients approximately 5 times. This meant that nanofiltration, using the selected membrane and the optimal operating conditions, could therefore minimize the wastewater environmental impact and at the same time obtain salt depleted lactose concentrate, than could be used as a raw material in the pharmaceutical, food or paper industries, and a salt enriched permeate almost free from organic matter, that could be reused in the process. Rektor and Vatai (2004) developed a complex membrane filtration technology for whey processing to obtain large-scale protein and lactose fractionation, comparing three different modules differing in the separation efficiency of the valuable whey components and complexity of the proposed treatment technology.

Another research regarded the increased utilization of ultrafiltration for pre-concentration of milk, which causes large quantities of milk concentration permeate, a low-value by-product of dairy industry. Paseephol et al. (2008) evaluated the potential of milk permeate to be a source for lactulose production, using calcium carbonate-based catalysts.

Whey lactose was used as a low cost carbon source for producing kefiran, a water-soluble exopolysaccharide that consists of approximately equal amounts of glucose and galactose, industrially (Cheirsilp and Radchabut, 2011).

An alternative usage of cheese whey is proposed by Martin-Diana et al. (2006). Whey permeate at different concentrations (0.5%, 1.5% and 3%) was used as natural sanitizing agent in the washing treatment of fresh-cut lettuce and carrots, and then compared with a chlorine (120 ppm). The authors monitored the microbiological, quality and nutritional markers over 10 days, discovering that 3% whey permeate is a promising formula for decontamination of fresh-cut vegetables. However, further investigations are needed in order to optimize this treatment in terms of shelf life, nutritional value, safety and quality.

Barile et al. (2009) determined the compositions of a variety of neutral and sialylated oligosaccharides in Gorgonzola whey permeate, suggesting structures and possibly biological activities similar to those of human milk oligosaccharides.

Yoghurt whey from expired date products could be a big a source for lactic acid production by *Lactobacillus casei* (Alonso et al., 2010). Lactic acid is widely used in food industry, pharmaceutical and recently for biopolymers production. Vasala et al. (2005) used *Lactobacillus salivarius* (a lactic acid bacterium species that can grow at high salt concentration) to ferment lactic acid in cheese whey and lactose mother liquor. *L. salivarius* is also an ideal organism for lactic acid fermentation in high-salt high lactose conditions, and it is also a potent probiotic when used to produce animal feed from dairy wastes.

The potential of three lactic acid bacteria strains to design a starter culture for developing functional/healthy whey-based drinks were evaluated (Pescuma et al., 2008). Maragkoudakis et al. (2010) evaluated the suitability of "scotta", the liquid milk whey by-product from Ricotta cheese manufacturing, as growth substrate for commercial probiotic and starter cultures, testing different treatments. Scotta presented favorable characteristics as potential growth substrate, to be further exploited as substrate for the production of a probiotic fermented drink. Also Koutinas et al. (2009) proposed the production of novel dairy starter cultures using whey as raw material. The developed technology involved biomass production from whey followed by thermal drying of cultures, and their efficiency in lactose and milk whey fermentations was studied. Authors found that the most suitable culture according its technological properties was kefir. The casein peptides have potential to exert numerous biological effects in the body, which are being exploited by the food industry.

A review by Phelan et al. (2009) focused on casein-derived peptides, discussing their selected biological effects, their application in industry, in addition to safety aspects and regulations relating to the use of these peptides. Muro Urista et al. (2011) listed the main peptides obtained from milk protein and the past research studies about its production and biological activities. Moreover, an analysis was made on the methods to determinate the biological activities, the separation of bioactive peptides and its structure identification. Finally, the paper explicated the experimental animal and human trials done in the past year.

As 80% of whey is emitted into river systems, Ostoji et al. (2005) proposed to process whey into food and pharmaceuticals to avoid environmental organic pollution. Their research showed that low-temperature regime of whey concentration and fractionation, based on vacuum concentration and diafiltration, preserves whey proteins undenatured.

3.3. Meat and derivatives

Globally, the frequency of meat consumption has been increasing whereas the demand of less valuable products - such as blood, entrails and some muscles, widely consumed in the past due to poverty needs – has been decreasing. For this reason, meat industry discards large quantities of slaughterhouse by-products, which mainly include skin, bones, entrails, fatty tissues, feet, skull, etc.

Meat waste by-products constitute nearly 60%–70% of the slaughtered carcass, of which nearly 40% forms edible and 20% inedible (Bhaskar et al., 2007).

Therefore, meat industry tries finding new recovery solutions for these wastes that could be a serious risk both for the environment and for human health. Unfortunately, unlike to vegetable wastes, the recovery of meat industry by-products is bound by severe hygiene and health limitations. The most dangerous disease is the Bovine spongiform encephalopathy (BSE), for which the European Union promulgated legislative measures in order to avoid that products containing BSE could end up in the distribution chain (Regulation 999/2001and 853/2004).

Despite these difficulties, some researchers addressed their studies to wastes of meat and its derivates.

Toldrá et al. (2012) analyzed possible uses of meat wastes, distinguishing three ways of recovery: human food, pet food and other non-food and non-feed applications. The authors claimed that there was a large variety of applications of meat by-products, not only for human and animal foods, but also in biotechnology and chemical industry.

Selmane et al. (2008) wanted to investigate the influence of the methods and of their operating conditions on the extraction, purification and concentration of meat proteins (beef, pork lungs and chicken meat) in order to maximize protein recovery and to enhance protein functional properties for subsequent application as food ingredients. Three functional properties, namely gelling, emulsifying and foaming properties, of the resulting concentrates were compared to those of commercial ingredients from milk. The authors found that yields of protein recovery were between 48 and 55% (w/w). (Bhaskar et al., 2007) prepared a protein hydrolysate from pre-treated sheep visceral mass (including stomach, large and small intestines) by enzymatic treatment using fungal protease. The authors found that these by-products held a considerable potential for preparation of protein hydrolysates that was rich in some of the essential amino acids. The hydrolysates may be used as flavor enhancers, functional ingredients or as nutritional additives to foods of low protein quality.

Chicken meat could be a source of functional proteins to be added for novel food preparation. (Tahergorabi et al., 2012) used isoelectric solubilization/precipitation to recovery functional muscle proteins from skin-on bone-in chicken drumstick (i.e., model dark chicken-meat processing by-products). The results found were positive and the authors recommended the addition of TiO_2 during the extraction process. Krasnoshtanova (2010) developed methods for increasing the efficiency of enzymatic hydrolysis of industrial substances with technical preparations of hydrolases. Waste by-products of meat processing plants could be organized to obtain highly competitive, valuable products based on enzymatic hydrolysates through recycling the byproducts of the major processes. The results of the study were used for developing kinetic models of the processes and determining their optimal conditions ensuring a degree of substrate conversion of at least 95%. It was found that hydrolysis at increased temperatures (55–65 °C) made unnecessary to maintain aseptic conditions and that alkyl hydroxy benzenes could be used to increase the efficiency of enzymatic processes. The study by Gómez-Guillén et al. (2011) was a collection of recent researches on collagen and gelatin extraction from non-mammalian species (fish and poultry), as well as new processing conditions and potential novel or improved applications, such as emulsifiers, foaming agents, colloid stabilizers, etc. As a result of the recent BSE crisis and subsequent hygiene restrictions, (Deydier et al., 2005) proposed new valorization means for meat processing by-products. They characterized meat and bone meal combustion residues in order to evaluate their physical and chemical properties. They revealed that meat and bone meal combustion residues are calcium (30.7%) and phosphate (56.3%) rich compounds, mainly a mixture of $Ca_{10}(PO_4)_6(OH)_2$ and -$Ca_3(PO_4)_2$. Significant levels of sodium (2.7%), potassium (2.5%) and magnesium (0.8%) are also observed. Ash particles are relatively small, from a few millimeters to micrometer, with almost 90% smaller than 1 mm. These compounds could be used as natural source of phosphate with no heavy metal content.

Used casing waste discharged from frankfurter/sausage production constitutes a major organic waste stream produced by the meat processing industry (Cumba, 2005). Therefore, industry has a great interest to convert cellulosic spent casing waste into useful byproducts, since they were found to be an excellent source of

Table 2
Summary of review results with reference and number of papers related, divided by sector and type of waste.

Sector	Type	Reference	Total no.
Fruits and vegetables	Apple	Henríquez et al., 2010 Huber and Rupasinghe, 2009 Shalini and Gupta, 2010 Wolfe and Liu, 2003	4
	Berry	Bakowska-Barczak et al., 2009 Górecka et al., 2010 Pap et al., 2004	3
	Citrus fruit	Bampidis and Robinson, 2006 Bicu and Mustata, 2011 Fernández-López et al., 2004 Kato-noguchi and Tanaka, 2006 Scordino et al., 2007 Viuda-Martos et al., 2011 Crizel et al., 2013	7
	Exotic fruit	Abdalla et al., 2007 Ajila et al., 2010 Ashoush and Gadallah, 2011 Ayala-Zavala et al., 2010 Canteri et al., 2010 Kang et al., 2010 Naik et al., 2012 Sareena et al., 2012a, 2012b Ueno et al., 2003 Upadhyay et al., 2012 Morais Ribeiro da Silva, 2014	12
	Potatoes	Kanatt et al., 2005 Nelson, 2010 Okuno et al., 2002 Sabeena Farvin et al., 2012	4
	Tomatoes	Baysal et al., 2000 Ćetkoviet al., 2012 Dumas et al., 2003 García Herrera et al., 2010 Ishida and Chapman, 2009 Kalogeropoulos et al., 2012 Machmudah et al., 2012 Papaioannou and Karabelas, 2012. Riggi and Avola, 2008 Strati and Oreopoulou, 2011 Urbonaviciene et al., 2012 Zuorro et al., 2011	12
	Olives	Bertin et al., 2011 Bouaziz et al., 2008 Cardinali et al., 2012 Delgado-Moreno et al., 2007 Fernández-Bolaños et al., 2004 Federici et al., 2009 Ghanbari et al., 2012 Karantonis et al., 2007 Lozano-Sánchez et al., 2011 Sánchez-Monedero et al., 2008 Suárez et al., 2009 Uribe et al., 2012 Ramos et al., 2013	13
	Other vegetables	Awg-Adeni et al., 2010 Domínguez-Perles et al., 2010 Dominguez-Perles et al., 2011 Kapusta et al., 2007 Karp et al., 2011 Lante et al., 2011 Manso et al., 2010 Stojceska et al., 2008 Verma et al., 2011 Fuentes-Alventosa et al., 2013	10
	Miscellaneous	Aguedo et al., 2012 Angulo et al., 2012 Ayala-Zavala et al., 2010 Djilas et al., 2009 Do Espírito Santo et al., 2012 Krisch et al., 2009 Mateos-Aparicio et al., 2010 Mohdaly et al., 2010 Nawirska and Kwaśniewska, 2005 Papaioannou and Liakopoulou-Kyriakides, 2012 Peschel et al., 2006 Reddy and Yang, 2005 Stabnikova, 2005 Sud et al., 2008 Zykwinska et al., 2008	15
Dairy products	Whey	Alonso et al., 2010 Barile et al., 2009 Cheirsilp and Radchabut, 2011 Diaz et al., 2004 Kosseva, 2011 Koutinas et al., 2009 Martin-Diana et al., 2006 Minhalma et al., 2007 Muro Urista et al., 2011 Nguyen et al., 2003 Ostoji et al., 2005 Paseephol et al., 2008 Pereira et al., 2002 Pescuma et al., 2008 Phelan et al., 2009 Prazeres et al., 2012 Rektor and Vatai, 2004 Smithers, 2008 Vasala et al., 2005	19
Meat and derivatives	Miscellaneous	Bhaskar et al., 2007 Cumba, 2005 Deydier et al., 2005 Gómez-Guillén et al., 2011 Krasnoshtanova, 2010 Selmane et al., 2008 Tahergorabi et al., 2012 Toldrá et al., 2012	8
Miscellaneous	Miscellaneous	Balasundram et al., 2006 Dhillon et al., 2012 Leães et al., 2010 Waldron et al., 2004	4
Total			111

waste cellulose. Two potential uses for the waste are to hydrolyze the cellulose into sugars or to use the spent casing waste as a substrate for the production of cellulase (Cumba, 2005).

3.4. Miscellaneous

In this section studies regarding miscellaneous food wastes were collected.

The Total food (Waldron et al., 2004) conference highlighted new developments in innovation and research, facilitating transfer of knowledge among agrofood-industry stakeholders. The objective was to discuss about the most significant global research and development aimed to exploit the entire quantity of food resources rather than the final portion consumed. Proceedings collect several studies focused on waste minimization, water and energy recovery during food processing, added-value by-products from vegetable and dairy food chain, exploitation of invaluable residues to produce biofuel and food safety concerns.

Leães et al. (2010) evaluated antimicrobial activity by *Bacillus* sp. *PP 11* on several by-products of food industry, such as grapes, soybean (meal and fibrous wastes), fish and cheese whey. The major activity was found on soybean meal, followed by fish and soy fibrous wastes, showing they could be used as cheap substrate for antimicrobial activity of *Bacillus* sp. *P11*.

Balasundram et al. (2006) explored phenolic compounds from fruit, vegetable and beverage by-products as source of natural antioxidants, discussing practical aspects to be considered, e.g. extraction efficiency, availability of sufficient raw material, and toxicity or safety considerations.

Dhillon et al. (2012) produced citric acid from Aspergillus niger NRRL-567 using several food industry wastes, such as brewery spent liquid (BSL), lactoserum and starch industry water sludge. The citric acid was produced varying and evaluating several parameters, such as: temperature (25–35 C), pH (3–5), addition of inducers, incubation time and supplementation with different proportions of apple pomace ultrafiltration sludge. These wastes can be used as alternative substrate for citric acid production.

4. Discussion and conclusions

The review of the literature about food waste recovery and industrial symbiosis in the food industry showed that the majority of the studies focus on restricted examples and pilot-scale laboratory experiences, while only few cases contain data about economic and technical feasibility on existing full-scale studies. In general, there is a lack of specific studies related to logistic concerns of industrial symbiosis, e.g. case studies with the characteristics and the quantity of food wastes produced by a company, the geographical distribution of other companies that could benefit from that wastes, and etc.

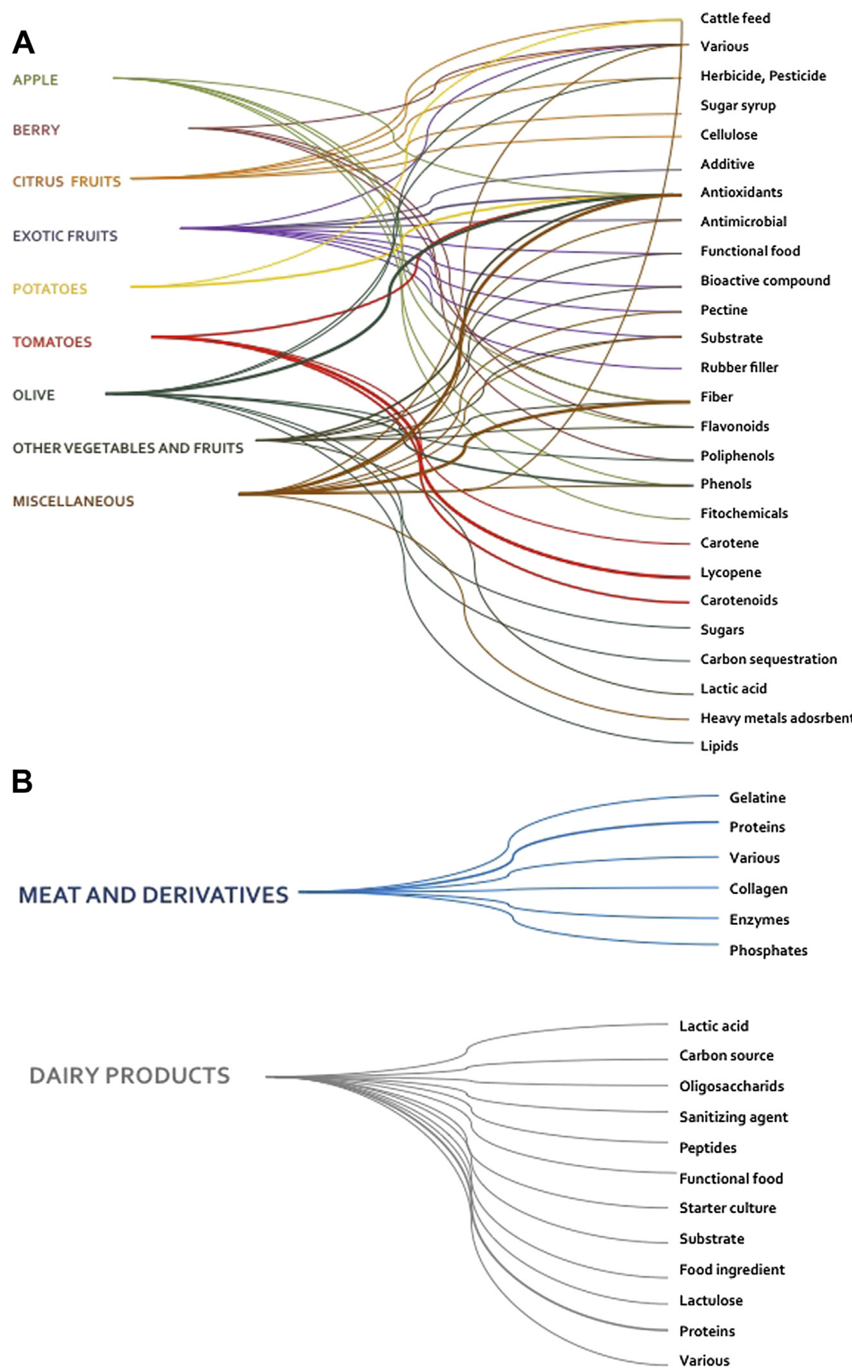

Fig. 1. **A**. Summary of valuable compounds derivable from fruits and vegetables analyzed. **B**. Summary of valuable compounds derivable from meat and derivatives and dairy products.

Table 2 summarizes the number of papers analyzed, divided by sector and type of wastes. The most promising sources of valuable compounds from fruits and vegetables (Table 2, Fig. 1A) are: olives, exotic fruits and tomatoes, which can provide several valuable compounds. According to the results of this review, researches mainly focus on antioxidants, fiber, phenols, polyphenols and carotenoids extraction, due to their high possibilities of application and potentials. For what concern meat and derivatives proteins are the most extracted substances, while lactic acid, proteins and peptides from dairy by-products are mainly obtained.

Furthermore, it was observed that the food wastes need further processing step before being used. This transformation implies high costs in research and development. Hence, it is essential to obtain valuable and high added-value products in order to justify the investment. An investigation to identify the type and amount of wastes, the potential for exploitation, the geographical location of producers, intermediaries (e.g. laboratories which could be involved in the transformation and valorization of wastes) and finally, the potential end-users will be necessary. This problem requires the involvement of several stakeholders, e.g. creating consortia of interested parties that could enhance the economic potential of the companies and support the initial investment. To this end, further studies would be necessary to identify the amount and type of wastes, their potential of exploitation, and the geographical distribution of producers, users (e.g. laboratories), and potential purchasers.

Further key considerations related to present industrial symbiosis potential in FWm emerged from this research. It is clear that the promotion of industrial symbiosis in the food industry is possible only upon assessment of available technologies and of materials potential in terms of quality and quantity. Indeed, in order to promote an industrial symbiosis among companies, feasibility studies are essential to classify the type and amount of wastes and to identify which industrial sector/activity might transform and use them. On the other hand, these evaluations are necessary for assessing also the sustainability of the whole recovery process proposed, to avoid the risk of burdens shifting from an environmental compartment to another. For instance, extraction procedures of compounds presented may involve the use of potential polluting chemicals, such as solvents or additives. The benefits of reuse and recovery should not be undermined by environmental impacts caused by new production processes. Hence, it is preferable to promote direct reuse practices (i.e. the replacement of a virgin raw material) without manipulations or to evaluate the processes for the bio-refinement adopting environmental assessment methodologies encompassing the entire life cycle of the by product (e.g. life cycle assessment).

Finally, it is remarkable that the risk of excessive manipulations and modification of food could be critical in some cases; this issue should be further investigated to avoid potential risks to consumers' health.

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