Comprehensive REVIEWS in Food Science and Food Safety

Recovery of High Value-Added Nutrients from Fruit and Vegetable Industrial Wastewater

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Abstract: The industrial processing water of fruit and vegetables has raised serious environmental concerns due to the presence of many important bioactive compounds being disposed in the wastewater. Bioactive compounds have great potential for the food industry to optimize their process and to recover these compounds in order to develop value-added products and to reduce environmental impacts. However, to achieve this goal, some challenges need to be addressed such as safety assurance, technology request, product regulations, cost effectiveness, and customer factors. Therefore, this review aims to summarize the recent advances of bioactive compounds recovery and the current challenges in wastewater from fruit and vegetable processing industry, including fruit and beverage, soybean by-products, starch and edible oil industry. Moreover, future direction for novel and green technology of bioactive compounds recovery are discussed, and a prospect of bioactive compounds reuse and sustainable development is proposed.

Keywords: food industry, nutrients, recovery, wastewater

Introduction

The wastewater discharged from agriculture, municipalities, and industries cause serious pollution (Food and Agriculture Organization of the United Nations [FAO], 2015) and due to a high organic loads and nutrient content in the food industry wastewater, reflects in the chemical oxygen demand (COD) reaching tens of thousands of milligrams per liter. According to the latest environmental data from China's National Bureau of Statistics (Table 1), the wastewater discharged during food processing accounts for about 19% of the total industry waste; furthermore, the COD of wastewater is in the top 34% of all waste discharges as shown in Figure 1 (National Bureau of Statistics of China, 2014).

The fruit and vegetable processing industry (FVPI) produces impressive quantities of wastewater. An investigation of 11 FVPI units was conducted, and the results showed that water consumption and wastewater generation reached 1.8×10^5 to 6.0×10^5 m^3/year and 130 to 330 m^3/hr, respectively (Valta et al., 2016). Wastewater contains large amounts of organic substances expressed as 5-day biochemical oxygen demand (BOD_5) (500 to 6100 mg/L) and COD (806 to 7732 mg/L), indicating a serious environmental problem (Puchlik & Ignatowicz, 2017) and requiring a high cost for water treatment as shown in Table 2. Therefore, the removal of these bioactive substances is a challenge in the wastewater treatments.

In comparison to other industrial wastewaters, the high contents of COD in FVPI wastewater contain a variety of high value bioactive substances, such as proteins, polysaccharides, flavonoids, pigments, polyphenols, and dietary fiber (Barbera & Gurnari, 2018; Cassini, Tessaro, Marczak, & Pertile, 2010). These bioactive compounds represent an interesting opportunity for wastewater valorization, some of these might provide antioxidants, antimicrobial agents and kinds of food additive, others might be further transformed into more sophisticated natural chemicals, macromolecules or biofuels for various applications (Federici, Fava, Kalogerakis, & Mantzavinos, 2010), and even novel food might be developed with these nutrients (De, Macciola, Lembo, Aretini, & Nag, 2007; Goula & Lazarides, 2015). Therefore, the abandonment of such renewable wastewater not only leads to serious ecological risks but also results in a loss of nutrient resources and poor economics. Thus, there is a strong motivation to develop the methods and technologies to recovery of nutrients and wastewater reuse systems for FVPI (Xie, Shon, Gray, & Elimelech, 2016)).

Available technologies such as membrane technologies, ozonation, adsorption, solvent extraction, etc., can significantly reduce COD, soluble solids, and other impurities in wastewater (Malik et al., 2017; Park, Hong, Tai, & Choi, 2010; Zhao & Yu, 2015). However, most of these methods are not suitable for FVPI wastewater due to its high COD value, high biomacromolecule contents, and high viscosity. Aerobic and anaerobic microbial digestions, widely used to treat the wastewater, would cause the introduction of toxic microbes and a loss of nutrients (Shahrul et al., 2013). Membrane separation technologies allow the recovery of the bioactive compounds, but the high viscosity of the

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Table 1–Characteristics of wastewater discharge from various industries in China.

Sector	Industrial waste water treated (10000 tons)	Industrial waste water discharged (10000 tons)	COD discharged (ton)	Ammona nitrogen (ton)
Total	4,998,694	1,869,626	2,745,819	210,466
Mining and processing	630,167	219,241	176,324	6,929
Processing of petroleum, coking, and nuclear fuel	73,453	84,019	90,328	15,850
Extraction of petroleum and natural gas	100,211	6,146	9,824	544
Processing of food from agricultural products	114,709	139,166	440,584	18,774
Manufacture of foods, wine, drink, refined tea, and tobacco	113,302	128,185	298,399	16,973
Manufacture of textile, textile wearing, and apparel	209,991	213,922	258,304	18,405
Manufacture of leather, fur, feather products, and footware	20,099	22,628	48,556	3,704
Manufacture of paper and paper products	374,419	275,501	478,190	16,319
Manufacture of raw chemical materials and chemical products	393,362	263,665	335,976	66,535
Others	6,452	9,800	19,930	796

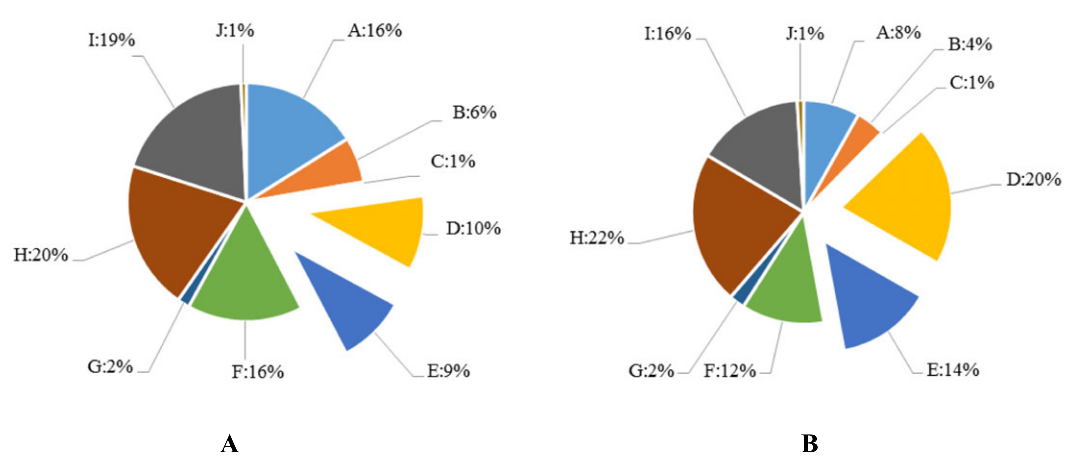

Figure 1–Wastewater and COD discharge from various industries in China. (A) Proportion of various industrial wastewater discharged; (B) Proportion of COD in various industrial wastewater: A, mining and processing; B, processing of petroleum, coking and nuclear fuel; C, extraction of petroleum and natural gas; D, processing of food from agricultural products; E, manufacture of foods, wine, drink, refined tea and tobacco; F, manufacture of textile, textile wearing and apparel; G, manufacture of leather, fur, feather products, and foot ware; H, manufacture of paper and paper product; I, manufacture of raw chemical materials and chemical products; J, others.

wastewater will cause serious membrane fouling and inefficient separations (Hang et al., 2015a). In addition, these generally nontoxic bioactive substances have a risk of being contaminated with toxic solvents or chemicals that will be used in the wastewater treatments, which works against bioactive compound recovery. Another limitation for recovery of the nutrients from FVPI wastewater is that the nutrient contents of waste streams from different industries are quite different, such as pectin in fruit-processing wastewater, and phenolic compounds in edible oil industry, requiring tailored recovery technologies and conditions. Therefore, this review summarizes the challenges and advances of the recovery of bioactive nutrients from different FVPI wastewater of the fruit- and beverage-processing industry, soybean products industry, starch industry, and edible oil industry. The review summarizes the physicochemical properties of several types of wastewater, various technologies for nutrient recovery from wastewater, and highlighted the potential for resource utilization of FVPI, as well as prospect new technologies that FVPI can be used for nutrient recovery.

Methods

This study focuses on nutrient recovery from wastewater of FVPI; wastewater here was taken as processing water and liquid waste. Therefore, individual literature about semisolid waste is included. The review is based on the scientific literature, but, not exclusively, data from official websites and book chapters are also mentioned.

Perspectives in Nutrient Recovery from FVPI Wastewater

There are an increasing number of studies focusing on the nutrient recovery and water reuse, and the concept of zero discharge has recently been proposed in many areas of industrial productions; food industry is no exception (Lee & Okos, 2011; Tabassum, Zhang, & Zhang, 2015; Tong & Elimelech, 2016; Wang et al., 2015). However, no further indication was shown about nutrient recovery and application in most of studies, and the substances recovered were usually treated in a low-value way as fertilizer and

Table 2–Characteristics and treatments of wastewater from FVPI.

Type of food industry	Characteristics of wastewater	Nutrient content	Water discharge	Wastewater treatment	References
Fruit and beverage industry	BOD5 (500 to 6100 mg/L) COD (806 to −7732 mg /L)	Phenolic compounds, organic acids, pectin,	1800 t wastewater for per 1 t canned fruit products 220 to 870 L for per 1 L products beer products 22.5 m^3 for per 1 m^3 beverage products	Aerobic and anaerobic digestions (UASB, ABR, ASBR)	Alkaya and Demirer (2015), Amuda and Amoo (2007), El-Kamah, Tawfik, Mahmoud, and Abdel-Halim (2010)
Soybean products industry	High COD (>16000 mg/L) Total solids (18200 mg/L) Total suspended solids (4000 mg/L)	Whey soy proteins(4,000 mg/L) (lipoxygenase, beta-amylase, soybean agglutinin, etc.) Soybean isoflavones (100 mg/L) Soybean saccharides	20 t wastewater for per soybean protein isolates per 1 t	Aerobic and anaerobic digestions (UASB, ABR, ASBR)	Jiang et al. (2011), U.S. Environmental Protection Agency (1990)
Starch industry	High COD (>1000 mg/L) and BOD High soluble substances	1.5% crude protein	5 t wastewater for per 1 t starch 1,000 kg of potatoes releases 5 to 12 m^3 of potato juice	Aerobic and anaerobic treatments Floucculation Membrane processes	Wojnowska et al. (1982)
Edible oil industry	For olive oil: COD (45000 to 220000 m g/L) BOD_5 (35000 to 100000 mg /L) TSS(1000 to 9000 mg /L)	Olive oil industry (per 100 g FW): 4 to 16 g organics (sugars, polyphenols, fibres, etc) 0.4 to 2.5 g inorganic compounds (potassium salts and phosphates)	For olive oil industry 0.5 to 1.5 m^3 for every ton of olive processing	Aerobic and anaerobic treatments Electrocoagulation Membrane processes	Davies et al. (2004), Rahmanian, Jafari, and Galanakis (2014)
	For palm oil: BOD_5 averages about 25000 mg/L COD of 50000 mg/L, SS of 18000 mg/L	Palm oil industry: Carotene, protein, carbohydrate, nitrogenous compounds, lipids and minerals, etc.	For palm oil industry 2.5 t of POME are produced for every ton of oil extracted in an oil mill.		Ahmad et al. (2010), Wu et al. (2007)

feed or waste oil to be sold (Lee & Okos, 2011; Tabassum et al., 2015).

Most researchers currently focus on the valorization of manufacturing waste. However, the nutrients in wastewater are receiving less attention in food industry. The rich nutrients present in FVPI wastewater are drawing high interests from researchers on the valorization of manufacturing. Thus, the recovery of nutrients and recycling of water from FVPI wastewater will have great economic potential. Furthermore, the bioactivities and properties of such recovered nutrients have many applications in the food industry as food ingredients for functional and nutraceutical foods as well as the pharmaceutical industry, which may bring great economic benefit in spite of the fact that it will be a hard process for products developed to find market share (Figure 2). A few studies have estimated the nutrients presented in FVPI wastewater and indicated the values of bioactive compounds recovery (Russo et al., 2014). The bioactive substances recovered in the wastewater of FVPI by different technologies and their applications are described in this review.

Fruit and beverage industry

There is a great need for the valorization of fruit-processing wastes such as pomace, peel, and pellets (Satari & Karimi, 2018). Wastewater, however, is rarely considered for nutrient recovery, though they are also containing an abundance of nutrients, including polysaccharides, proteins, and secondary metabolites such as phenolic acids, flavonoids, anthocyanidines, anthocyanins, carotenoids, and saponins (Banerjee et al., 2017). Several reports related to nutrient recovery in the FVPI were introduced in the following sections.

Polysaccharides. Pectin is heteropolysaccharide commonly found in terrestrial plants and plays an important role as a gelling agent, stabilizer, and a fat replacer for food applications in the food industry. In human body, pectin exhibits various functions including decreasing blood lipids for combating various types of cancers (Naqash, Masoodi, Rather, Wani, & Gani, 2017). An investigation conducted on pectin in 26 food waste process streams, although the pectin structures and yields present a very high diversity according to the different origin, the results showed that all of these process streams could be used as valuable source of pectin (Müller-Maatsch et al., 2016). There has been much research on pectin extraction from fruit-processing wastes; therefore, the potential of resources utilization of wastewater has recently received increased attention.

An industrial-scale process for pectic polysaccharides recovery has been designed in citrus canning processing that mainly included water reuse, filtration, and ethanol precipitation. Approximately 0.30% and 0.45% (w/v) of pectic polysaccharides could be obtained from reused acidic and basic effluents, respectively. Estimated output value of approximately $1.8 million annually was achieved in factory production (Chen et al., 2016). A pilot-scale recovery of low molecular weight fraction including oligosaccharides (about 11 mg/mL) and flavonoids (~3 mg/mL) by alcohol and filtered water through distillation and water desalting by electrodialysis was designed. The recovered flavonoids demonstrated remarkable inhibition of human nonsmall cell lung cancer PC-9

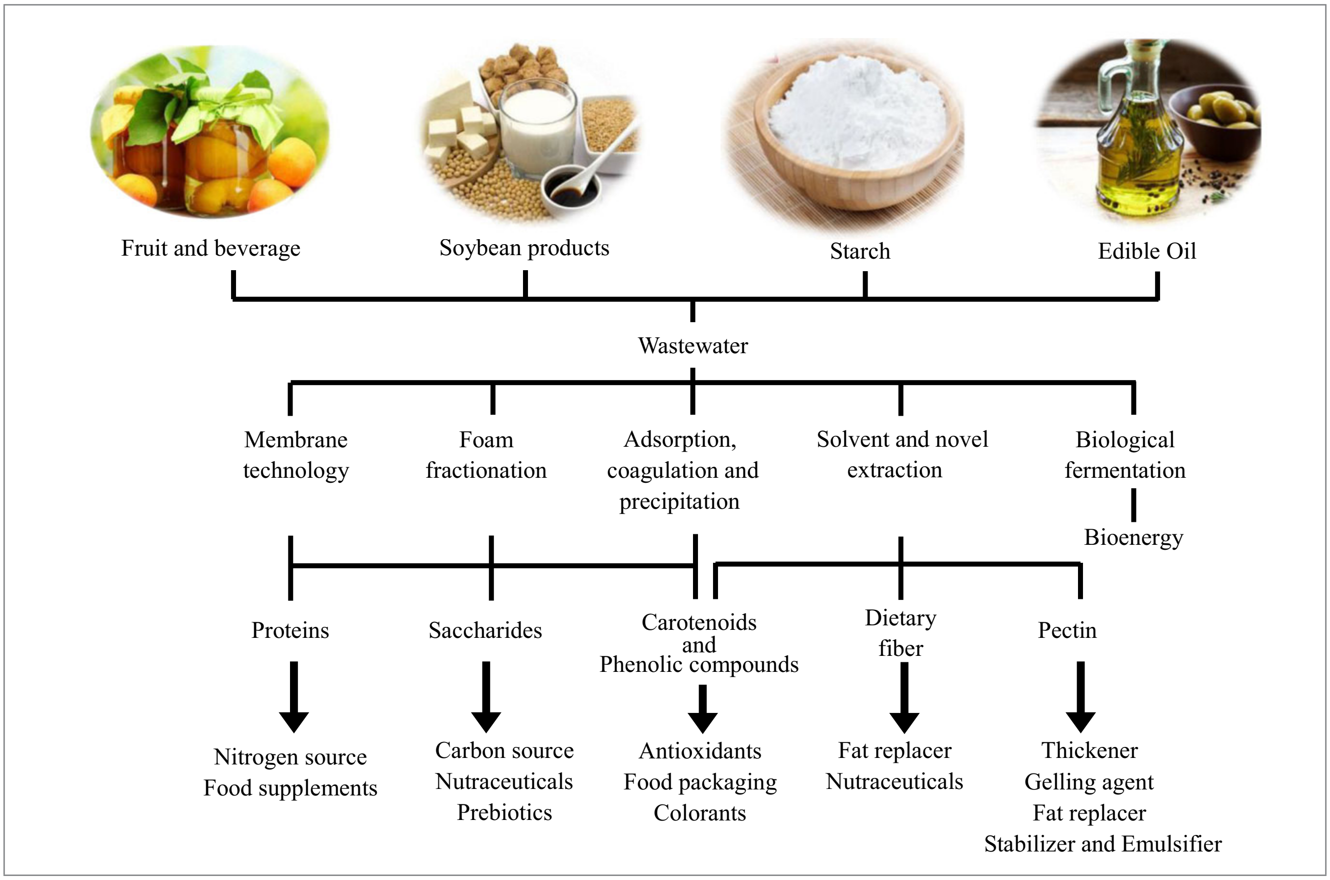

Figure 2–Application of nutrients recovered from wastewater of FVPI.

cells in nude mice (Yan et al., 2018). The pectin extracted from wastewater was then evaluated, and their application as a fat alternative to replace fat in ice cream indicated that this type of pectin has potential to be used as fat replacer (Zhang et al., 2018).

Carotenoids. Carotenoids, regarded as the most important food antioxidants, have been associated with a decreased risk of chronic diseases (Desmarchelier & Borel, 2017). Carotenoid sources, their general characteristics, applications, and the great importance in human health lead more attention to the valorization of the daily production and discharged industrial bioresidues derived from vegetable peels, seeds, and pericarp (Martins & Ferreira, 2017). Therefore, carotenoids recovery from wastewater has gained interest in recent years.

Carotenoids are extracted from peach-processing wastes by ethanol and result in yield of 168.59 μg/g dry weight (DW) of total carotenoids including 67.55 μg/g of β-carotene, 86.75 μg/g of cryptoxanthin, 12.08 μg/g of zeaxanthin, and 2.2 μg/g of lutein (Vargas, Jablonski, Flôres, & Rios, 2016). Rhamnolipid was used as a foam stabilizer, the fractionation for lycopene recovery from the tomato-processing wastewater. Under the optimal conditions of 1.5 g/L rhamnolipid concentration, temperature of 50 °C, pH of 7.0, volumetric gas flow rate of 150 mL/min, and loading liquid volume of 500 mL, an enrichment ratio and recovery of the lycopene were 4.4 and 83.4%, respectively. The rhamnolipid used in this extraction could be reused (Liu, Wu, Wang, Li, & Ding et al., 2015).

Organic acids. Organic acids, including citric acid, lactic acid, malic acid, acetic acid, succinic acid, fumaric acid, and ascorbic acid, are widely used in the pharmaceutical and food industries. Apple pomace is the mainly used as substrate for organic acid production by solid-state fermentation (Dhillon, Kaur, Sarma, & Brar, 2013; Shojaosadati & Babaeipour, 2002). Wastewater from these processes may be considered as potential resource of recovering organic acids.

Recovering tartaric acid with bioactive polyphenolics from wine lees was investigated by using cation exchange resin, and the recovery of 74.9% tartaric acids was reached. The evaluation results indicated that the process was cost-effective and environmentally friendly and can recover tartaric acid and avoid the waste calcium sulfate sludge of the conventional process (Kontogiannopoulos, Patsios, & Karabelas, 2016). L-malic acid could be recovered by bipolar membrane electrodialysis, a novel kind of electrodialysis for preparation of acid and base, from beverage industrial wastewater, achieving 93 to 97% recovery with an energy consumption of 1.15 to 1.27 kWh/kg L malic acid (Lameloise & Lewandowski, 2012).

Phenolic compounds. Fruits and vegetables are abundant sources of phenolic compounds. The antioxidant and cytoprotective activities of polyphenols in fruit and vegetable wastes and by-products are important in demonstrating their potential health benefits in human nutrition. This also provides considerable economic benefit to food processors; hence, an increasing effort has been made to recover these from the wastes (Aires, Carvalho, & Saavedra, 2017; Hildeh, Christian, & Nigel, 2009; Kabir et al., 2015).

A nanofiltration (NF) process for recovering phenolic compounds, including anthocyanins and flavonoids, from press liquors was obtained from pigmented orange peels, and the separation of phenolic compounds and sugars was carried out using four kinds of NF membranes with different molecular weight cutoffs. The highest yields of anthocyanins and flavonoids were 89.2% and 70%, respectively (Conidi, Cassano, & Drioli, 2012). This membrane process was exploited for separation of tartaric acid and polyphenolic compounds recovered from winery waste lees (Kontogiannopoulos et al., 2016). The concentrate, passed through the 1 kDa membrane was polyphenol products with antioxidant activity ($EC_{50} = 10.0$ mg sample/mg DPPH), was obtained for further purification (Kontogiannopoulos, Patsios, Mitrouli, & Karabelas, 2017).

At present, the nutrient recovery from FVPI is mostly from solid wastes, including peel, pomace, pellet, and seeds by extraction. Although high contents of valuable nutrients are in wastewater, the progress is limited due to lack of suitable technologies.

Soybean products industry

The soybean products, a traditional and popular food, are increasingly consumed around the world, especially in many Asian countries. As one of the biggest discharges in food industrial wastewater, more than 3 million tons soybean-processing wastewater was discharged into effluent annually in China (Zong & Ma, 2008). The wastewater contains high loads of COD of over 16000 mg/L, total solids of 18200 mg/L, and total suspended solids of 4000 mg/L (EPA, 1990), and other nutrients recovery of proteins, isoflavones, and polysaccharides in the soy-processing wastewater has drawn great interest in the food-processing research area.

Soybean protein. Soybean protein, produced by the soybean-processing industry, has major health benefit effects on appetite, calorie intake, anthropometry, blood pressure, fasting blood sugar, and lipid profile of the obesity (Tahavorgar, Vafa, Shidfar, Gohari, & Heydari, 2014, 2015). A number of studies have shown the soy protein concentrates can be used as material for active packaging to prevent foodstuff from the adverse effects such as oxygen, moisture, and UV irradiation (Ciannamea, Stefani, & Ruseckaite, 2016; Han, Yu, & Wang, 2017) and in other food applications for their antioxidant activities (Moure, Domínguez, & Parajó, 2006; Ranamukhaarachchi, Peiris, & Moresoli, 2016; Yoo & Chang, 2016).

The foam separation and ultrafiltration (UF) and other membrane technologies have been developed to recover proteins from soy industry wastewater. Foam fractionation can be used for the removal of surface-active contaminants from wastewater streams through two steps including interfacial adsorption in the liquid phase and foam drainage in the foam phase (Li, Wu, Wang, & Liu, 2014).

A hybrid system with UF and reverse osmosis (RO) has been designed for the recovery of soluble substances from soybean soaking water. The concentrates from the UF-RO system can serve as a raw material for culturing algae or preparing animal feeds. In addition, the RO permeates from the two-stage system can be reused, which fully demonstrates the advantages of membrane technology (Hang et al., 2015b). A two-stage foam separation technology was developed with the column of inclined foam phase in which recovery of the proteins reached 80% in the second stage after initial enrichment in the first stage (Jiang, Wu, Li, & Liu, 2011). Foam fractionation of soy proteins from waste was conducted in which the protein composition was effectively recovered at 30.6% and contained a Kunitz trypsin inhibitor (the major ingredient), lipoxidase, ß-amylase, and lectinan (Li et al., 2014).

Isoflavones. Soy isoflavones are diphenolic compounds present in plants, such as soybeans, red clover, and kudzu root, and there is growing evidence that they exhibit strong bioactivities as antiobesity (Wang, Wang, Pan, & Ho, 2017), anticancer (Kucuk, 2017), antioxidant (Szymczak et al., 2017), and other beneficial effects on the human body (Hu et al., 2017; Kucuk, 2017; Szymczak et al., 2017; Vázquez, Flórez, Guadamuro, & Mayo, 2017; Wang & Wu, 2017; Wang et al., 2017).

Soy isoflavones are usually present in soy wastewater during the production of soy protein isolates. However, most soy processers discharge large quantities of the wastewater to sewage treatment plants (Wang & Murphy, 1994). The isoflavone recovery is rarely reported. A membrane intensive scheme was developed based on a laboratory-scale process in which isoflavones were recovered from the waste stream while soymilk was prepared as the main product, and isoflavones were concentrated by RO (Xu, Lamb, Layton, & Kumar, 2004).

A combination of foam fractionation and acidic hydrolysis using chitosan microspheres to separate isoflavone aglycones with a desorption ratio of isoflavone aglycones finally reached to 94.82% recovery rate (Liu, Wu, Wang, Li, & Yin et al., 2015). Isoflavone aglycones recovered by foam fractionation have higher antioxidant activity and bioavailability than other soy isoflavones (Cao et al., 2012; Liu, Zhang, Wu, Wang, & Wang, 2013). In addition to the recovery of proteins and isoflavones from soy wastewater, a study also was conducted to recover oligosaccharides (Matsubara, Iwasaki, Nakajima, Nabetani, & Nakao, 1996). Such oligosaccharides are well known to have a benefit for intestinal health.

Starch industry

There are varieties of starch products, including corn, wheat, potato, and tapioca starch. The potato starch industry, for example, processes 1 metric ton of potatoes' starch to generate 5 to 12 m^3 of potato juice containing 30 to 41% of proteins in total solids (Wojnowska, Poznanski, & Bednarski, 1982). This type of wastewater contains high COD (more than 1000 mg/L) and high soluble substances, including saccharides and proteins.

Protein. Potato starch-processing wastewater has been reported to be a good source of protein; foam separation and membrane processes are primarily applied for protein recovery. An inclined foam separation column has been used to recover the protein. Under optimal conditions, the recovery and enrichment ratios can reach to 84.1% and 1.3%, respectively. Moreover, the residual solution had good qualities, thereby reducing the pollution of the wastewater (Mu, Liu, Zhang, & Sun, 2014). The methods combining several processes, including sedimentation, centrifugation, paper filtration, microfiltration (MF), and UF have also been used to achieve high yields of concentrated proteins. With these multiple pretreatments, a large portion of starch and fiber are removed, and 30% reduction of UF membrane fouling is achieved by MF pretreatment while at the same time increasing the purity and concentration of protein (Dabestani, Arcot, & Chen, 2017). Other studies were also conducted to recover proteins using techniques including expanded bed adsorption (EBA) (Strætkvern & Schwarz, 2012) and simulated moving bed chromatography technology (SMBC) (Andersson, Sahoo, & Mattiasson, 2008).

The sporamin of sweet potato, initially called ipomoein, is the major storage proteins in sweet potato tuberous roots (Jones & Gersdorff, 1931) that present more than 80% of the total soluble protein (Maeshima, Sasaki, & Asahi, 1985). Sporamin has antitumor activity, and its mechanism of action is under investigation (Ghayoumian, Alihashemi, Omidioskuie, Nikokar, & Kabiri, 2017; Qian et al., 2017; Qian, Qi, Chen, Zeng, & Yao, 2017; Yao & Qian, 2011). There was an effort made to obtain sporamins from sweet potato extract solution using batch foam fractionation. By adjusting pH values, the sporamins and β-amylase were recovered one after another, and the high total protein was recovered up to 87% (Ko, Loha, Prokop, & Tanner, 1998). In another study, the sporamin was obtained by foam fractionation from potato starch extraction wastewater. A new technology, natural fermentation of starch slurry, was used to lower the pH without adding any acid. This resulted in sporamin recovery of up to 87.9% (Li & Mu, 2012).

Polyphenol oxidase. Polyphenol oxidase (PPO) is a group of Cu-containing enzymes that can catalyze the oxidation of phenols to *o*-quinones and cause undesirable enzymatic browning in fresh-cut fruits (Mayer, 2006; Taranto et al., 2017). The PPOs have multiple functions and have been widely applied in a range of industries, such as in organic synthesis, the treatment of industrial dyes, wastewaters, pulp, and paper bleaching, and in the removal of phenolics to increase the stability of beverages (Cheng et al., 2015). PPOs are typically nutrients richly present in potato starch-processing waste. A method for recovering PPOs used pH adjustment for PPO precipitation and separation of both PPO and β-amylase from sporamins by 50% acetone and precipitation of sporamins by 80% acetone. This process resulted in 4.3×10^5 units of PPO, 4.0×10^6 units of β-amylase, and 8.70 g sporamins (Cheng et al., 2015).

Different materials processed in starch industry, including potato, yam, cassava, corn, and bean, lead to wastewater with different features and characteristic components, and these need to be investigated and ensure efficient nutrient recovery. A large number of recovery processes rely on anaerobic bioreactors (Antwi et al., 2018; Qin et al., 2018).

Edible oil industry

Olive oil manufacturing process yields 20% of olive oil, 30% of olive cake, and 50% aqueous liquor (Goula, Chasekioglou, & Lazarides, 2015). The aqueous liquor, namely olive mill wastewater (OMW), is a mixture comprising of 4 to 16 g organics (sugars, nitrogenous compounds, volatile acids, fats, polyphenols, and fibers) and 0.4 to 2.5 g inorganic compounds (mainly potassium salts and phosphates) per 100 g fresh weight (Davies, Novais, & Martins-Dias, 2004). The palm oil mill effluent (POME) represents another example, and these contain nutrients like carotene, high concentrations of protein, carbohydrates, nitrogenous compounds, lipids, and minerals (Wu, Mohammad, & Jahim, 2007).

Phenolic compounds. Phenolic compounds have been the focus of research on the nutrient recovery from edible oil industry wastewater (Bertin, Ferri, Scoma, Marchetti, & Fava, 2011; Zbakh & Abbassi, 2012). A large number of studies have revealed that OMW and POME are perceived as rich sources of natural phenolic compounds for development by food industry. These not only improve the sensory quality of food, but they can enhance the antioxidant capacity in fatty food matrices (Wang, Wang, Zhang, & Li, 2017). In addition, the recovered polyphenols, mainly in form of hydroxytyrosol, are also of interest for the food industry, cosmetic industry, or pharmaceutical industry (Dammak, Neves, Isoda, Sayadi, & Nakajima, 2016; Galanakis, Tsatalas, & Galanakis, 2017).

A 3-year study introduced a comprehensive membrane system consisting of MF, UF, NF, and RO. After running this process over years, the retentates from RO showed high phenolic content (78.6 mg/g DW) with a potassium content of 22 g/kg. The retentates represent good sources of natural antioxidants and potassium (Bellumori, Cecchi, Romani, Mulinacci, & Innocenti, 2017). A continuous-flow ion exchange process was examined for phenol recovery from OMW. The column regeneration exhibited nearly 100% phenolic yield, and this type of phenolic solution was easily concentrated and can be used in food, cosmetics, or pharmaceutical sectors (Víctor-Ortega, Ochando-Pulido, & Martínez-Ferez, 2016). A clean technology integrated centrifugation, batch evaporation, and drowning-out crystallization-based separation process was designed for the separation of polyphenols from OMW. The results showed that the highly concentrated polyphenols isolated up to 75% (w/w). Moreover, this isolate was even accepted as food grade (Dammak et al., 2016).

Carotenes. Comparing the fruit-processing wastewater, the olive and palm oil wastewater is also rich in carotenoids. Several examples of carotene production by different technologies are presented as follows.

The edible oil industry wastewater is important for containing oil and carotenes. The adsorption chromatography process has been adopted to recover the carotenes with a content about 450 ppm from POME. Carotenes can then be concentrated to about 25-fold using adsorption chromatography (Ahmad, Chan, Shukor, & Mashitah, 2010). Researchers isolated *Microbacterium* sp., a carotene-producing bacterium, from olive oil wastes. The bacterial growth and carotene production were accompanied by a decrease in carbon and nitrogen source levels. The results suggested that the waste can be a potential substrate for carotene recovery (Borroni, González, & Carelli, 2017). In addition, Tween 80 was explored to separate phenols and carotenoids from OMW. The DPPH test demonstrated that the recovered carotenoids maintained high antiradical activity (Katsoyannos et al., 2012).

Pectin. Pectin exists widely in plants and has important applications in food industry. Continuous progress has been made in technologies of pectin recovery from fruit-processing waste. With the trend of resource utilization and nutrient recovery, edible oil wastewater has become a potential source of pectin as well.

Purified pectin of low molecular weight in the range of 2 to 40 KDa was extracted from olive oil by-products, named "alperujo," by steam treatment at 160 °C. The extracts contain high content of neutral sugars and high percentages of acetylation displayed similar emulsion stability to apple pectin, and a considerable bile-acid binding activity paralleling the values obtained for citrus pectin (Rubio-Senent, Rodríguez-Gutiérrez, Lama-Muñoz, García, & Fernández-Bolaños, 2015). Evidence was presented that the pectin extracted from alperujo exhibited better biological properties than citrus and apple pectin (Rubio-Senent et al., 2015).

Protein. Protein in POME is also usually recovered by membrane technology. For example, the pretreatment with depth and surface filtration prior to UF was conducted. Proteins and carbohydrates, the retentate, can be used as fertilizer or animal feed. Moreover, the study explored the effects of molecular weight cutoff and applied pressure on membrane fouling and proteins recovery (Mohammad, Yap, & Wu, 2009; Wu et al., 2007). The solid-state fermentation experiments were performed with *Paecilomyces variotii* for two-phase olive-mill waste treatments, the semisolid waste. A 46% increase of the protein content was achieved from the fermented product. The amino acid profile of which was significantly improved, and the product could be used as animal feed (Giannoutsou, Katsifas, Geli, & Karagouni, 2012).

Dietary fiber. The components of dietary fiber in olive during three main ripening stages were examined. The results suggested that olive waste was a potential source of dietary fiber (Galanakis, 2011). Based on these data, a novel method to recover dietary fiber was developed. The process involves the treatment of waste with mixtures of ethanol and acids followed by precipitation of alcohol insoluble residue (AIR) about 64.8 g/100 g waste dry matter with boiling concentrated ethanol, from this 5.1 g total fiber/100 g AIR was obtained. The analysis results showed that the fiber was composed of galacturonic acid, arabinose, and glucose (Galanakis, Tornberg, & Gekas, 2010). In a subsequent study, the AIR was separated into different fractions including water-soluble and insoluble AIR that can be used as fat replacement in meatballs (Charism, Eva, & Vassilis, 2010).

A wide variety of POME and OMW nutrient recovery processes have been reported. An integrated system based on these technology for recovery of these nutrient products have been established. Bioactive compounds obtained can be expended to other kinds of edible oil industry such as peanut, rapeseed, corn, soy, rice bran oil; however, they have not yet been reported.

Problems of Wastewater Recovery

The loss of valuable nutrients in the wastewater of the FVPI is a problem that the industry recently has been tackling and needs to overcome some challenges in safety assurance, improvement of technologies, revising regulations and laws, and cost and customer factors.

Safety assurance

The FAO and the World Health Organization (WHO) urged all countries to be more vigilant about food safety as early as 2007. It was pointed out that there is a lack of adequate food safety systems. The problems, such as the presence of microorganisms, residues of agricultural chemicals (pesticides, veterinary drugs, etc.), and unauthorized food additives, never stop (FAO, 2007). These issues make the recovery and reuse of compounds from FVPI wastewater always controversial.

The microbiological risk assessment in foods has been identified as an important area of research by the Codex Alimentarius Commission (CAC) (CAC, 1999). Many microbes are eliminated in each step of wastewater treatment, as summarized by NRC (National Research Council) in Table 3, they may cause security problems such as foodborne diseases though (FAO, 2007). The nutrients recovered from wastewater, which certainly contain microbes, need monitoring and management. In addition, the chemical agents residues during food processing also result in safety issues of the nutrients recovered.

However, when it comes to wastewater and food safety, the focus has mainly on the use of wastewater in irrigation nutrient removal; products of recovered nutrients are rarely discussed. A system of hazard analysis critical control point (HACCP), adopted by CAC, to identify, evaluate, and control hazards which are significant for food safety was established in food industry (CAC, 1999). Nevertheless, a tool to assess hazards and establish control systems that focus on the prevention of the reutilization of recovered nutrient has not yet been reported.

Technologies

At present, some kinds of technologies such as membrane technology, foam fractionation, and extraction are commonly used for nutrient recovery; however, these technologies have not achieved good efficiency yet. All the technologies for nutrient recovery in food industry wastewater are summarized in Table 4.

Physical technologies.

Membrane technology. Membrane technology appears as a good alternative for nutrient recovery, and MF, UF, NF, and RO are the most common pressure-driven processes. These membrane processes can separate a feed into two parts: permeate and retentate streams. The membrane, a porous filtration medium, acts as a barrier to prevent masses movement of selected phases in applications of in water and wastewater treatment, and they are made of different kinds of materials. MF membranes are made of a wide range of inorganic materials (such as alumina, zirconia–carbon composites, ceramics, and so on) and natural and synthetic polymers (such as polypropylene, polycarbonates, polysulfone, and so on). UF membranes are mainly made of polysulfone-type materials (such as polyether sulfone, polyphenyl sulfone, sulfonated polysulfone, and so on) Most NF membranes are multiple-layer thin-film composites of synthetic polymers such as polyamide, polyvinyl alcohol, sulfonated polysulfone, and sulfonated polyether sulfone. Salt rejection by NF membranes is mainly due to electrostatic interaction between the ions and the NF membrane. Cellulose acetate and derivatives are widely used as the RO membrane. Thin-film composite membranes containing a polyamide-separating barrier on a polysulfone or polyethylene will be the material of choice for RO applications. The membrane module properties mainly include membrane material (for example, a change in the polymer or backing material), pore size (nominal and absolute), porosity, permeability, membrane symmetry (that is, symmetric, asymmetric, or composite) (Wang, Chen, Hung, & Shammas, 2011).

Different pore sizes of the membranes determine applications of these technologies, for example, RO is widely used for seawater desalination because it can essentially reject salts, whereas NF is a process-separating monovalent and multivalent salts so that it can effectively remove hardness for drinking water production. The rejected species of UF include sugars, biomolecules, polymers and colloidal particles, so it has lots application in organic matters separation, especially in food industry, such as whey production in dairy industries and wine or fruit juice clarification. The MF membrane has pore sizes ranging from 0.1 to 10.0 mm, through which microorganisms cannot pass, according to which the typical application of MF is disinfection in water treatment (Wang et al., 2011). The factors influencing membrane performance include pore size, operating parameters, membrane material, membrane configuration, and so on (Castro-Muñoz, Barragan-Huerta, & Fíla, 2018).

For nutrients recovery, membrane technologies have many advantages over traditional water or wastewater treatment processes; the main advantage of the membrane process system lies in the lower energy consumption, and other advantages as follows (Castro-Muñoz et al., 2018):

(a) Membrane separation systems are easy to operate, and fewer chemicals are used in the process.
(b) Microorganisms such as bacteria and viruses can be removed by size exclusion.
(c) Membrane systems occupy less floor space in comparison to the conventional treatment systems.
(d) Permeates and concentrates can be both suitably reused, which may reduce the intake of raw water and provide savings on raw water–processing costs (Wang et al., 2011).
(e) Nonuse of additional phases and heating source in the membrane operations are advantageous for biologically active products aimed at human consumption (Conidi, Cassano, & Garcia-Castello, 2014).

Despite the advantages mentioned above, a number of researchers have focused on controlling membrane fouling; the

Table 3–Average numbers of microorganisms found in various stages of wastewater and sludge treatment.

Microbe	Number per 100 mL of effluent				Disease
	Raw sewage	Primary treatment	Secondary treatment	Tertiary[a] treatment	
Fecal coliform MPN[b]	1000000000	10000000	1000000	<2	Dysentery Typhoid fever Gastroenteritis
Salmonella MPN	8000	800	8	<2	Salmonellosis Typhoid fever
Shigella MPN	1000	100	1	<2	Bacillary Dysentery Shigellosis
Enteric virus PFU[c]	50000	15000	1500	0.002	Gastroenteritis
Helminth ova	800	80	0.08	<0.08	Ascariasis Taeniasis Ancylostomiasis Trichuriasis
Giardia lamblia cysts	10000	5,000	2,500	3	Giardiasis

[a]Coagulation, sedimentation, filtration and disinfection.
[b]MPN = Most probable number.
[c]PFU = Plaque-forming units.

membrane fouling remains a major barrier, which still cannot be completely avoided especially for various food industrial material (Bagheri & Mirbagheri, 2018; Meng et al., 2017). Besides, biofouling caused by the bioactive compounds rises chemical demand for cleaning purposes, which increases the production of sludge for treatment or disposal, leading to an environmental problem that needs to be dealt with (Castro-Muñoz et al., 2018).

Membrane processes are often affected by their cost. The cost of a given installation is determined by two parts: the capital cost and the operational cost. The capital cost, or the installation investment, can be further divided into three parts: membrane modules; costs of piping, pumps, electronics, and vessels; and pretreatment and posttreatment. Definitely, the membrane costs for carrying out the separation could be relatively high, but the cost of the recovered product tends to be higher. The cost of the high-added value solutes (for example, polyphenols, anthocyanins, sugars, proteins, and dietary fibers) is high based on the traditional methods used for extracting them (Castro-Muñoz, Conidi, & Cassano, 2018); Besides, membrane cost may be rather low in the future providing better membrane availability. With a decrease in membrane price and development of new membrane materials, membrane systems can achieve more effective water treatment efficiency with economic feasibility and membrane systems will require less footprint due to their compactness (Wu, 2019).

Statistical data have shown that wastewater recovery systems market size for 2016 was valued over USD 20 billion and is predicted to expand over 8% by 2024, among which food and beverage part is shown to be augmented by increasing water usage and growing consumer affinity toward processed food. In addition, membrane filtration wastewater recovery system market is predicted to expand over 9% by 2024. Declining membrane costs along with their increasing operational efficiency will enable the technology expansion across diverse water treatment solutions; continuous technological advancements coupled with increasing stringency of water quality criteria will further stimulate the technology adoption (Global Market Insights, 2018). Furthermore, an increasing number of researchers have suggested that membrane technologies recovery pilot trials have the potential to scale up to large-scale application with lower cost (Nor, Ramchandran, Duke, & Vasiljevic, 2016). So we may envision great prospects on large-scale application of wastewater recovery of food industry, especially FVPI, by membrane technology, though most of nutrients recovery cases are still at the trial stage.

From an environmental perspective, many researchers have pointed out that nutrients recovery by membrane technologies have positive effects on reduction of energetic consumption and environmental impact (Conidi, Drioli, & Cassano, 2017); for a membrane process, it can compensate for several treatment units in conventional water treatment design. These characteristics are of prime importance to water professionals in their endeavor to mitigate the negative impact of wastewater disposed in the natural ecosystems of the earth (Castro-Muñoz et al., 2018).

Adsorption. Adsorption is often used for phenolic compounds or proteins from FVPI wastewater, with the advantages of low operational costs and recyclability of adsorbents. However, the lack of selectivity and sometimes the clogging of a packed bed may lead to a product that requires further purification, such as the phenolic compound products obtained from OMW (Frascari et al., 2016). A new attempt about preparation of grape pomace activated carbon, developed from grape pomace, for polyphenols recovery from wine wastewater was reported recently (Nayak, Bhushan, & Rodriguez-Turienzo, 2018); so the use of various newly discovered novel absorbing materials provides a new thinking.

Foam fractionation. Foam fractionation, known as "protein skimmers," is very effective in the separation of surfactant from aqueous solution. Now it is commonly used for enrichment of bioproducts such as protein recovery from FVPI wastewater, for it has advantages of simple equipment and environmental compatibility (Shi & Wu, 2016), although foam fractionation is only suitable for protein solutions at low concentrations (Wenzig, Lingg, Kerzel, Zeh, & Mersmann, 1993). Furthermore, some nonsurface-active materials such as riboflavin and folic acid are reported to be recovered by foam fractionation in recent years (Huang, Wu, Liu, Hu, & Li, 2016), which shows a good development for nutrient recovery, but few cases are reported on FVPI or food industrial wastewater.

Chemical technologies.

Precipitation. Precipitation is one of the most popular technologies that play an important role in protein and enzyme recovery normally using salts, polyelectrolytes, and organic solvents as precipitants and isoelectric precipitation. However, it may lead to risk of denaturation and products usually require further purification due to the precipitation which is not very selective (Cheng et al., 2015). Now, studies have focused on nitrogen and phosphorus recovery from industrial wastewater

Table 4–Technologies of nutrients recovery from wastewater of FVPI.

Type of food industry	Recovery technologies	Added-value resources	Limitations	Advantages	References
Fruit and beverage industry	Ion exchange	Phenolic compounds	High consumption of acid and base, organic matter leaching from resins	Reproducibility of resins and simplicity of devices.	Kammerer, Schweizer, Carle, and Kammerer (2011)
	Organic solvent extraction	Pectin, carotenoids, and phenolic compounds	High cost of solvent and toxicity of solvent	Simple operation	Chen et al. (2016), Ji and Min (2016)
	SFE, MAE, UAE, PLE, EAE	Carotenoids and phenolic compounds	Many parameters to optimize, coextraction of nontarget classes of compounds	Safety and environment-friendliness, high efficiency	Ferrentino, Asaduzzaman, and Scampicchio (2016)
Soybean Products Industry	Adsorption	Soybean isoflavone and protein	High cost of adsorbents	Simple operation, reproducibility of adsorbents, and conservation of functional qualities	Zong and Ma (2008)
	Membrane processes	Whey soy proteins	Membrane fouling and scaling; high requirement of feed water; high capital and operating cost	Simple operation and high separation efficiency	Cassini et al. (2010), Hang et al. (2015b)
	Foam fractionation	Whey soy proteins and isoflavone aglycones	Problem of recovery of bioactive substances without surface activity	Low-energy consumption, simple devices and operation	Li et al. (2014), Liu et al. (2015)
Starch Industry	Precipitation	PPO, β-amylase, sporamins, and small molecular nutrients	Uncompleted recovery of proteins, and high control accuracy of pH value	Reducing of membrane fouling	Cheng et al. (2015)
	Adsorption	Potato protein			Andersson et al. (2008), Strætkvern and Schwarz (2012)
	Foam fractionation	Proteins			Mu et al. (2014)
	Membrane processes	Potato protein, and polysaccharide			Dabestani et al. (2017)
Edible oil industry	Adsorption	Carotene, phenolic compounds and proteins			Ahmad et al. (2010)
	Solvent extraction	Phenolic compounds, pectin and dietary fiber			Katsoyannos et al. (2012), Rubio-Senent et al. (2015)
	Ion exchange	Phenolic compounds			Víctor-Ortega et al. (2016)

Notes. EAE, Enzyme-Assisted Extraction; MAE, Microwave-Assisted Extraction; SFE, Supercritical Fluid Extraction; PLE, Pressurized Liquid Extraction; UAE, Ultrasound-Assisted Extraction

(Sengupta, Nawaz, & Beaudry, 2015), and unfortunately few studies on protein recovery from the wastewater that is similar to wastewater of FVPI, rich in macromolecule organic components, can be used as the reference (Yang, Sun, Mengyan, & Wang, 2016).

Solvent extraction. Several types of macromolecules, including pectin, proteins, dietary fibers, and others, are often recovered by conventional chemical solvents, such as ethanol, which are economical and easy-to-use, according to the U.S. FDA; ethanol has "GRAS" (generally recognized as safe)" status (Galanakis, 2012). Solvent extraction is widely used in nutrients recovery for water samples, such as recovery of melanoidins and polyphenols by methyl ethyl ketone from sugarcane molasses distillery wastewater (Kaushik, Basu, Raturi, Batra, & Balakrishnan, 2018), saponin by *n*-butanol from the aqueous extract of reetha (*Sapindus mukorossi*) pericarp (Samal, Das, & Mohanty, 2017), and aromatic oils contained higher amounts of citral by n-hexane and ethyl acetate from lemongrass (*Cymbopogon flexuosus*) condensate waste water (Rao, Adinarayana, Kumar, Rajput, & Syamasundar, 2016). However, the low selectivity of extraction is the main disadvantage and requires the further steps to obtain pure targeted compounds, though it is simple to operate (Ji & Min, 2016; Katsoyannos et al., 2012).

Other extraction technologies. In addition to solvent extraction, extraction with less pollution such as enzyme-assisted extraction (EAE), microwave-assisted extraction (MAE), supercritical fluid extraction (SFE), pressurized liquid extraction (PLE), ultrasound-assisted extraction (UAE), are gaining much attention for their beneficial properties of relatively low process cost, mild operating conditions, short process times, and environmental sustainability. These processes have been applied in processing waste for nutrient recovery (Nayak et al., 2015; Tatke & Rajan, 2014), but in a few cases, mostly about by-products, these processes have been applied to liquid samples, for example, fast and sensitive recovery of aroma compounds from the vinegar by SFE (Lu et al., 2011), squalene from wine lees by UAE (Naziri et al., 2016), and acetic acid from fermented wastewater by pressurized CO_2 (Reyhanitash, Zaalberg, Ijmker, Kersten, & Schuur, 2015). These processes are potentially useful for nutrient recovery from wastewater of FVPI. However, the extraction materials are usually solid fruit and vegetable samples like seed, kernel, or other by-products (Alara, Abdurahman, Mudalip, & Olalere, 2018; Thirugnanasambandham, 2017; Roselló-Soto et al., 2015); it may be an indication that concentration of wastewater before extraction is an efficient method for compounds recovery.

The different compositions for each type of wastewater require different treatment systems. A considerable portion of FVPI wastewater is still inadequately managed and reused. Each technology has its advantages and disadvantages. Physical technologies are relatively targeted with complex pretreatment and high costs. Chemical technologies have the advantages of simple operation, while it uses a lot of chemicals agents, and they may have an impact on quality and activity. Therefore, selection processes for appropriate recovery applications are crucial, and to gain acceptance effective treatment systems are most important.

Regulations and laws

The regulation concerning the reuse of FVPI wastewater is far away to be clear. WHO introduced a guideline for water recycling in agriculture and aquaculture early in 1989; it addressed the practice of wastewater reuse in agriculture, greenspace irrigation and aquaculture (WHO, 1989). In 2006, the guideline was revised (WHO, 2006); it included wastewater use in agriculture, which is certainly a method combining water and nutrient cycling, wastewater, and excreta use in aquaculture for procurement of cheap protein, which shares similar goals with resource utilization of FVPI wastewater, but it is not yet universal and has been used with varying degrees of intent and success. In addition, health issues and health protection measures, as well as socio-cultural, environmental, economic, and policy aspects were presented (Victor, Kotter, O'Brien, Mitropoulos, & Panayi, 2008).

A water-recycling HACCP system was established in 2001 (Casani & Knøchel, 2002). Different regulations for food industry and agricultural water use and pollution were proposed using a similar HACCP method to ensure the safety of water reuse (Kirby, Bartram, & Carr, 2003). Some countries in Europe have already adopted the regulations of wastewater reuse in agriculture (Lavrnić, Zapater-Pereyra, & Mancini, 2017).

In 1976, the United States was confronted with serious problems of municipal and industrial waste. The Congress passed a law named the Resource Conservation and Recovery Act (RCRA). However, this act was mainly targeted at solid waste (US EPA, 2017). The definition of recovery just meant the process of obtaining materials or energy resources from solid waste and did not mention about food-processing materials or wastewater. There are scarcely any explicit laws providing guidance or regulation of high value-added utilization of nutrients from FVPI or food industrial wastewater (US EPA, 2014; US GPO, 2012).

Above all, FVPI or food industrial wastewater was rarely mentioned in regulations and laws. The existing regulations governing the use of wastewater should be revisited to consider FVPI and other food industrial wastewater use as a separate issue. Furthermore, according to a range of potential application of the recovered nutrients products in food industry, guidelines and standards are needed to direct production and ensure food safety. Planning without sound mechanisms for implementation is usually a futile exercise. The objectives of nutrients recovery should be pursued by elaboration of more regional policy guidelines as above.

Cost and consumers factors

Although recommendations of nutrient recovery are constantly touted, the concept will be only theoretical without implementation by enterprises and government and support from consumers.

Technology cost requires government a deliberate action of commercial implementation of nutrient recycling and reuse in food industry. Lower-cost traditional methods are often complex and time consuming, and nonsafe with chemical contaminations. With the framework of the EMWater Project "Efficient Management of Wastewater, its Treatment and Reuse in the Mediterranean Countries" funded by EU, pilot plants were designed for applying low-cost techniques for wastewater treatment and reuse. It was pointed out that successful demonstration projects and public awareness programs are necessary to convince people of the benefits (Petta, Kramer, & Baz, 2007). Therefore, the point is to develop efficient technologies and novel products with a high added value to outweigh the high costs for nutrient recovery. An increasing amount of research suggests that nutrient recovery or wastewater reuse can provide both considerable environmental and economic benefits (Chen et al., 2016; Wu et al., 2016).

In addition, consumer acceptance of such products still needs to be demonstrated as potential risks still exist in taking by-products from food processing as the food additives and ingredients (Schieber, Stintzing, & Carle, 2001), and the same goes for the nutrients recovered from wastewater. Furthermore, consumer protection must always take priority over economic interests. Enhancing public awareness of the insufficient respectively wrong wastewater treatment and reuse and the need for hygienically safe disposal was also highlighted in the EMWater project (Petta et al., 2007). Novel products that meet the consumers' high quality standards for safety and organoleptic characteristics need to be developed by research (Galanakis, 2012). Consumers should be guided to have a correct view to the nutrients obtained from food-processing wastewater, which may improve the efficient utilization of resources, energy saving, and environment protection.

Conclusion

The wastewater with high organic contents is usually treated as a low-value discharge in FVPI and has significant adverse environmental impact. The value-added compounds from FVPI wastewater can be recovered mainly using various technologies according to multiple studies. However, many problems and concerns are still present including food safety issues, inefficient technologies, a lack of specialized regulations and laws, and unclear economic benefits and psychological resistance from consumers.

Therefore, how these issues can be addressed? Emphasis may be put on production processes and recovering technologies. First, water recycling and reuse is important, so that nutrients in wastewater are concentrated, recovering technologies, such as solvent extraction can be more efficient. Second, technologically speaking, it is necessary to develop efficient technology, and simple chemical or physical processes combining with biotechnology, such as above-mentioned EBA and SMBC, will also have a desired effect, novel technologies such as electrodialysis with ultrafiltration membrane) and reverse membrane bioreactor, which have made continuous progress in cleaner production and water reuse, may play important roles in nutrient recovery in the future. Third, novel coagulants and adsorbents also arouse interests, such as some edible coagulants, which take the food safety issue into consideration, provide assurance for nutrients reuse and simplify the follow-up operation.

At national levels, for the government department concerned and other international organizations such as WHO, EPA, GWP, and IUCN, it is imperative to elaborate guidelines and projects and establish sound mechanisms, so that these can be taken as resource documents for promotion of nutrient recovery and reuse. Equally importantly, the core concept of green productions and sustainable development need to be effectively communicated to producers and consumers. In short, nutrient recovery from FVPI wastewater not only can provide a good ecological impact but also promote human sustainable development, but the use of FVPI wastewater as a sustainable option may not catch on readily in the near future.

Abbreviation

ABR	anaerobic baffled reactor
AIR	alcohol insoluble residue
ASBR	anaerobic squencing batch reactor
BOD5	biochemical oxygen demand
CAC	Codex Alimentarius Commission
COD	chemical oxygen demand
DW	dry weight
EAE	enzyme-assisted extraction
EBA	expanded bed adsorption
EC50	half maximal effective concentration
FAO	Food and Agriculture Organization of the United Nations
FVPI	fruit and vegetable processing industry
FW	fresh weight
GWP	Global Water Partnership
HACCP	hazard analysis critical control point
IE	ion exchange
IUCN	International Union for Conservation of Nature
MAE	microwave-assisted extraction
MF	microfiltration
NF	nanofiltration
OMW	olive mill wastewater
PLE	pressurized liquid extraction
POME	palm oil mill effluent
PPO	polyphenol oxidase
RCRA	Resource Conservation and Recovery Act
RO	reverse osmosis
SFE	supercritical fluid extraction
SMBC	simulated moving bed chromatography
SS	suspended solid
SSF	solid-state fermentation
TSS	total suspended solid
UAE	ultrasound-assisted extraction
UASB	upflow anaerobic sludge blanket digestion
UF	ultrafiltration
U.S. EPA	U. S. Environmental Protection Agency
WHO	World Health Organization

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Author Contributions

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