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Review

Microbial strategies for bio-transforming food waste into resources

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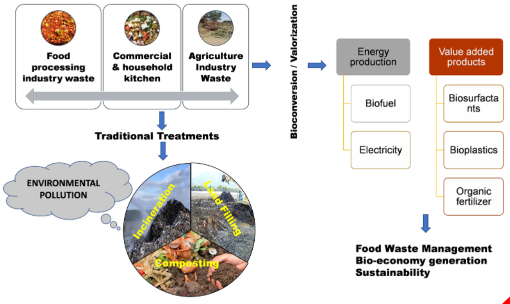
GRAPHICAL ABSTRACT



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ABSTRACT

With the changing life-style and rapid urbanization of global population, there is increased generation of food waste from various industrial, agricultural, and household sources. According to Food and Agriculture Organization (FAO), almost one-third of the total food produced annually is wasted. This poses serious concern as not only there is loss of rich resources; their disposal in environment causes concern too. Food waste is rich in organics, thus traditional approaches of land-filling and incineration could cause severe environmental and human health hazard by generating toxic gases. Thus, employing biological methods for the treatment of such waste offers a sustainable way for valorization. This review comprehensively discusses state-of-art knowledge about various sources of food waste generation, their utilization, and valorization by exploiting microorganisms. The use of microorganisms either aerobically or anaerobically could be a sustainable and eco-friendly solution for food waste management by generating biofuels, electrical energy, biosurfactants, bioplastics, biofertilizers, etc.

1. Introduction

Food is an essential component for the survival and existence of life. Organisms at different evolutionary levels consume food in different form viz. micro-organisms ingest in the form of macromolecules like carbohydrate, fats, nitrogenous compounds, vitamins and minerals contrastingly higher eukaryotes like humans feed upon a complex version of food i.e. in the form of fruits, vegetables, cereals, pulses,

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Table 1
Value added and bioactive compounds from different food processing industrial waste.

Food Industry category	Waste generation [illegible]o tonnes)	Type of food processed	Value added and bioactive compounds	Reference
Fruits Processing Industry	NA	Grape processing industry	[illegible]nol, dietary fibre, grape seed oil, pomace oil, oleanolic acid, polyphenols (catechin, epicatechin, ga[illegible]cid, and resveratrol), flavanols (proanthocyanidins), anthocyanins (enocyanin), procyanidins, [illegible]alates, citric acid, single cell protein.	Galanakis 2017; Schieber 2017
	5742	Apple juice processing industry	[illegible]tin, [illegible] acid, citric acid, aroma compounds, biogas, ethanol, butanol, and pectinases	Schieber 2017; Kiran et al., 2014
	NA	Citrus processing industry	Essential oil[illegible]ene), phenolics, pectin, antioxidants, ethanol, organic acids, and flavanoids	Matharu et al. 2016
	NA	Mango	Starch[illegible], sterols, [illegible]opherols, tannins, flavonols, xanthones, anthocyanins, and alkylresorcinols	Schieber 2017
	13,532	Banana	Lig[illegible], cellulo[illegible]emicellulose, phenolic compounds (prodelphinidins, flavonol glycosides), [illegible]nidin[illegible]d fla[illegible]s	Schieber 2017; Kiran et al., 2014
	1829	Pineapple	[illegible]tin, phen[illegible]nds, carotenoids and bromelain, and dietary fibre	Schieber 2017; Kiran et al., 2014
	NA	Berries	Phytochem[illegible] polyphenols, pectin and dietary fibre	Rohm et al., 2015
Vegetable processing industry	62,229	Potatoes	Lysine, pro[illegible] (patatin), Steroid[illegible]oids, cellulolytic enzymes, adsorption dyes, and biopolymer films	Kiran et al., 2014; Matharu et al. 2016; Schieber 2017
	12,874	Tomatoes	Carotenoids [illegible]ycop[illegible] pectin	Kiran et al., 2014; Schieber 2017
		Carrot	α-carotene, β-ca[illegible] dietry[illegible]e	Schieber 2017
	5891	Onions	Pectin, fructans, phenolic [illegible]s and dietary fiber	Kiran et al., 2014; Schieber 2017
Cereal and Pulses industry	NA	Wheat	Carbohydrates, oligosacchari[illegible]enolic co[illegible] lipid soluble vitamins, folic acid, phytosterols, amino acids and peptides	Schieber 2017
	26,738	Rice bran	Proteins, lipids, dietary fibe[illegible]nerals[illegible] antioxidant[illegible]tamin E and oryzanol)	Kiran et al., 2014; Schieber 2017
	2735	Legumes	Activated carbon, proteins, lipids, fat[illegible]ids, vitamins, [illegible]erals and phenolic compounds	Kiran et al., 2014; Parate and Talib, 2015
Beverage Industry	105	Coffee	Antioxidants, vitamins, enzymes, cel[illegible]e, starch, lipids, [illegible]otein[illegible] pigments, citric acid, gibberellic acid, ethanol, biogas, dyes, and dieta[illegible]bres (cellulose, hemice[illegible]s, lignin, pectin, gums)	Murthy and Naidu, 2012; Kiran et al., 2014
	NA	Tea	Caffeine, polyphenols, triacontanol, an[illegible]	Sui et al., 2019
Dairy Industry	16,560	Milk	Biodiesel, ethanol, whey protein, Lactose, [illegible]east, and mine[illegible]	Kiran et al., 2014; Parashar et al., 2016; Lappa et al., 2019
Meat and Seafood Processing Industry	1344.5	Meat and poultry	Fertilizer, animal feed, blood meal, meat and bone meal, fe[illegible]meal, lactic acid and probiotics,	Kiran et al., 2014; Ning et al., 2018; Yaakob et al., 2019
	NA	Fishes	Chitosan, and glycosaminoglycans,	Prameela et al., 2017
	6000 to 8000	Shrimps	Nutraceuticals (Astaxanthin), chitin and chitinase	Kiran et al., 2014, Yan and chen, 2015; Prameela et al., 2017; Kumar et al., 2018
		Crabs	Chitin, calcium carbonate and protein	Yan and chen, 2015
		Lobster	Chitin	Yan and chen, 2015
Edible oil Industry	21,462	Oil	Biosurfactants like rhamnolipids and glycolipids, biodiesel, tocophero[illegible]rols, squalene, a[illegible] cell protein	Henkel et al., 2012, Kiran et al., 2014
		Olives	Phenolic compounds, polyphenols, carotenoids, phytosterols, squalene, and [illegible]ary fib[illegible]	[illegible]n et al., 2014; Schieber 2017

meat, and dairy products. A major concern arise when this indispensable commodity i.e. food is misused and mismanaged at any stage of the food life cycle leading to serious social, economical and environmental consequences.Table 1.

The leftover or precooked food which generates biodegradable organic waste is termed as food waste (FW). As per the definition given by The Food and Agriculture Organization (FAO), FW is “food losses of quality and quantity through the process of the supply chain taking place at production, post-harvest, and processing stages”. Specifically FW corresponds to the loss of food at the end of food life cycle (Tsang et al., 2019). Generation of FW also leads to considerable loss of other resources like water, land, labour and energy. It was estimated by FAO that annually 1.3 billion tonnes of wasted food is generated globally. This wasted food is one-third of the total food produced globally, whose production corresponds from 28% of agricultural area utilizing 1.4 billion hectare of the world’s fertile land (Karthikeyan et al., 2018; Paritosh et al., 2017). It is projected that economic and population growth will lead to increased FW generation in next 25 years in Asian countries. The urban FW is expected to rise 138 million tonnes by 2025 as compared to in 2005 (Paritosh et al., 2017). Out of the total waste generated globally, Asia contributes to highest FW 278 million tonnes, whereas Vietnam produced approximately 11.55 million tonnes of FW (Kiran et al., 2014). This FW includes fresh fruits, vegetables, dairy products, bakery products, and meat from diverse sources, including discharges from households, hospitality sector, food processing industries, commercial kitchens, and agriculture waste (Karthikeyan et al., 2018; Kiran et al., 2014).

The disease control centers prevented the use of FW as animal feed, thus preferentially the disposal of FW was done through fermentation, composting, and landfilling (Tsang et al., 2019). Conventionally, FW is an element of municipal solid waste which is dumped or incinerated. The high moisture content of FW leads to the generation of dioxin by incineration, whereas dumping in open area causes environmental and health issues. FW is estimated to generate 3.3 billion tonnes of CO^2 per year, thereby contributing in the emission of greenhouse gases (Paritosh et al., 2017). To increase environmental sustainability and overcome socio-economic concerns, valorization of FW for the production of value added products is an ideal approach attracting [illegible]tion of researchers worldwide. This is also evident as [illegible] researches on valorization of FW has increased ≥9[illegible] during the last decade from 2009 to 2018. Therefore, this review [illegible] to understand the sources and nature of FW that can be efficiently converted [illegible] value added products such as biodiesel, ethanol, biohydrogen, methane, butanol, biosurfactants, bio-plastics, organic fertilizers and electric power generation highlighting the significance of discarded/dumped FW.

2. Sources of food waste generation

2.1. Food processing industries

2.1.1. Cereals and pulses

On a global scale, significant proportion of the human diet is filled by cereal grains obtained from seeds of Gramineae family such as wheat, rice, barley, maize, sorghum, millet, oat, and rye. According to the FAO, globally total crop production during 2016 reached 2577.85 million tons. In contrast, the production of coarse grains (cereal grains other than wheat and rice used primarily for animal feed or brewing) was 1330.02 million tons (FAO-AMIS, 2017). The production ranking in the year 2014 was corn 1253.6, rice paddy 949.7, wheat 854.9, barley 146.3, oat 23.2, and rye 15.8 tonnes (Papageorgiou and Skendi, 2018). The cereal and pulses processing industry produce a large quantity of by-products like bran and germ, during processing (Anal, 2017). India is the worlds’ largest producer of pulses producing a considerable amount of husk as a by-product during processing (Parate and Talib, 2015). Husk is recycled in many ways to produce high-end products. There are many crops which generate husk as a by-product of processing. Apart from utilization as animal feed the straw, husk and dried leaves of crops like wheat, corn, rice, and barley is utilized in traditional way for making thatching roofs, baskets, broom, hand fans, handbags and in preparation of decorative items. It is used as cleaning and polishing agent in metal and machine industries. Rice husk can be used as pet feed fiber, fertilizer and substrate for vermicomposting technique, and in the production of construction material like light weight bricks (Kumar et al., 2013). Husk obtained after cocoa pod processing was utilized for pectin extraction and production of vermicompost, oyster mushrooms, livestock feed, and other value-added products (Dede and Ozdemir, 2018). Furthermore, coconut husk has multiple household applications like rope, broom, mat, tiles, fishing net, and mattresses. It is also employed for the production of second generation bio-ethanol (Bolivar-Telleria et al., 201[illegible]). These by-products are rich in nutrients, generally consists of dietary fibers, proteins, lipids, fatty acids, vitamins, minerals and phenolic compounds but still they arrive finally as animal feed, fuel, and biorefinery substrate. For production of refined flour, bran and germ, a portion of grain is removed as they adversely affect the processing properties (Verni et al., 2019). The by-product of barley pearling process serves as a rich source of bioactive compounds like pr[illegible]es, insoluble dietary fiber, phenolics and it contains [illegible] times more v[illegible] than in whole barley grain (Papageorgiou and Skendi, 2018). The husk is used in fermentation process to adjust moisture [illegible] maintain the porosity of fermentative material for gaseous exchange during distillation (Tan et al., 2014).

2.[illegible] Fruits and vegetables

Fruits and vegetables are energy rich food items with high moisture content having rich nutritive profile consisting of soluble carbohydrates (glucose, fructose), vitamins, minerals, fibers, polyphenols and other bioactive compounds (Schieber, 2017). Fruit and vegetable wastes were generated during different steps of food supply chain starting from farm [illegible] including production, processing, packaging, handling, storage and transportation (Ji et al., 2017). Fruits and vegetables are classified to waste category only when a consumer disqualifies it from degree of acceptance. This may arise due to several factors such as discoloration, wounding or chilling, biochemical reactions (enzymes, antioxidants, phenolic compounds and oxygen), thermal treatment, microbial attack (rotting, softening and surface growth), and degree of ripening. India is the second largest producer of vegetables and fruits in the world sharing 10% and 14% of global production, respectively. It leads to economic loss worth of US $483.9 million per year due to wastage of about 50 million tons, accounting for 30–40% of total production in India (Panda et al., 2016). Central de Abasto, the second largest fruit and vegetable market in the world, at Mexico City, produced 895 tonnes of waste/day. China produces approximately 1.3 million tonnes of this waste per day (Ji et al., 2017). According to a report of FAO in 2014, UK alone produced 5.5 million tonnes of potatoes; around 3% to 13% of harvested crop never reaches to customer and is wasted due to “grading losses” in supermarkets. This generated waste is processed by composting, land-filling, incinerating or used as animal feed. These disposal methods give rise to serious environmental concern such as toxic and greenhouse gas emission, microbial proliferation due to high content of moisture and landfill leachate (Ji et al., 2017; Dessie et al., 2018).

Reduction of fruits and vegetable waste is warranted to alleviate the increasing demand for food production and improving the overall efficiency of food supply chain (Matharu et al., 2016). Growing public concerns about hunger, fruits and vegetable losses, food security reasons, conserving the environment from pollution, socio-economic factors have accelerated research into FW domain towards finding better ways of using this natural and renewable resource. The starch, cellulose and/or hemicelluloses of fruit and vegetable waste is hydrolyzed to soluble sugars and further fermented to produce ethanol and hydrogen (Díaz et al., 2017). Microbial processing of fruits and vegetable waste has opened new horizons for value addition to rejected fruits and vegetables. Several high-end commodities was reported to be produced by utilizing FW such as fermented beverages (fenny, vineger), single-cell proteins (*Saccharomyces* sp., *Candida utilis*, *Endomycopsis fibuligera* and *Pichia burtonii*), single-cell oils, polysaccharides, dietary fibre, polyphenols, bio-pigments (carotenoids), fragrances, flavours (vanillin), essential oils, biopesticides, plant growth regulators, enzymes (cellulase, amylase, protease, phytase, etc), biohydrogen, bioethanol and biogas (Panda et al., 2016; Schieber 2017; Sabu et al., 2002; Bogar et al., 2003a; Pandey and Soccol, 2000; Benjamin and Pandey, 1997). Acidogenic fermentation of fruit and vegetable wastes produces lactic acid (Wu et al., 2015) whereas in solid state fermentation they are hydrolysed using crude enzyme mixtures to produce succinic acid (Dessie et al., 2018).

2.1.3. Dairy

Around 29 million tonnes of dairy products are wasted in Europe every year. This dairy waste is derived from the processing industry, spoilage of the dairy products due to microbial attack, and inappropriate handling (Mahboubi et al., 2017). Dairy waste consists of complex organic constituents like fat, protein, sugar, traces of food additives, and detergents that are used for maintaining proper hygiene and clean in place (CIP). Dairy products are the most perishable commodities due to their rich composition and absorbability. Fungal contamination in milk produces visible or non-visible defects, such as off-odor and flavor development.

India is reported as the largest milk producing nation and simultaneously produces 1 to 3 times of effluent for every volume of processed milk, thus generating 3.739–11.217 million m^3 of waste per year. While manufacturing of cheese, a considerable amount of whey is produced as a by-product of processing which generated 9 kg of whey per kg of cheese produced (Parashar et al., 2016). Another constituent of [illegible] produce i.e. raw milk, contaminates groundwater due to the presen[illegible] of ammonia, nitrogen, and nitrate that is converted to nitrite ther[illegible] causing methemoglobinemia. During processing of raw milk arou[illegible] 2.5–3.0 L of wastewater is generated per litre of proc[illegible]k (Sing[illegible] et al., 2014), carrying about 14–830 mg/l of total [illegible]rogen [illegible]ncentration (Kushwaha et al., 2011). Wastewater hold[illegible] [illegible]nifican[illegible] [illegible] of nutrients, like carbohydrates, lipids, protein[illegible] Mil[illegible] [illegible] and gives rise to organic and inorganic for[illegible] of nitrog[illegible] [illegible]ch as nucleic acids, urea, proteins, and NO− 2, [illegible] 3, NH+ [illegible]spectively (Kushwaha et al., 2011). It was fo[illegible] th[illegible] elevated conc[illegible]ation of NO3 > 40 mg/L in groundwater [illegible] a cau[illegible] methemoglobinemia (Fewtrell, 2004).

This raises serious env[illegible]mental concerns a[illegible] demands the employment of microbial [illegible]ted me[illegible]d of waste conversion including activated sludge, seque[illegible] [illegible] reacto[illegible] tickling filter, anaerobic sludge blanket, and aerated [illegible]ons (Di[illegible] al., 2014). Dairy waste is rich in organic [illegible]cilitat[illegible] the [illegible]wth of microorganisms hence a large num[illegible] of va[illegible]-added p[illegible]cts can be obtained by utilizing dairy ind[illegible] waste [illegible] lactose and protein (Lappa et al., 2019). It is a suitable sub[illegible] [illegible]duction using *Saccharomyces cerevisiae* via enzymatic [illegible]olysis of fermentable sugar (Parashar et al., 2016). Filamentous fung[illegible] [illegible]duce a variety of enzymes capable of hydrolyzing complex carbohydra[illegible] to simple sugar hence aids in high quality biomass production that can be used as animal / fish feed and even for human consumption as single cell protein with a GRAS status (Mahboubi et al., 2017).

2.1.4. Edible oil

Edible oil industry generate waste during various steps of refining process like degumming, neutralization, bleaching, deodorization, oxidative or hydrolytic rancidity. This hydrolytic rancidity is caused due to the oxidation of lipids, aging, moisture, presence of oxygen and effluent coming out of industry laden with lots of fatty acids, carbohydrates and protein (Okino-Delgado et al., 2017). Waste cooking oil is an oil-based substance that resulted from multiple deep fat frying process which makes fat unsuitable for human consumption due to the formation of polar compounds like free short-chain fatty acids, mono- and di-glycerides, aldehydes, ketones, polymers, cyclic and aromatic compounds. It was reported that edible oil industry annually produces 350.9 million tonnes of de-oiled cake and oil meal as a by-product, which is a concentrated source of protein. After pretreatment, this waste is further utilized for preparing human nutrition products, animal feed and fertilizer (Chang et al., 2018).

Traditionally, effluents from oil processing industry were released directly into the soil and groundwater which leads to oily film formation on aquatic surface causing a serious threat to survival of aquatic animals, blockage of sewage and drains due to emulsification of organic matter, oil methanization worsening green[illegible] (Okino-Delgado et al., 2017). Advance methods emp[illegible] microbia[illegible]lls for biodegradation of organic matter from efflu[illegible] thereby pr[illegible]cing various high-end products such as bio-ba[illegible]d zw[illegible]nic biosu[illegible]ctants. *Pseudomonas aeruginosa* synthesiz[illegible] biosurfacta[illegible] such [illegible] rhamnolipids and glycolipids, biodiesel p[illegible]uction [illegible]ing lip[illegible]quid hydrocarbon biofuels (Henkel et al., [illegible]; Che[illegible] al., 2018). Edible oil industry waste was reported t[illegible] be a[illegible] source f[illegible]ealth constructive products such as toco[illegible]rols, ste[illegible] squal[illegible] which were used in different industrie[illegible] [illegible]aw material, [illegible] for SCP production (Diwan et al., 2018) [illegible]ri[illegible]tical formul[illegible]ns and cosmetics in the form of soap stalk (S[illegible]erazi an[illegible]hesar, 2016).

2.1[illegible] poultry and egg[illegible]

[illegible]eat poultry and egg processing industry is a huge segment of food ch[illegible] system. Eu[illegible]ean Union annually accounts for approximately 11 mi[illegible] tonnes o[illegible]roduction. About 3.5 billion pounds of beef was prod[illegible] [illegible]a in 2006, contributing $26 billion to its economy. Conseque[illegible] vast quantity of animal by-products, slaughterhouse [illegible] and wastewater is generated (Ning et al., 2018). This comprises [illegible] cattle, 47% from sheep and lambs, 44% from pigs and 37% [illegible]rom chicken 37%, which is inedible in nature, thereby generating a huge mass of waste by slaughterhouses in environment (Adhikari et al., 2018).

Major wastes material generated in industry include feathers, hairs, skin, horn, hooves, soft meat, deboning residues, bones, etc. In addition to this, the slaughter house wastewater consists of blood residue, protein, animal fat (lard and tallow), detergent residues and high organic matter (carbon, nitrogen and phosphorous). Rendering of perishable animal waste extends a possible alternative way to eradicate the environmental issue along with revenue generation. Rendering industries produces meat and bone meal, hydrolyzed feather meal, blood meal, fish meal, animal fats (lard and tallow) (Yaakob et al., 2019). Lactic acid fermentation of slaughterhouse waste is a promising approach to utilize slaughterhouse waste for the production of lactic acid bacteria that can be used as a probiotic product (Ashayerizadeh et al., 2017). Due to high nutritional composition slaughterhouse waste can be utilized for various value-added product generation like biomass (*Scenedesmus* sp.) as fish feed (Yaakob et al., 2019), a clean energy substitute i.e. methane produced by anaerobic digestion of wastewater (Ning et al., 2018), biogas production from poultry litter, blood in food applications (blood sausage, blood cake, blood pudding, blood curd) and non-food application (fertilizer, binder) (Adhikari et al., 2018). Biodiesel has been produced from chicken manure biochar by pseudo catalytic transesterification reaction, from pork fatty waste by fermentation employing *Staphylococcus xylosus* and from eggshells by transesterification of triglycerides with methanol using homogeneous catalysts (Marques et al., 2016). It has multivariate applications in the pharmaceutical, cosmetic product development industry.

2.1.6. Sea foods and aquatic life

Marine ecosystem supplies around 20% of the world's food to humans, therefore plays a vital role in feeding a significant population of the world. It is estimated that around 183 million tonnes of seafood would be needed by 2030 for feeding. Generally, 50–70% of seafood raw material is wasted every year (Kumar et al., 2018). Globally producing about 6–8 million tonnes of waste in the form of crabs, shrimp and lobster shells, where Southeast Asia contributes 1.5 million tonnes in totality. In seafood's the utilizable mass of marine animal is less, crabs yield 40% meat of whole mass, in tuna fishes only 75% of fillets is available. This generates a huge amount of waste, including inedible parts like shrimp shells, crab shell, prawn waste, fish scales and endoskeleton shell of crustacean. Shells and scales of aquatic animals such as shrimps, lobsters and fishes harbor useful chemicals such as protein, chitin and calcium carbonate. Dried shrimps and crabs contain about 50% of chitin on dried basis, generating a revenue of around $100–120 per tonne (Yan and Chen, 2015), and is used as animal feed supplement, bait or fertilizer. Seafood waste is chitinaceous in nature, harbouring pathogenic microbes, carcinogens, aflatoxins and other health risks it can cause due to bioaccumulation of these contaminants.

The conventional method for seafood waste disposal includes ocean dumping, incineration, landfilling, and wastewater discharge of seafood processing industry. It contains high organic material load that potentially causes euthrophication and oxygen depletion of receiving water bodies (Yan and Chen, 2015). Chitin, the major component of seafood waste is insoluble in water and inert to most of chemical agents hence leads to environmental pollution and bio-fouling, thus stipulating biological processing of this waste material as a step toward environment protection and a sustainable way of billion-dollar revenue generation as bio-economy (Yan and Chen, 2015; Kumar et al., 2018).

Indian shrimp processing industries produces more than 0.15 million tonnes of shrimp waste annually. Waste of shrimp processing industries was used to produce nutraceutical compound such as astaxanthin (3,3′-dihydroxy-ß-carotene-4,4′-Dione), a xanthophyll carotenoid present in crustacean waste that was extracted th[illegible] oxidative transformations of ingested β-carotene or zeaxanthin by [illegible]d microalgae (Prameela et al., 2017). Chitosan is an important bi[illegible]lymer extracted from exoskeletons of crustaceans waste. It was report[illegible] to exhibit antibacterial activity against *Enterococcus f[illegible]cherichi[illegible] coli*, *Staphylococcus aureus*, and *Candida albicans* (H[illegible]ein et[illegible] 2013). Glycosaminoglycans (GAGs) extracted from ma[illegible] animal[illegible]aste is of better quality to that of terrestrial organism[illegible] (Va[illegible] Waste of Seafood processing industries i[illegible]potentia[illegible]rce for functional and bioactive compounds prod[illegible] through en[illegible]-mediated hydrolysis.

2.2. Commercial and househol[illegible]tchens

Urbanization, rapid [illegible]nomic [illegible]elopment and uncontrolled population growth has incr[illegible]d th[illegible]onsumpt[illegible]n of food leading to many folds increase in th[illegible]genera[illegible]of kitche[illegible]aste annually (Zhao et al., 2017a). In 201[illegible]reas o[illegible]a [illegible]uced 200,000 kg of domestic waste. Pres[illegible]y Chi[illegible]s produc[illegible]more than 30 million tonnes of kitchen w[illegible]every [illegible] It has been estimated that annually 2.5 billion tonnes of F[illegible]opean Union out of food supply chain (Li et al., 201[illegible]

Kitchen waste[illegible]W) is a kind of anthropogenic organic waste, usually discharged f[illegible] public catering rooms, restaurants, households, canteens of school and factory etc. (Li et al., 2017; Zhao et al., 2017b; Liu et al., 2019). The waste generated by restaurants, commercial and institutional kitchens is different from municipal solid waste and is referred to as kitchen waste (KW). KW includes fruits, vegetables, cooked food wastes, meat, used fat, oil and grease. On wet basis KW broadly comprises of fruits 38.2%, vegetables 41.5%, staple food 7.6%, egg shell bones 7.2%, shells and pits 2.5%, and meat 2.3% (Zhao et al., 2017a). Chemically it comprises of carbohydrate polymers (cellulose, hemicellulose, pectin and starch), protein, lignin, fats, organic acids, inorganic salts and others (Chen et al., 2017; Zhao et al., 2017b). KW is generated during various food processing operations such as handling, processing, production, storage, transportation and consumption. Commercial and household Kitchen wastewater is generated during various activities like washing and rinsing foodstuffs, cooking, cleaning dishes, cooking utensils, and general housekeeping.

Traditional methods of decomposition of kitchen waste such as land-filling, composting, incineration and direct or indirect discharge of wastewater into the environmental system is detrimental to the ecosystem and human health (Chen et al., 2019). Kitchen waste is biodegradable biomass with higher moisture content and a pool of nutrients facilitating the growth of pathogenic microorganisms causing rotting and breeding of flies and mosquitoes in shorter span of time. It emits toxic substances, greenhouse gases, a huge amount of leachate in water bodies and foul smell of ammonia and hydrothion. Ammonia produced during decomposition of kitchen waste has[illegible]gent order which can cause serious irritation in the respi[illegible]y tract, r[illegible]ss of eyes and skin, while hydrothion is highly toxic[illegible]umans (Zha[illegible] al., 2017a). The uncontrolled generation and [illegible]mprope[illegible]nagemen[illegible]uld produce lethal and life-threatening co[illegible]quences o[illegible] env[illegible]ment. It was reported that kitchen waste[illegible]ld be [illegible]d as a [illegible]te for generation of numerous high value[illegible]ducts [illegible] biosurfactant production using *Pseudomonas aerugin[illegible]a* (C[illegible]l., 2018[illegible]butanol production by enzymatic hydrol[illegible] (Chen [illegible] 2017[illegible]actic acid production by *Lactobacillus am[illegible]ilus*, volatile [illegible]s and hydrogen from mixed culture (Liu [illegible]l., [illegible]9), cellulose [illegible]oduction via *Aspergillus niger* in solid state fermentatio[illegible]thanol production by a process of successive liquefa[illegible] pre-sacchar[illegible]tion, and simultaneous saccharification and[illegible]mentation (Nishimu[illegible] et al., 2017). It can be used to harness en[illegible]y liberating products like biogas, bioelectricity, biodiesel, etc. N[illegible]-composites[illegible]opolymers and edible film like materials can be sy[illegible]ized using[illegible]W as substrate. FW can be transformed to huge array of [illegible]adde[illegible] products including antioxidants, pigment, nutraceutica[illegible]etary fiber, organic acids, high fructose syrup, single-cell [illegible]ein, vermicompost, biofertilizer, xanthan gum, and wax esters, si[illegible]usly reducing environmental burden (Liu et al., 2019).

2.3. Agricultural waste

Waste framework directive 2008/98/EC laws defines waste as "any substance or object which the holder discards or intends or is required to discard". Agriculture waste is an organic substance involving straw, bagasse, molasses, spent grains, husk (rice, maize, and wheat), shell (walnut, coconut, and groundnut), skin (banana, avocado), crop stalks (cotton), plant waste, livestock and poultry manure (Dai et al., 2018). In 2013, FAO reported that about 250 million tonnes of non-edible plant waste from different crop processing is generated as agro-industrial waste (Heredia-Guerrero et al., 2017). Being world's largest grain producer, China produced 1.75 × 10^9 tons of agriculture waste, of which 9.93 × 10^8 tonnes was contributed by crop straw, 4.52 × 10^8 tonnes from livestock and poultry manure, and 3.03 × 10^8 tonnes from forest residues in 2013 (Dai et al., 2018). Asia alone generates 4.4 billion tonnes of solid wastes annually. Agro-industrial waste generation from different sources in India is more than 350 million tonnes per year (Madurwar et al., 2013).

Traditionally, agricultural waste is either incinerated/burnt off or allowed to rot in fields, thereby causing serious air pollution and is also exacerbating soil pollution, water pollution and food contamination. These traditional approaches liberate toxic gases (such as N_2O, SO_2, CH_4,), smoke, greenhouse gases into thfe air, and other carcinogenic chemicals such as dioxins, furans and polycyclic aromatic hydrocarbons, which are detrimental to the environment as well as for human health. Exposure to these chemicals causes severe development damage in fetuses, infants, children, and adults (Cheng and Hu, 2010). Agricultural waste is biodegradable and organic, possessing a repository of nutrients such as polysaccharides (starches, cellulose, hemicellulose), proteins, lignins, fibers, minerals, vitamins, and others (Madurwar et al., 2013). Agriculture waste is porous and loose in constitution containing carboxyl, hydroxyl, and other reactive groups, so agricultural biomass can be used for wastewater remediation as an adsorption material, hence "reducing waste by waste" (Dai et al., 2018). Apart this, the chemical composition of agriculture waste proves it as a versatile candidate bearing potential to synthesize a number of products such as bioplastic from cuticles present on the outer layer of plants parts such as leaves, stem, flowers (Heredia-Guerrero et al., 2017).

Agriculture waste can be a cheap and natural substitute for production of multiple high valued products. Microbes can readily feed upon agriculture waste to generate an array of high end products such as pigments, phytochemicals, antibiotics, different enzymes (endoglucanase, β-glucosidase, amylase, glucoamylase) by utilizing peels, seeds, oil cakes, field residues, and bran (Bogar et al., 2003b; Selvakumar et al., 1998; Singh et al., 2006). Xanthan is a type of exopolysaccharide that acts as food additive in food industry and is reported to be produced by action of *Xanthomonas* species on agro waste as substrate (Sadh et al., 2018).

Food additives play a significant role in enhancing the technological properties of food. Mushroom is ecology and economy balancing crop derived of lignocellulosic agro waste (wheat paddy, rice paddy, banana leaves, cotton stalks) by mushroom fungi *Lentinula edodes* and *Pleurotus* sp. (Philippoussis, 2009). Agro-industrial waste is reported to be a good carrier for enzyme immobilization and solid state fermentation (Sadh et al., 2018).

Agricultural material can be utilized to produce suitable substitutes of construction material with improved qualities like light weight, biodegradable and eco-friendly material. It can be used to develop several construction items like fiber-board made from cotton stalk with no chemical additives, thermal insulating walls and roofs, waste-create bricks made from recycled paper mills waste and cotton waste. Cement replacer is manufactured from sugar industries waste (bagasse ash) [illegible] oil palm shell as a coarse aggregate for structural concrete production (Madurwar et al., 2013).

3. Food waste utilization for energy production

The current strategies of landfilling or incinerating [illegible] do not eliminate the environmental and economic stress [illegible] valorization gaining much interest. FW can be converted to different forms of energy molecules or biofuels, viz. biogas, hydrogen, ethanol [illegible] biodiesel, butanol and methane (Table. 2).

3.1. Production of biofuels

3.1.1. Biodiesel

Increasing environmental pollution, fuel demand, and depletion of fossil fuels have intensified the requirement of alternative fuels. Biodiesel emerged [illegible] alternative fuel that can be acquired from oils and fats. It is green fuel whose production is expensive because of the high cost feedstock, thus in order to reduce the cost, possibility to utilize FW as [illegible] feedstock have been investigated (Karmee et al., 2015). FW can [illegible] converted to biodiesel by direct transesterification employing acid/alkaline catalyst or of microbial oils that are produced by oleaginous microorganisms (Kiran et al., 2014). Microbial oils have similar fatty acid composition as plant oil thus microbial oils can be used as raw material for production of biodiesel. FW hydrolyzate can be used as nutrient source and culture medium for the cultivation of microalgae for biodiesel production. *Aspergillus oryzae* and *Aspergillus awamori* was used to prepare FW hydrolyzate, which served as growth medium for cultivation of *Chlorella pyrenoidosa* and *Schizochytrium mangrovei* yielding 10–20 g biomass. The fatty acids produced by *C. pyrenoidosa* and *S. mangrovei* were suitable for the production of biodiesel (Pleissner et al., 2013). Waste cooking olive oil was reported to serve as a substrate by *Penicillium expansum* and five different strains of *Aspergillus* sp. for the production of biomass rich in lipid. Among these, *Aspergillus* sp. ATHUM 3482 yielded highest amount of lipid 0.64 g/g dry cell weight (Papanikolaou et al., 2011). Biodiesel production from vegetable oils, animal fats and butter was reported to globally yield 24.5 GJ energy per year (Kiran et al., 2014). Cubas et al. (2016) reported biodiesel production employing corona discharge plasma reactor technology (CDPT). This technique offers several advantages such as increased esterification, easy biodiesel separation, and no co-product generation. CDPT has been efficiently used for biodiesel production from waste frying oil in the absence of chemical catalyst.

3.1.2. Ethanol

Wide industrial application of ethanol has increased its demand globally. It is prominently used as a feedstock chemical for synthesis of ethylene (Kiran et al., 2014) and an essential [illegible] material for production of polyethylene. Traditionally cellulose and starchy crops, e.g. sugar cane, rice, and potato were used for production of bio based ethanol (Thomsen et al., 2003). Commercial enzymes [illegible] available to convert starch to glucose which is further fermented to ethanol by *Saccharomyces cerevisiae*, whereas cellulose hydrolysis is difficult (Kiran et al., 2014). Thus FW with low cellulosic content serves as a better alternative for the production of bioethanol. [illegible] improve the purity and yield of ethanol, FW is autoclaved prior [illegible] fermentation, as harsh or thermal treatment may cause partial degradation of nutritional components and sugar (Sakai and Ezaki, 2006). Dried FW has reduced surface area which results in decreased reaction efficiency between substrate and enzyme, thus fresh and wet FW was reported to be an efficient source for ethanol production. Furthermore as cellulose or starch cannot be directly converted to ethanol by yeast thus the conversion efficiency [illegible] dependent on carbohydrate saccharification (Kiran et [illegible] 2014). For this a mixture of enzymes namely glucoamylase, α-amylase, β-amylase and pullulanase etc. will be added for high molecular weight substrates. Hong and Yoon (2011) reported the production [illegible] 26 g ethanol and 60 g reducing sugar in 48 h of fermentation by [illegible] 100 g of FW. Kitchen garbage and non-diluted FW was reported to yield 17.7 g/L/h and 0.49 g ethanol per g sugar by simultaneous saccharification and fermentation process (Ma et al., 2009). Several countries including Japan, Finland and Spain had developed pilot scale plants to convert their FW to bioethanol (Kiran et al., 2014).

3.1.3. Biohydrogen

Hydrogen is a potential renewable energy source with high energy yield of 142 MJ/kg (Jarunglumlert et al., 2018). In nature, hydrogen is not readily available but can be produced from primary energy source. Hydrogen being carbon free with the highest energy output and yielding water on combustion is globally used as a substitute to fossil fuels (Nikolaidis and Poullikkas, 2017). Biohydrogen is hydrogen gas produced employing biological processes. The production of biohydrogen through fermentation using FW requires less energy and simultaneously recycles the waste generated, thus it has become the most favored method. Carbohydrate-rich FW is preferred for the production of biohydrogen gas as it has 20 time higher potential than protein or fat-based FW. Hydrogen production from FW had been reported employing several fermentation processes such as continuous, semi-continuous, batch, single or multiple stages (Kiran et al., 2014). Upflow anaerobic sludge blanket (UASB) and anaerobic sequencing batch (ASBR) reactors have been used with high hydrogen producing rates because of their high biomass concentration in the reactor (Karthikeyan et al., 2018). For these processes, solid retention time (SRT), hydraulic retention time (HRT), and organic loading rate (OLR) affect the production of hydrogen. An optimized SRT with low HRT enhanced the technical feasibility and productivity of biohydrogen production. However, the role of a higher OLR is yet debatable as it affects the process in both ways, suggesting an optimal OLR for maximum biohydrogen production (Kiran et al., 2014).

As in anaerobic digestion, the process of dark fermentation is set at low HRT with high acidic condition to inhibit methanogenic activity. The dark fermentation process for the production of biohydrogen from

Table 2
Biological process for valorization of food waste.

S. No.	Substrate	Biological Proc[illegible]ssociated	[illegible]bes Associated	Product Obtained	References
1.	Noodle Waste	Saccharification and ferment[illegible]	Sacchar[illegible]ces cerevisiae K35	Bioethanol and Biodiesel	Yang et al., 2014
2.	Waste cooking olive oil	Fermentation	*Penic[illegible]nsum*	Biodiesel	Papanikolaou et al., 2011
3.	Mixed Food Waste (Potato peel waste, Banana Peel, Household waste)	Enzymatic Hydrolysis and [illegible]mentation	A[illegible]re o[illegible]ylase, βamylase, and [illegible]mylase;*S[illegible]romyces cerevisiae* H058	Bioethanol	Karmee, 2016
4.	Agricultural residue waste	Enzymatic hydrolysis and Flash Pyrolysis	[illegible]rb[illegible]rase, p[illegible]se and lipase	Hydrochars and bio-oil	Karmee, 2016
5.	Cooking oil waste	Enzyme immobilization	Lipase	Biodiesel	Heater et al., 2019
6.	Spent coffee grounds	Extraction and transesterification	Catal[illegible]KOH)	Biodiesel	Kondamudi et al., 2008
7.	Cane molasses and starch rich food waste	Fermentation	*Clost[illegible]n acetobutylic[illegible]um beijerinckii* P260	Biobutanol	Girotto et al., 2015; Huang et al., 2015; Ujor et al., 2014
8.	Mixed food Waste	Microbial electrolysis cell (MEC) and Anaerobic Digestion	Exoelect[illegible]ria	Methane	Park et al., 2018
10.	Carbohydrate rich food waste	Fermentation,	Up-flow anaerobic slu[illegible]ket (UASB) and anaerobic sequencing batch (ASBR[illegible]ctors	Biohydrogen	Kiran et al., 2014, Karthikeyan et al., 2018
11.	Industrial wastewater domestic wastewater and excess sludge	Microbial Fuel Cell	Catalyst (Microbial cel[illegible]	Electricity	Li et al., 2016; Cercado-Quezada et al., 2010
12.	Kitchen waste oil	Fermentation	*Pseudomonas aeruginosa*	Biosurfactant	Chen et al., 2018
13.	Soy molasses	Fermentation	*Pseudomonas aeruginosa* ATCC 1[illegible]45	Glycolipid biosurfactant	Rodrigues et al., 2017
14.	Dairy effluent (cheese whey)	Fermentation	*Pseudomonas aeruginosa* SR17	Biosurfactant	Patowary et al., 2016
15.	olive oil mill waste	Fermentation	*Bacillus subtilis* and *Pseudomonas ae[illegible]*	[illegible]surfactant	Ramírez et al., (2015
16.	Cane molasses	Fermentation and biosynthesis	*Alcaligenes* sp. NCIM 5085	P[illegible]ydroxybutyrate (PHB)	Tripathi et al., 2019
17.	Nutrient-rich food waste	Hydrolysis, fermentation and Biosynthesis	*Halomonashydrothermalis, Halomonascampaniensis*	Poly[illegible]ydroxybutyrate (PHB)	Tsang et al., 2019
18.	Dairy waste	Fermentation and biosynthesis	*Bacillus megaterium* SRKP-3	Polyh[illegible]tyrate (PHB)	Pandian et al. 2010, Tsang et al., 2019
19.	Food waste	Anaerobic digestion, aerobic composting	*Microbial cells*	[illegible]rganic [illegible]zer and solid [illegible]til[illegible]	Ma et al., 2019, More et al., 2017

glucose follows two major pathways, *viz.* butyrate and acetate pathways that utilize one mole of glucose, yielding two and four moles of biohydrogen, respectively (Karthikeyan et al., 2018). Mixed cultures of *Enterobacter* and *Clostridium* produce hydrogen from waste, which is readily utilized by hydrogenotrophic bacteria (Li and Fang 2007). Seed biomass is heated to reduce microbial biohydrogen consumers, while suppressing lactate production, thus increasing biohydrogen production. Untreated FW abundantly contain lactic acid bacteria whereas pretreated FW is dominated by biohydrogen producers (Kiran et al., 2014).

3.1.4. Methane

Anaerobic production of methane is favored because of its renewable energy source utilization, low residual waste production and low cost. The waste produced through this process is nutrient rich that can be used as soil conditioner or fertilizer (Kiran et al., 2014). The energy content of methane is 55.5 MJ/kg. Anaerobic digestion produces methane through biodegrading and reducing organic waste. The production of methane by this process is affected by several parameters such as alkalinity, pH, organic loading rate, nutrients, reactor type, volatile fatty acids, carbon/nitrogen ratio, operation temperatures, ammonium ions, and substrate characteristics (Park et al., 2018). A decrease in pH and volatile fatty acids accumulation minimizes the production of methane gas during anaerobic digestion (Chen et al., 2008). Park et al. (2018) reported that the use of microbial electrolysis cell (MEC) with anaerobic digestion reactor enhances the methane production rate by 1.7 times as compared to the anaerobic digestion reactor alone. MEC increases the rate of degradation of volatile fatty acids, concentrated organic wastes and non-degradable organic matter thereby improving methane production. During this process, methane is formed at cathode by electrons released from exoelectrogenic bacteria when MEC pa[illegible] low voltage in the reactor.

Pretreatment of FW could be an efficient strategy that aids in proteins/lipids digestibility, reducing acidification rate, altering biological and physico-chemical properties, thus avoiding proc[illegible]tion and improving the recovery of methane. The pretreatment process commonly includes physical (grinding), thermal, acid and alkali treatment, high-pressure treatment, pulse discharge of high [illegible] mediated, micro-aeration and biological treatment ([illegible]ikeyan et al., 2018). Thermal treatment followed [illegible] alkali treatment [illegible] the best pretreatment strategies for anaerobic [illegible] of FW. Alk[illegible] pretreatment enhanced the yield of methane by 25%, [illegible]ereas when combined with thermal treatment, the [illegible]d further en[illegible]d to 32% (Naran et al., 2016). FW of 54 [illegible]ferent fruits and vegetables produced 180–732 mL methane [illegible] volati[illegible] solid. Furthermore fruits and vegetables waste in a two [illegible] a[illegible]obic digester yielded 530 mL per g volatile solid by utilizing 95[illegible] volatile [illegible] (Kiran et al., 2014). Zhao et al., 2017a) [illegible] the e[illegible] of [illegible]sence of varying salt (NaCl) concentratio[illegible] in FW. [illegible]hey obse[illegible] that low salt concentration increased [illegible] acidific[illegible] and hydrolysis processes while inhibiting methanogen[illegible] [illegible] concentrations inhibited both methanogenesis and ac[illegible]ation.

3.1.5. Biobutanol

Butanol, a four carbon alcohol is considered more advanced biofuel compared to ethanol as it offers several advantages such as improved combustion efficiency, higher energy density, lower vapour pressure and property to dissolve in vegetable oils in order to reduce their viscosity (Girotto et al., 2015). Traditionally, cane molasses and starch (corn, potato, and wheat) are used for the production of biobutanol through fermentation process. Economic viability of biobutanol production via fermentation process is mainly influenced by the substrate cost, which accounts for about 50% of the cost of production (Ujor et al., 2014). Several studies have reported the efficiency of *Clostridium* species for the production of biobutanol using FW as a substrate (Girotto et al., 2015; Huang et al., 2015; Ujor et al., 2014). *Clostridium acetobutylicum* produced biobutanol through fermentation process by utilizing FW. Lactose-rich waste whey yielded 0.3 g of butanol per g of carbohydrates (Girotto et al., 2015). Similar yields of biobutanol were observed from starch-rich industrial FW such as bread liquid, batter liquid and inedible dough (Ujor et al., 2014). *Clostridium beijerinckii* strain P260 utilized 81 g/L of FW procured from retail store in Illinois, USA containing white bread, sweet corn, and mashed potatoes to produce biobutanol with a yield of 0.38 g/g and a high productivity of 0.46 g/L/h (Huang et al., 2015). Jesse et al., (2002) reported varying production of acetone:butanol:ethanol (ABE) by *Clostridium beijerinckii* strain BA101 upon action on different FW types viz. agricultural waste yields 20.3 g/L and starch-rich packing [illegible]7 g/L whereas control starch yielded 24.7 g/L ABE. Th[illegible] difference i[illegible] production could be attributed to the difference in the n[illegible] of the waste material. Since employing FW showed reasonabl[illegible] good [illegible]tities of [illegible]butanol, FW valorization for biobutanol pr[illegible]tion can [illegible] effi[illegible]t strategy for waste management, promot[illegible] econo[illegible]c viab[illegible]

3.2. Electric power [illegible]eration

Since mo[illegible] th[illegible] generated [illegible] disposed through conventional methods like inciner[illegible] compost, and landfill, which were uneconom[illegible]and unsusta[illegible] processes, leading to toxic gas emission or [illegible] water contamina[illegible] (Paritosh et al., 2017). Thus, recovering en[illegible]y or electricity employing FW is considered as eco-friendly, econo[illegible]c, pollution [illegible]ducing and sustainable approach. This can be ac[illegible]ed by anae[illegible]bically treating the FW in specific devices such as micr[illegible] fuel [illegible] (MFC) (Li et al., 2016). MFC utilizes microorganisms as cataly[illegible] recovery of electricity generated by using diverse wastes [illegible]ding industrial wastewater domestic wastewater and excess sludge ([illegible] 2016; Cercado-Quezada et al., 2010). Briefly in MFC, microorganisms oxidize organic matter transferring electrons to anode and at cathode the oxidized compounds or oxygen get reduced microbially or by abiotic process (Cercado-Quezada et al., 2010). Organic matter rich FW serves as energy source for electricigens in MFC, hydrolysis of this organic fraction is the rate limiting step in electricity production (Li et al., 2016). Pretreatment of FW employing microwave and sonication was reported to further enhance substrate hydrolysis, which in turn increases the efficiency of electricity generation (Yusoff et al., 2013). MFC containing FW leachate at a concentration of 5000 mg/L produced maximum power 15.14 W/m^3 and open circuit voltage of 1.12 V. Power output reduced with increasing substrate concentration 20,000 mg/L; this reduction was attributed to anode chamber microbial inhibition (Rikame et al., 2012). MFC performance was significantly decreased by the deposition of cations and microorganisms on fouled membranes. Jia et al., (2013) reported the microbial community structure in MFC loaded with FW collected from canteen of Harbin Institute of Technology. They have reported a maximum 18 W/m^3 power density at a chemical oxygen demand (COD) of 3200 ± 400 mg/L. The 454 pyrosequencing of the amplified 16S rRNA gene revealed the presence of different genera in anode biofilm of which fermentative *Bacteroide* and exoelectrogenic *Geobacter* were the dominant ones. Food industry wastes such as wine lees, yogurt waste and fermented apple juice in combination with two inoculums sources garden compost and anaerobic sludge was evaluated for electricity production by MFC (Cercado-Quezada et al., 2010). Of these, only yogurt waste inoculated with compost leachate exhibited the generation of stable power density of 44 mW/m^2. Organic fraction rich composite FW from canteen of CSIR-Indian Institute of Chemical Technology (IICT), India generated electricity upon action of anaerobic consortia as anodic biocatalyst in MFC. It was shown that OLR significantly affected the production of electricity from FW. OLR at 1.01, 1.74, and 2.61 kg COD/m^3-day generated 188, 295, and 250 mV electricity, respectively (Goud et al., 2011).

4. Bio-conversion of food waste to value added products

4.1. Biosurfactants

Biosurfactants are surface active compounds of biological origin prominently produced by diverse microorganisms including bacteria, fungi, and yeast (Gaur et al., 2019a; Gaur et al., 2019b). Globally, they are estimated to generate a revenue of over 18 Billion USD with a market of 30.64 Billion USD in 2016 (Singh et al., 2019). The compound annual growth rate of biosurfactant market is estimated to be 5.6% from 2017 to 2022. This increasing demand impulse to explore cheap waste material as substrates thus reducing the production cost while obligating waste management. Thus, FW from house-holds and various food industries can be employed as substrate for biosurfactant production aiding in curtailing the production cost while diminishing the pollution. One of the prominent FW produced from house-holds and commercial kitchens is used waste oil. Kitchen waste oil (KWO) is rich in protein and moisture content, thus encourages microbial growth. *Pseudomonas aeruginosa* isolated from KWO preferentially utilized KWO over glucose, glycerol, molasses, and rapeseed oil as a fermentation substrate for biosurfactant production (Chen et al., 2018). Another major waste from Indian food (dairy) industry is from *paneer* production. With the annual production of 0.15 million tonnes of *paneer* generated two million tonnes of waste whey, which is often released in the environment without any pretreatment that leads to soil and water pollution (Parashar et al., 2016; Patowary et al., 2016). *Pseudomonas aeruginosa* SR17, a hydrocarbon-contaminated soil isolate utilized *paneer* whey to yield 2.7 g/L of biosurfactant (Table. 2). The production further enhanced to 4.8 g/L by additionally supplementing it with mineral salts and glucose (Patowary et al., 2016). Another strain of *Pseudomonas aeruginosa* ATCC 10,145 utilized soy molasses a[illegible] carbon source for biosurfactant production (Rodrigues et al., 201[illegible]). A strain of *Pseudozyma* sp. produced biosurfactant which showed potential application as laundry detergent additives (Sajna et al., 2013). Soy molasses is generated during soyabean processing [illegible] low commercial value, although rich in proteins, carbohydrates, [illegible] lipids. *Pseudomonas aeruginosa* ATCC 10,145 produced [illegible].7 g/L glycolipid biosurfactant by utilizing 120 g soy molasses as fe[illegible] Ramírez et al., (2015) reported that *Bacillus subtilis* [illegible] *Pseudomonas aeruginosa* utilized olive oil mill waste [illegible] to synthesize biosurfactant. These bacteria utilize remaining [illegible] supplements as carbon source, whereas other waste components serve as nutrients.

4.2. Bio-plastics

Plastics are traditionally being synthesized from petrochemicals through irreversible processes (Tsang et al., 2019). Petroleum derived polymers are [illegible] degraded by microorganisms and their high persistence [illegible] serious environmental concerns thus an alternative to these synthetic plastics i.e. bioplastics comes into play. As microorganisms [illegible] products can synthesize these bioplastics. These bioplastics are preferred over synthetic ones delineating environmental burden while being ecofriendly. Substitution with bioplastics also offers a reduction in global warming concern as the energy requirement for petroleum based synthetic plastic production (77 MJ/kg) is more as compared to bioplastics (57 MJ/kg) (Gironi and Piemonte, 2011). Land-filling of FW leads to undesirable outcomes such as groundwater contamination and greenhouse gas emissions, thus bioconversion of FW to generate bioplastics is an optimal strategy for waste disposal. The bioconversion of FW to plastics requires pretreatment to enhance biological and physico-chemical properties. The pretreatment strategies include physical, chemical, biological and enzymatic hydrolysis. Physical treatment converts FW into fermentable organic compounds employing thermal and mechanical processes, including heating, milling, ultrasound, and microwaves (Tsang et al., 2019). Fermentable sugars are formed using chemical treatment, which includes acid or alkali treatment. Biological treatment includes microorganism to utilize FW as fermentable substrate. Polyhydroxyalkanoate (PHA), hydroxybutyrate (PHB), polybutylene succinate (PBS), starch blends, polyvinyl alcohol (PVA) and polylactic acid (PLA) are the major biodegradable polymers (Prabisha et al., 2015; Pandey and Soccol, 1998; John et al., 2007; Ramachandran et al., 2007; Tripathi et al., 2019; Tsang et al., 2019).

Alcaligenes sp. NCIM 5085 through an optimized fermentation process (7.5 L) utilized cane molasses and yielded 70.89% of high molecular weight PHB with 0.312 g/L/h productivity (Tripathi et al., 2019). Another strain *Halomonas campaniensis* strain LS21 grew in cellulose, starch, fatty acids, fats, and proteins rich FW and produced 70% PHB at 37 °C. *Bacillus megaterium* SRKP-3 utilized [illegible] to produce PHB (Pandian et al., 2010, Tsang et al., 201[illegible]). Felix et al. ([illegible]015) reported the production of bioplastics from freshwater red swamp crayfish. As per the United States Department of Agriculture, 45% [illegible] the Crayfish entering in United States of America food market resulted in waste only. Guidelines by European Union suggested the potential use of FW as animal feed, but disease control concerns made it illegal. Thus, valorizing FW by converting it to value added products holds an ideal end use practice.

4.3. Organic fertilizers

Conventional inorganic fertilizers contribute to increased atmospheric methane emission; organic fertilizers are considered effective alternative improving yield of crops along with reduction in methane emission. As per [illegible] market research, it has been estimated that emerging market of organic fertilizer would touch a value of over $150–109 per annum [illegible] 2020. FW has been traditionally used as animal feed and organic fertilizer prepared by composting or vermicomposting (Du et al., 2018). Agriculture waste has been utilized for mushroom cultivation [illegible] a substrate (Philippoussis et al., 2006). It reduces environmental burden and also at the same time enhances crop productivity and changes soil bacterial community. Residue of biogas production from FW can be used as organic fertilizers or soil conditioner due to nutritional and carbon content along with macronutrients (N, K, P, Ca, Mg) and microelements (Fe, Cu, Zn and Al) capable of improving and stimulating plant growth (Zhu et al., 2015).

Organic fertilizers can be synthesized from FW by employing several processes such as anaerobic digestion, aerobic composting using microbes, chemical hydrolysis method (treating FW *via* alkaline or acid hydrolysis at 600–1000C), and *in-situ* degradation of natural organic matter. It produces fertilizers in the form of digestate / soil conditioner, compost, soluble bio-waste compost (SBC), degraded crop, minerals and as liquid organic fertilizers (Du et al., 2018). Liquid organic fertilizers (LOF) are directly delivered at root zone of individual plant in irrigation system and are therefore, advantageous in plant growth than other fertilizers. They are readily available for absorption by plant and the quantity required per field is also less, as well as the degradation process of LOF is quite easier (More et al., 2017). The efficacy of organic fertilizers can further be improved by combining methane oxidizing bacteria such as methanotrophs (Singh and Strong 2016). Organic fertilizers can support the growth of microalgae also. It can be used as an alternative nutrient medium to cultivate *Chlorella vulgaris* for synthesis of biodiesel (Lam and Lee, 2012).

5. Conclusions

Food is an indispensable commodity contributing to major section of organic waste generated worldwide. Improper management of FW leads to environmental hazards by releasing toxic components viz. greenhouse gases, nitrates, ammonia etc.. Presently, microbial processing of FW offers environmental protection and a sustainable way for the genesis of billion dollar revenue. It can be concluded from this review that microorganisms can be efficiently employed for biotransforming FW into complex biomolecules, bio-fertilizers, biofuels, biochemicals and electrical energy. As FW is a rich source of nutrients, its valorization is proven to be a promising approach towards FW management.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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