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Review article

Conversion of food and kitchen waste to value-added products

Raveendran Sindhu[a,*], Edgard Gnansounou[b], Sharrel Rebello[c], Parameswaran Binod[a], Sunita Varjani[d], Indu Shekhar Thakur[e], Ramkumar B. Nair[f], Ashok Pandey[g]

[a] *Microbial Processes and Technology Division, CSIR-National Institute for Interdisciplinary Science and Technology (CSIR-NIIST), Trivandrum 695 019, India*
[b] *Ecole Polytechnique Federale de Lausanne, ENAC GR-GN, GC A3, Station 18, CH, 1015, Lausanne, Switzerland*
[c] *Communicable Disease Research Laboratory, St. Joseph's College, Irinjalakuda, India*
[d] *Gujarat Pollution Control Board, Gandhinagar 382 010, India*
[e] *School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India*
[f] *Mycorena AB, Stena Center 1A, 412 92 Gothenburg, Sweden*
[g] *CSIR-Indian Institute of Toxicology Research (CSIR-IITR), 31 MG Marg, Lucknow 226 001, India*

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ABSTRACT

Food and kitchen waste - omnipresent in every corner of the world serve as an excellent source of value added products owing to high organic content. Regardless of existence of various traditional methods of land filling or biogas production used to harness food waste energy, effective conversion of food to valuable resources is often challenged by its heterogenous nature and high moisture content. The current paper tries to lay down the prospects and consequences associated with food waste management. The various social, economical and environmental concerns associated with food waste management especially in terms of green house gas emission and extended rate of leachate generation also has been discussed. The difficulties in proper collection, storage and bioconversion of food waste to valuable by-products are pointed as a big hurdle in proper waste management. Finally, the wide array of value added products developed from food waste after pretreatment are also enlisted to emphasis the prospects of food waste management.

1. Introduction

Industrialization as well as improper waste management leads to accumulation of large amount of kitchen and food waste. As per the reports of FAO, a major portion of food produced, harvested and used is lost as waste in almost all types of food as depicted in Fig. 1 (http://www.fao.org/save-food/resources/keyfindings/en/). Improper waste management leads to several health hazards as well as environmental issues. Collection, storage as well as improper segregations are the major concerns limiting proper waste conversion. Hence steps to be adopted by Government by adopting strict rules as well as by introducing waste collection, sorting and storage centres to make it feasible to a certain extent.

Compared to the tonnes of waste generated, a proper waste management strategy is lacking in most of developing countries. Concepts of waste to wealth strategy currently practiced in most industrialized countries have solved this issue to a certain extent. Several countries like USA, Japan, Singapore, Sweden, Canada as well as Germany have operational waste to energy plants that proved the efficient conversion of wastes to energy. This has dual benefits like waste management as well as contribution to energy security of the country. Most of the developing countries like India lack systems for proper waste management due to insufficient infrastructure, improper planning, policy framework and funds (Sharholy et al., 2008). Furthermore, the gap between the policy and implementation is very large and is one of the main barriers for efficient bioconversion.

Recent studies showed that though composting is an effective method for bioconversion of waste, its main challenges are gaseous emissions and impurities. Nitrous oxide and methane generated during composting, contributes significantly to global warming. Their impact is reported to be 310 and 20 times higher than carbon dioxide (Nasini et al., 2016). In most countries, food wastes contribute almost half of the total municipal wastes whereas; this percentage may be higher in developing countries. Organic components of food wastes include fruits, vegetables, cooked food wastes, meat etc. Food wastes are generated during production, handling, storage, processing and consumption (Gustavsson et al., 2011).

Esteban and Ladero (2018) reported an overview of food waste as a source of value added chemicals and materials. This presents an overview of chemical, enzymatic and biotechnological processes for the

* Corresponding author.
E-mail addresses: sindhurgcb@gmail.com, sindhufax@yahoo.co.in (R. Sindhu).

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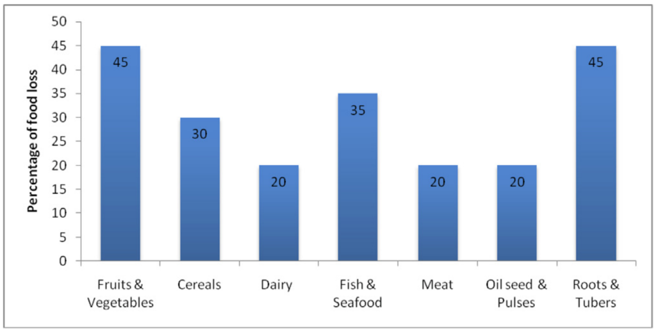

Fig. 1. Percentage of food lost in different food categories after production, harvest and use as per reports of FAO.

production of chemicals and materials using food waste as raw material. Dahiya et al. (2018) reported a review on food waste biorefinery – a sustainable strategy for circular bioeconomy. This review presents an overview of various bioprocesses employed for the generation of energy as well as various commodity chemicals.

Food and kitchen waste are mainly composed of organic fraction that includes carbohydrates, proteins, fats, lipids as well as inorganic components. The main challenge in conversion of food wastes is their heterogeneous nature as well as high moisture content and low calorific value. Composition of the food wastes varies depending upon the source. Hence, a common strategy cannot be adopted for all food wastes. Based on the source as well as composition, some kind of treatment may be carried out to make it accessible for the growth of microorganisms and to produce desired product of interest in an eco-friendly and economic way.

The present review gives an overview of different value added products produced from food and kitchen wastes.

2. Current conversion strategies

Different types of waste conversion strategies are available which can be adopted based on the properties of the waste (Fig. 2). Commonly adopted conversion strategies include thermal, chemical or biochemical conversions. Thermal conversions include gasification, pyrolysis and incineration. Biochemical conversions include composting and anaerobic digestion. Recently several fermentation as well as combined processes is available for the production of various industrially important products. Since food waste is a heterogeneous mixture, many microbes cannot utilise this as such. Hence some kinds of physical or chemical or combined pretreatment to be carried out to make it accessible for further enzymatic saccharification for the production of value added products.

Most of the food wastes are used for land filling or for generation of conventional energy. Food wastes are biodegradable and contain high moisture hence suitable for the production of bioenergy by anaerobic digestion. The major limitations in anaerobic digestion of food waste are the lowering of pH during anaerobic digestion due to production of volatile fatty acids. This will inhibit growth of methanogenic microbes. Adopting integrated or alternative strategies can overcome this issue. Previous studies revealed that focussing on the production of a single product from food and kitchen waste is not economically viable. Several research and developmental activities are going on throughout the world for the conversion of heterogeneous food wastes to multiple value added products, which will lead to the development a feasible and economically viable strategy of bioconversion of food wastes (Dahiya et al., 2018).

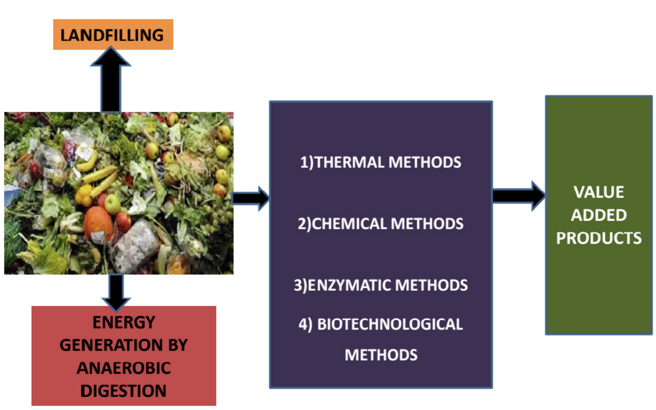

Fig. 2. An overview of food waste management.

3. Value added products from food and kitchen waste

Different value added products can be produced from kitchen and food wastes. This includes activated carbon adsorbent, antioxidants, bioactives, bioethanol, biobutanol, biodiesel, biogas, bioelectricity, biopolymer, bionanocomposite, chitosan, corrosion inhibitors, DHA, industrial enzymes, films, high fructose syrup, levulinic acid, mushroom cultivation, nutraceuticals, organic acids, pigments, single cell protein, sugars, vermicompost, wax esters and xanthan gum. Table 1 gives an overview of different value added products produced from food and kitchen wastes.

3.1. Activated carbon adsorbent

Activated carbon adsorbent finds applications in various fields like purification and separation in various industrial fields. Hence, its demand is increasing day by day. Saygili et al., (2015) reported conversion of grape industrial processing waste to activated carbon and its application in the adsorption of cationic and anionic dyes.

The study revealed that grape industry processing waste as a low cost and cleaner precursor for the production of low cost activated carbon with activation with zinc chloride. It effectively removes cationic and anionic dyes from aqueous solution. The adsorption capacity was found to be higher than commercially available as well as agro-waste based carbonaceous materials.

3.2. Antioxidants

Antioxidants are compounds that prevent oxidation of molecules to form free radicals. Hence, these compounds play an important role as preservatives in foods and cosmetics as well as function as oxidation inhibitors in fuels. Antioxidants also reduce risk of certain human diseases. Synthetic antioxidants have potential health hazards. These lead to increased consumption of natural antioxidants that have more health benefits. Several food industry wastes like peels, seeds etc. serve as a source for the production of antioxidants.

Amado et al., (2014) reported antioxidant extraction from potato peel waste. The conditions for extraction were optimised by adopting a response surface strategy optimising various process parameters like temperature, solvent concentration and extraction time. The optimum conditions of extraction were 34 min of extraction time, temperature of 89.9 °C and ethanol concentration of 71.2% and 38.6% for extraction of phenolics and flavonoids respectively. The study revealed potato peel as a good source for antioxidants that can effectively limit oxidation of oils.

Barba et al., (2016) reported several green strategies for extraction of antioxidant bioactive compounds from winery wastes and by-products like grapes stalk, grapes marc, grapes seeds etc. Grape seeds serve as a rich source of antioxidant – vitamin E. These novel green strategies seem to be superior when compared to conventional strategies in terms of energy consumption and processing time as well as the use of harmful and expensive solvents.

Table 1
Profile of value-added products from kitchen and food waste.

Section Number	Product	Source	Microorganism	Reference
3.1.	Activated carbon adsorbent	Grape industrial processing waste	–	Saygili et al. (2015)
3.2.	Antioxidant	Potato peel waste	–	Amado et al. (2014)
		Winery waste/by-products	–	Barba et al. (2016)
		Olive fruit/by-products	–	Wang et al. (2017)
3.3.	Bioactives	Marine processing waste/fish	–	Harnedy and FitzGerald (2012)
3.4.1.	Bioethanol	Pineapple leaves	Yeast	Chintagunta et al., 2017
		Potato peel/mash waste	*Aspergillus niger Saccharomyces cerevisiae*	Chintagunta et al. (2016)
		Unprocessed food waste	*Thermophilic anaerobe*	Dhiman et al. (2017)
		Kitchen waste	–	Nishimura et al. (2017)
3.4.2.	Biobutanol	Starchy food waste	*Clostridium beijerinckii* NCIMB 8052	Ujor et al. (2014)
		Amorphophallus konjac waste	*Clostridium acetobutylicum* ATCC 824	Shao and Chen (2015)
3.4.3.	Biodiesel	Mixed non-edible oils/castor seed oil/waste fish oil	–	Fadhil et al. (2017)
		Waste pepper seeds	–	Lee et al. (2017)
		Waste palm oil	–	Thushari and Babel (2018)
		Waste oils with high acidic value	–	Hu et al. (2017)
3.4.4.	Biogas	Food waste	–	Deepanraj et al. (2017)
		Food waste	–	Wu et al. (2016)
3.4.5.	Bioelectricity	Orange peel biomass	*Enterococcus Paludibacter Pseudomonas*	Miran et al. (2016)
		Food waste	*Geobacter Bacteroides*	Jia et al. (2013)
		Acidogenic food waste leachate	–	Rikame et al. (2012)
		Canteen based composite waste	–	Goud et al. (2011)
3.5.1.	Biopolymer (Plastic films)	Post-harvest tomato plants and urban food waste	–	Nistico et al. (2017)
	Biopolymer (Medium chain length polyhydroxyalkaonates)	Fruit pomace/waste frying oil	*Pseudomonas resinovorans*	Follonier et al. (2014)
	Biopolymer (Polyhydroxybutyrate)	Molasses spent waste	–	Khardenavis et al., 2009
3.5.2.	Bio-nanocomposite	Waste vegetable oil	–	Fernandes et al. (2017)
		Jack fruit peel derived pectin	–	Govindaraj et al. (2017)
3.5.3.	Chitosan	Shrimp shell waste	–	Gomez-Rios et al. (2017)
3.6.	Corrosion inhibitors	Tomato peel	–	Grassino et al. (2016)
3.7.	Docosahexenoic acid (DHA)	Mash from potato chips industry	*Thraustochytriidae* sp. AS4-A1	Quilodran et al. (2010)
3.8.1.	Amylase	Kitchen waste	*Chryseobacterium Bacillus* sp.	Hasan et al. (2017)
		Banana peel	*Aspergillus niger* NCIM 616	Krishna et al. (2012)
3.8.2.	Cellulase	Soy bean hulls	*Aspergillus niger* NRRL3	Julia et al. (2016)
		Alkali pretreated kitchen waste residue	*Aspergillus niger* NS-2	Bansal et al. (2012)
3.8.3.	Protease	Waste bread pieces	*Aspergillus awamori*	Melikoglu et al. (2015)
3.8.4.	Pectinase	Hazelnut shell	*Bacillus subtilis*	Uzuner and Cekmecelioglu (2015)
		Citrus waste peel	*Aspergillus niger*	Ahmed et al. (2016)
3.8.5.	Xylanase	Grape pomace	*Aspergillus awamori*	Botella et al. (2007)
3.9.	pH indicator films	Blueberry agro-waste	–	Luchese et al. (2017)
3.10.	High fructose syrup	Beverage waste	–	Haque et al. (2017)
3.11.	Levulinic acid	Cellulosic food waste	–	Chen et al. (2017)
3.12.	Mushroom cultivation	Olive mill waste	Oyster mushroom	Ruiz-Rodriguez et al. (2010)
		Onion juice waste	*Pleurotus sajor-caju*	Pereira et al. (2017)
3.13.	Nutraceuticals	Shrimp waste	–	Prameela et al. (2017)
		Tomato processing waste	–	Poojary and Passamonti (2015)
3.14.1.	Acetic acid	Waste cheese whey	–	Pal and Nayak (2016)
3.14.2.	Fumaric acid	Apple industry waste biomass	*Rhizopus oryzae*	Das et al. (2015)
3.14.3.	Citric acid	Apple pomace ultrafiltration sludge	*Aspergillus niger* NRRL 567	Dhillon et al. (2011)
		Banana peel	*Aspergillus niger*	Karthikeyan and Sivakumar (2010)
		Fruit wastes	*Aspergillus niger* DS1	Kumar et al. (2003)
3.14.4.	Succinic acid	Citrus peel waste	*Actinobacillus succinogenes*	Patsalou et al. (2017)
		Oil palm empty fruit bunch	*Actinobacillus succinogenes* ATCC 55618	Akhtar and Idris (2017)
		Fruit and vegetable waste	*Actinobacillus succinogenes*	Dessie et al. (2018)
3.14.5.	Lactic acid	Food waste/waste activated sludge	–	Zhang et al. (2017)
		Mixed restaurant food waste and bakery waste	*Aspergillus awamori Aspergillus oryzae*	Pleissner et al. (2015)
		Waste *Curcuma longa* biomass	*Lactobacillus coryneformis Lactobacillus paracasei*	Nguyen et al., 2013
		Kitchen refuse	*Bacillus coagulans*	Tashiro et al. (2013)
3.14.6.	Propionic acid	Apple pomace	*Propionibacterium freudenreichii* T82	Piwowarek et al. (2016)
3.14.7.	Gluconic acid	Sugarcane molasses	*Aspergillus niger* ARNU-4	Sharma et al. (2008)

(*continued on next page*)

Table 1 (*continued*)

Section Number	Product	Source	Microorganism	Reference
3.15.	Pigments	Molasses/Corn steep liquor/bran/whey	–	Panesar et al., 2015
	Pigments (Carotenoids)	Waste cooking oil	*Blakeslea trispora*	Nanou and Roukas (2016)
	Pigments (Carotenoids)	Food waste	*Rhodotorula mucilaginosa*	Cheng and Yang (2016)
	Pigments (Yellowish-orange)	Pineapple waste	*Chryseobacterium artocarpi* CECT 8497	Aruldass et al. (2016)
	Pigments	Grape waste	*Monascus purpureus*	Silveira et al. (2008)
3.16.	Quercetin	Onion skin waste		Choi et al. (2015)
3.17.	Single cell protein	Mixed food waste	*Saccharomyces cerevisiae* *Kluyveromyces marxianus*	Aggelopoulos et al. (2014)
3.18.1.	Glucose	Potato peel waste	–	Kumar et al. (2016)
3.18.2.	D- Tagatose	Onion waste	–	Kim et al. (2017)
3.18.3.	D- Mannose	Coffee waste residue	–	Nguyen et al., 2017
3.19.	Vermicompost	Kitchen waste	–	Adi and Noor (2009)
3.20.	Vinegar	Pineapple waste	*Acetobacter aceti*	Roda et al. (2017)
		Olive oil press mill waste	–	Leonardis et al. (2018)
3.21.	Wax esters	Food industry waste	*Cryptococcus curvatus* *Rhodosporidum toruloides* *Lipomyces starkeyi*	Papadaki et al. (2017)
3.22.	Xanthan gum	Kitchen waste	*Xanthomonas campestris* LRELP-1	Li et al. (2017)

Olive fruits and by-products serve as a good source for antioxidants. Production of antioxidant phenolic compounds from olive pomace has many ecological and environmental benefits. Wang et al., (2017) developed an eco-friendly strategy like ultrasound assisted-enzymatic hydrolysis of olive waste for the extraction of antioxidant phenolic compounds. The optimised conditions of extraction are treatment time for 40 min, temperature of 55 °C and pH of 5.75. The study revealed that the phenolic extract can be used as a food additive enhancing antioxidant properties in fatty food with better economic benefits than synthetic additives.

3.3. Bioactives

Bioactives are compounds that show an effect on living organisms. These compounds show potential health benefits functioning as antimicrobial, antidiabetic, antihypertensive, anticoagulant, anticancer or hypo-cholesteraemic agents. Fish and shell fish processing wastes serve as an efficient source of bioactives. Harnedy and FitzGerald (2012) reported several bioactive peptides, proteins and amino acids from marine processing waste and fish. The marine processing wastes contain significant amount of diverse proteins that can act as a source for the production of diverse class of bioactives. Marine derived peptides function as promising nutraceuticals. Utilisation of the waste streams for the production makes it economically viable.

3.4. Fuels

3.4.1. Bioethanol

Increase in fossil fuel consumption as well as depletion of fossil fuels leads to energy crisis. This leads to search for alternative strategies of energy. Use of agro-residues or food waste serves as an ideal source for bioethanol production. Chintagunta et al. (2017) reported bioethanol production from pineapple leaf waste. Pineapple leaves are left out in the field after pineapple harvesting. The leaves contain 60–80% of holocellulose making them as an ideal feedstock for bioethanol production. Bioethanol production was carried out by simultaneous saccharification and fermentation using cellulase cocktail and yeast. Under optimised conditions 7.12% v/v of bioethanol was produced. Utilisation of pineapple leaf waste addresses the problems of fossil resources depletion and environmental pollution.

Bioethanol production from potato waste was evaluated by Chintagunta et al. (2016). Disposal of potato peeling waste is major ecological and environmental concerns associated with potato processing plants. Utilisation of this waste for bioethanol production is a promising approach. Ethanol production was evaluated using potato peel and mash wastes using a co-culture of *Aspergillus niger* and *Saccharomyces cerevisiae*. Under optimised conditions potato peels and mash wastes produced respectively 6.18% v/v and 9.3% v/v of bioethanol. The study showed that wastes generated from potato processing plants as an attractive raw material for bioethanol production.

Simultaneous hydrolysis and fermentation of unprocessed food waste into ethanol using thermophilic anaerobic bacteria was reported by Dhiman et al., (2017). Conversion of Raw and Untreated Disposal into Ethanol (CRUDE) was carried out. This is the first report where ethanol is produced in single reactor using a thermophilic anaerobe. This is a clean and green process eliminating hazardous chemicals as well as harsh conditions making it a green process.

Production of ethanol from a mixture of waste paper and kitchen waste was carried out by Nishimura et al., (2017). To develop a cost effective ethanol production strategy from waste paper, addition of food waste proved to be successful. Liquefaction of kitchen waste was carried out followed by simultaneous saccharification and fermentation, which is essential for effective fermentation. Ethanol concentration of 46.6 g/L and 45.5 g/L was observed after 96 h of fermentation in lab scale and pilot scale respectively. The kitchen waste acts as carbon source, nutrient source as well as acidity regulator.

3.4.2. Biobutanol

Biobutanol serves as a fuel for internal combustion engine. It is non-polar and studies revealed that it can work in gasoline compatible engines without any further modifications. Substrate cost is one of the major factors limiting butanol production. Ujor et al., (2014) first reported the feasibility of butanol production using industrial starchy food wastes. The study revealed that starchy food wastes serves as a viable source for the production of butanol. Batch fermentation carried out with *Clostridium beijerinckii* NCIMB 8052 using starch industry food wastes like inedible dough, breading's and batter liquids as substrate produced 14.4, 14.8 and 15.1 g/L of ABE (acetone-butanol-ethanol) concentration. The results demonstrate the potential of starchy food waste as an economically feasible substrate for butanol production.

Shao and Chen (2015) evaluated the potential of *Amorphophallus* konjac waste as a feasible substrate for ABE fermentation by *Clostridium acetobutylicum* ATCC 824. Utilisation of konjac waste enhances the feasibility of waste treatment and reduces environmental pollution. The strain utilises konjac waste as a feasible substrate for ABE fermentation. The results indicate that ABE concentration was more for separate hydrolysis and fermented (SHF) samples than simultaneous saccharified and fermented (SSF) samples. Under SHF 7.1 g/L of butanol was produced by *Clostridium acetobutylicum* ATCC 824.

3.4.3. Biodiesel

Biodiesel is composed of mono-alkyl-esters of long chain fatty acids. It has low volatility and high viscosity this may lead to gelling issues at low temperatures, which in turn leads to clogging of pumps. Blending can improve the fuel properties and common blend is B20. One of the main limitations in biodiesel production is the high cost associated with the production. This can be overcome by using non-edible oils as a source for biodiesel production. Mixed non-edible oils, castor seed oil (CSO) and waste fish oil (WFO) were evaluated for cost-effective biodiesel production by Fadhil et al., (2017). Different blends were tried and highest production was observed with equivalent blend (50: 50% WFO: CSO w/w). Under optimised conditions 95.2% w/w of biodiesel was obtained. The fuel properties were also in the acceptable range. Using mixed oil reduced the optimum temperature required for biodiesel production there by reducing the energy input, which in turn reduces the overall process economics.

Rapid biodiesel synthesis from waste pepper seeds (WPS) without lipid isolation step was developed by Lee et al., (2017). The study revealed that WPS contains 26.9 %w of lipid and 94.1 %w of the lipids can be converted into biodiesel. The optimum transmethylation temperature was observed as 390 °C. The process was carried out in presence of silica and proved to be effective in biodiesel production from waste pepper without lipid extraction.

Thushari and Babel (2018) reported utilisation of waste palm oil and sulfonated carbon acid catalyst derived from coconut meal residue for biodiesel production. Inexpensive catalyst was used for biodiesel production. The highest biodiesel yield from waste palm oil residue is 92.7% in an open reflux system using the catalyst. Fuel properties also were found to be compatible. Catalyst was found to be highly stable and reusable for four cycles without losing its activity.

Novel efficient procedure for biodiesel synthesis from waste oils with high acid value using 1-sulfobutyl- 3-methylimidazolium hydrosulphate ionic liquid as catalyst was developed by Hu et al. (2017). Various process parameters affecting biodiesel production were optimised like molar ratio of methanol to waste oils, catalyst concentration, reaction temperature and reaction time. Under optimised conditions biodiesel yield was 94.9%. Catalyst retained 97% activity after 5 cycles. The study proves an efficient and eco-friendly catalyst for the production of biodiesel from waste oils with high acid value.

3.4.4. Biogas

Biogas is a renewable gas that is a mixture of methane, carbon dioxide, hydrogen sulphide, moisture and siloxanes. It is produced by the anaerobic digestion of different wastes. Food waste is an important issue and its anaerobic conversion to biogas is promising. Several research and developmental activities are going throughout the world to address this issue. Deepanraj et al. (2017) observed that substrate pretreatment have significant effects on biogas production from food wastes. Different pretreatments like autoclave, microwave and ultrasonication of food waste were carried out and anaerobic digestion was carried out with poultry manure. Maximum biogas production (10.12%) and yield (9926 mL) was observed with ultrasonication pretreated samples. 41.96–46.52 g/L of volatile solids were also removed during the process.

Wu et al., (2016) developed an improved biogas production from food waste by co-digestion with de-oiled grease trap waste. The study was carried out in different digesters like mesophilic digester (MD), temperature-phased anaerobic digester (TPAD) and temperature-phased anaerobic digester with recycling (TPAD-R). Mono-digestion of food waste as well as co-digestion with de-oiled grease trap waste was carried out. The results indicate that co-digestion increased the biogas yield by 19% in MD and TPAD-R with a biogas yield of 0.60 L/g of volatile solids.

3.4.5. Bioelectricity

Food waste is a highly valuable, biodegradable and nutritious organic source that is available in excess amount rendering it difficult to manage. Hence, utilisation for other novel applications is a viable alternative way for value addition. Microbial fuel cells (MFC) are a promising efficient electrochemical technology to treat wastewater by providing clean energy. Bioconversion of organic components present in wastewater to electricity can be carried out by microorganisms. The main advantages of MFC for wastewater treatment include safe, clean, efficient as well as direct electricity production along with removal of organic components present in the wastewater. MFC are composed of a cathode and anode chamber separated by a proton exchange membrane. The organic components present in the wastewater are oxidised by bacteria and produce protons and electrons. Protons transferred through proton exchange membrane while the electrons are transferred through external circuit.

Mediator-less MFC were evaluated for conversion of orange peel biomass to bioelectricity by Miran et al., (2016). Under optimised conditions 0.59 V was generated from orange peel waste. The maximum power density and current density obtained were 358.8 mW/m^2 and 847 mA/m^2 respectively. Dominant microbial flora in the anode film was *Enterococcus*, *Paludibacter* and *Pseudomonas*. Jia et al., (2013) reported bioelectricity generation from food waste using MFC. The study revealed that organic loading rate of food waste has a significant effect on power output of MFC. Microbial community analysis revealed that exoelectrogenic *Geobacter* and fermentative *Bacteroides* are the dominant species that help in organic food waste conversion to bioelectricity. Rikame et al., (2012) generated electricity from acidogenic food waste leachate using dual chamber mediator less microbial fuel cell. In this study acidogenic fermentation and electrochemical performance were evaluated. Under optimised conditions maximum power density of 15.14 W/m^3, open circuit voltage of 1.12 V and 90% of COD removal were observed. The study revealed the possibilities of bioelectricity production from food waste leachate. Canteen based composite waste is a rich source of organic constituents. Goud et al., (2011) exploited canteen based composite waste as a suitable substrate for the production of bioelectricity using MFC. Maximum power output (295 mV, 390 mA/m^2) was observed with organic loading rates of 1.74 kg COD/m^3-day. Energy conversion efficiency was increased with intermittent loading rate due to effective utilisation of substrate.

3.5. Biomaterials

3.5.1. Biopolymer

Nistico et al., (2017) reported manufacture of plastic films from post-harvest tomato plants and urban food wastes. Composite films were prepared by compounding poly (vinyl alcohol-*co*-ethylene) with 2–10% post-harvest tomato plant powder. The study revealed that post-harvest tomato plant powder can be blended to make composite films in a cost competitive way. Follonier et al., (2014) evaluated the potential of fruit pomace and waste frying oil as a resources for the bio-production of medium chain length polyhydroxyalkanoates. One of the main limiting factors for the production of biopolymer when compared with petroleum based polymers is the high production cost and the main part is contributed by the carbon source. Hence, utilisation of cheap and waste by-product stream as a source of carbon like sugars and fatty acids seems a promising strategy. In this study, sugars and fatty acids derived from nine different fruit wastes were evaluated for medium chain length polyhydroxyalkanoates (mcl-PHA) by *Pseudomonas resinovorans*. Highest sugars were observed with Solaris grapes while apricot pomace contains the lowest level of inhibitors. Maximum mcl-PHA production of 21.3 g/L was observed with Solaris grapes. This study indicates a low cost strategy for the production of mcl-PHA by *Pseudomonas resinovorans*.

Utilisation of molasses spent waste for the production of bioplastic, polyhydroxybutyrate from activated sludge was reported by Khardenavis et al., (2009). Molasses spent wash were processed to obtain different ratios of carbon and nitrogen. The study revealed that there was 52% removal of chemical oxidation demand with a polyhydroxybutyrate accumulation of 28%. The study revealed the benefits of an un-utilizable and toxic molasses spent wash for the production of a value added product polyhydroxybutyrate.

3.5.2. Bio-nanocomposite

Waste vegetable oils (WVO) serve as an alternative source for the production of epoxy resin blends and composites. It is a potential low cost material and does not compete with food crops. Fernandes et al., (2017) reported production of epoxy resin blends and composites from waste vegetable oil. Purification of the WVO was carried out for the removal of by-products produced during frying and epoxidised for the formation of oxirane rings that are essential to obtain materials with good mechanical properties. Then milled recycled carbon fibres were added to the blends for further improvement of mechanical properties and reinforcement. The effect of epoxidised vegetable oils was compared with pure oil. The results demonstrate compatibility in tensile properties. This indicates the potential of valorisation of WVO as an alternative source for triglycerides and opens a novel application.

Jack fruit peel derived pectin/apatite bio-nanocomposites for bone healing applications was reported by Govindaraj et al., (2017). In this study, pectin was isolated from jack fruit peel and was mixed with apatite for the production of pectin/apatite bio-nanocomposite. Optimisation studies were carried out to get the bio-nanocomposite with better properties. Fabricated bio-nanocomposite showed cyto-compatibility, anti-inflammatory as well as cell adhesion testing showed good biocompatibility indicating its potential application as bone graft material. Physico-chemical and biological properties make them suitable for orthodontic and orthopaedic tissue engineering.

3.5.3. Chitosan

Chitosan is a polymer of N-acetylglucosamine units. Chemically it is produced by the de-acetylation of chitin. Chitosan is nontoxic, biodegradable and biocompatible and finds applications in various industries like food, agriculture and medicine. Chitin is found as a structural compound in arthropods and fungi. Utilisation of shrimp shell waste for the production of chitosan was reported by Gomez-Rios et al., 2017. Techno-economic analysis was carried out using Aspen plus software and it was found that the process is profitable as well as cost competitive. One of the major constrains in chitosan production is the material cost and the quality of the final product. Utilisation of shrimp shell waste serves as an economically viable alternative source for chitosan production.

3.6. Corrosion inhibitors

Grassino et al., (2016) evaluated the potential utilisation of tomato peel from canning factory as a source of pectin production and its application as a tin corrosion inhibitor. This helps in the waste disposal problem of canning factory waste to a value added product-waste to wealth strategy. Only few reports were available on the application of pectin extracted from fruit industrial waste as a corrosion inhibitor. The study revealed that the pectin extracted from tomato peel serves as an efficient corrosion inhibitor for tin, even at very low concentrations. Maximum inhibition efficiency was reported as 71%.

3.7. Docosahexaenoic acid (DHA)

Docosahexaenoic acid (DHA) is a long chain omega-3-fatty acids and is an essential polyunsaturated fatty acid. Deficiencies of DHA are associated with several diseases. Currently the main source of DHA is fish oil. Dietary DHA has positive impacts on hypertension, diabetics, myocardial infarction and cancer. Quilodran et al., (2010) evaluated the potential of residual mash from brewery by-product and liquid residues from potato chip processing factory as nutrient source for the production of DHA by *Thraustochytriidae* sp. AS4-A1. The percentage of DHA varies depending upon the composition of growth media. With residual mash from brewery by-product the strain produced 576 mg/L and supplementation of yeast extract, B-complex vitamins and monosodium glutamate significantly increased the productivity to 540 mg/L/day. The DHA production was observed during the growth period. The results indicate that brewery by-product serves as a cost-effective excellent nutrient source for the production of DHA by *Thraustochytriidae* sp. AS4-A1.

3.8. Enzymes

3.8.1. Amylase

Amylases are enzymes which degrades starch to smaller carbohydrates units like glucose, maltose and maltotriose. It is one of the most important industrial enzymes and finds applications in paper, textile, food, detergent and for fuel ethanol production. Commercial carbon and nitrogen source and commonly used for the production of amylases. Utilisation of agro-residues as well as food and kitchen waste serves as an alternative source for cost-effective amylase production. Hasan et al., (2017) observed amylase production by *Chryseobacterium* and *Bacillus* species using kitchen waste. Various process parameters affecting production were optimised and the study revealed that both the strains could utilise starchy kitchen waste for amylase production.

Krishna et al., (2012) utilised banana peel for the production of amylase by *Aspergillus niger* NCIM 616. The study revealed solid state fermentation as a promising strategy when compared to submerged fermentation. Supplementation of mineral salts to the medium improved amylase production by *A. niger* NCIM 616. Under optimised conditions the strain produced 13,000 units/mg protein/g substrate of amylase.

3.8.2. Cellulase

Cellulases are complex enzymes consisting of endocellulase, exocellulase and β-glucosidase. Complete hydrolysis of cellulose is brought about by the sequential action of these enzymes. These enzymes play an important role in biomass hydrolysis. Cellulase finds applications in different industries like biofuel, paper and pulp, textile, detergent, food and feed.

Julia et al., (2016) reported potential use of soy bean hulls and waste paper as supports in solid state fermentation for cellulase production by *Aspergillus niger* NRRL3. The use of soybean hulls provided high volumetric productivity at shorter times, this will have a positive impact on overall process economics. Endoglucanase activity (5914.29 U/L) was found to be four times higher, the exoglucanase activities (4551.19 U/L) were 9.5 times higher and β-glucosidase activities (984.01 U/L) were 1.7 times higher than waste paper alone at the same fermentation time. This process has economic benefits especially when a cellulase complex is required.

Complete cellulase system by *Aspergillus niger* NS-2 in solid state fermentation using agricultural and kitchen residues was reported by Bansal et al., (2012). Alkali pretreated agricultural and kitchen waste residues like corn cobs, carrot peelings, composites, wheat bran, wheat straw, orange peelings, potato peelings, pineapple peelings saw dust, rice husk moistened with water were found to be suitable for the production of cellulases without any additional nutritional sources. Maximum production was observed after 96 h of incubation. Wheat bran showed highest production CMCase, FPase and β-glucosidase activities of 310, 17 and 33 U/gds respectively.

3.8.3. Protease

Protease are enzymes which catalyses the hydrolysis of proteins. It finds applications in medicine, food and detergent industries. Waste bread pieces as a source for protease production by *Aspergillus awamori* in a packed –bed reactor were evaluated by Melikoglu et al., (2015). Highest protease activity was 80.3 U/g bread when the air flow was kept at 1.50 vvm. The study indicates the potential of waste bread as a feasible raw material for protease production.

Bread serves as an ideal substrate for solid state fermentation. It serves as a major food waste in many countries. Currently most of the bread wastes are used for land filling and it leads to methane production by anaerobic digestion. Methane shows 21 times more global warming potential when compared to carbon dioxide. Hence, utilisation of this waste for value addition seems promising in terms of economical as well as ecological benefits. Melikoglu et al., (2013) optimised various process parameters affecting protease production from *Aspergillus awamori* by adopting a stepwise strategy. Protease activities of 83.2 U/g of bread were recorded with particle size of 20 mm and incubation time of 144 h.

3.8.4. Pectinase

Pectinases are enzymes that hydrolyse pectins and find wide applications in food industries for clarification of fruit juice as well as tea and coffee fermentation. Other applications include production of pectic oligosaccharides, DNA extraction from plants and degumming of fibres. To meet the increasing demands, it is essential to develop strategies for cost-effective production. Several agro-industrial residues as well as fruits and vegetable wastes serve as an ideal substrate for pectinase production. Ahmed et al., (2016) evaluated the potential of citrus waste peel as a source for pectinase production by *Aspergillus niger*. Citrus waste contains high amount of soluble carbohydrates. Submerged fermentation was carried out in Czapecks - Dox medium supplemented with citrus peel waste that serves as sole carbon source. Maximum enzyme yield (117.1 μm/mL/min) was observed on the fifth day of fermentation.

Uzuner and Cekmecelioglu (2015) demonstrated the potential of hazelnut shell hydrolysate as a suitable low cost medium for the production of pectinase by *Bacillus subtilis*. Various process parameters affecting submerged fermentation was optimised by adopting statistical design experiments. Maximum polygalacturonase activity (5.6 U/mL) was observed with an incubation time of 72 h, pH of 7.0, incubation temperature of 30 °C, yeast extract concentration of 0.5% w/v and 0.02% w/v of KH_2PO_4.

3.8.5. Xylanase

Xylanases are enzymes which catalyse the hydrolysis of plant polysaccharide xylan. It finds applications in food, feed, paper and pulp industries. Grape pomace is the residue that is left out after juice extraction from grapes. It is not suitable as an animal food due to its low nutritive value as well as due to the presence of high level of phenolic compounds. The disposal of grape pomace leads to serious environmental hazards. Hence, utilisation of this for value addition seems promising. Grape pomace is unsuitable for fertilizer applications since the high phenol content may inhibit seed germination. Feasibility of grape pomace for the production of xylanases by *Aspergillus awamori* was evaluated by Botella et al., (2007). The study revealed that supplementation of additional carbon source as well as initial moisture content of grape pomace plays a significant role in enzyme production.

3.9. pH indicator films

Intelligent packing is an emerging area of food technology for better preservation. It involves some sensors that provide visual information to the customers like appearance or disappearance of a colour. Several research and development activities are going on in this direction and one such material is pH indicator film that is non-toxic and produces response to pH change. Luchese et al., (2017) developed a pH indicator film by blueberry agro-waste addition to starch based films. Corn starch, glycerol and blueberry powder were used to produce pH indicator films. Blueberry powder which is a by-product of fruit processing industry rich in anthocyanins was added with films to evaluate its role as an indicator because of the ability of anthocyanin to change its colour in acidic or basic environment. The pH indicator films were evaluated with buffers having different pH. The results indicate that blueberry powder acts as a potential pH indicator for intelligent food packing as well as for sensible food deterioration.

3.10. High fructose syrup

High fructose syrup (HFS) is commonly produced by enzymatic saccharification of starch to glucose followed by enzymatic isomerisation to fructose. Haque et al., (2017) made an effort to produce high fructose syrup from beverage waste. This is the first report on the conversion of beverage waste to HFS. The steps involved in the conversion of beverage waste to HFS include enzymatic hydrolysis, activated carbon treatment, ion exchange chromatography and ligand exchange chromatography. In this study, 47.5% of sugars were recovered as HFS. This proves a green process for nutrient recovery in beverage waste valorisation.

3.11. Levulinic acid

Levulinic acid is an important platform chemical and is a keto acid. It is produced by degradation of cellulose. Chen et al., (2017) developed a strategy for the production of levulinic acid from cellulosic food waste by catalyzation with Bronsted acids. Amberlyst 36 produced levulinic acid efficiently from vegetable waste. The yield was same with DMSO-water.

3.12. Fungal cultivation

Olive mill waste was exploited for cultivation of oyster mushrooms by Ruiz-Rodriguez et al., (2010). Different strains of oyster mushrooms were cultivated in wheat straw supplemented with different concentrations of olive mill waste (0–90%). The studies showed that except for colour of fruiting bodies there is no significant difference when compared to control grown on wheat straw. Total phenolic content, antioxidant activities were similar to that of control and no phenolic compounds were detected on oyster mushrooms grown on olive mill waste.

Pereira et al., (2017) utilised onion juice waste for the production of *Pleurotus sajor-caju*. Solid state fermentation was carried out using onion waste for the production of fruiting bodies of *Pleurotus sajor-caju*. The yield was 45.73%. The study proved the feasibility of onion waste as a substrate for the cultivation of *Pleurotus sajor-caju*.

In a recent study, Nair et al., 2017 has demonstrated the use of waste bread for the cultivation of food-grade edible strains of filamentous fungi, such as *Neurospora intermedia, Aspergillus oryzae,* belonging to ascomycetes and *Mucor indicus, Rhizopus oryzae*, belonging to zygomycetes group. The fungal biomasses that are high in protein are further used as animal or fish feed component. The study also demonstrated the use of waste bread as ethanol substrates using the filamentous fungi.

3.13. Nutraceuticals

Nutraceuticals are nutritive pharmaceuticals that provide health benefits. Shrimp processing industries generate tonnes of shrimp wastes annually. They serve as a cheap source for the production of nutraceutical astaxanthin. It is the main xanthophyll carotenoid in crustacean waste. Quality of the nutraceutical depends on the strategies adopted for extraction, nutrient content as well as its efficacy as a dietary supplement. Astaxanthin finds wide applications as antioxidant, cardio-protective, anti-hypersensitive, anti-tumorigenic. It can be extracted by several chemical strategies as well as green techniques like microbial fermentation or enzymatic extraction. Utilisation of shrimp waste for astaxanthin production helps in better waste management (Prameela et al., 2017).

Lycopene, a red pigment, is a potent antioxidant. Poojary and Passamonti (2015) extracted lycopene from tomato processing waste that is an abundantly available industry by-product. It was extracted using acetone-hexane mixture. Lycopene yield of 3.47–4.03 mg/100 g of processing waste was obtained with a recovery of 65.22–75.75%.

3.14. Organic acids

3.14.1. Acetic acid

Acetic acid is a carboxylic acid widely produced by anaerobic fermentation of substrates by anaerobic bacteria. Development of an economically - viable strategy for the production of acetic acid and whey protein from waste cheese whey was reported by Pal and Nayak (2016). They have developed a multistage membrane integrated hybrid reactor system for the production of high purity acetic acid and whey protein from waste cheese whey. The study revealed an eco-friendly and cost effective process for the continuous production of 98% pure acetic acid.

3.14.2. Fumaric acid

Fumaric acid finds applications in food, medicine as well as in the preparation of resins and mordants. The demand is increasing each year. Mostly the fumaric acid is produced by petro-chemical route. Biological route of fumaric acid production will be economically viable and eco-friendly. Different waste biomass can be used as a source for fumaric acid production. Fumaric acid production using apple industry waste biomass by *Rhizopus oryzae* 1526 was evaluated by Das et al., (2015). The study revealed that solid state fermentation yields (52 g/kg wt. of substrate) more fumaric acid when compared to submerged fermentation (25.2 g/L). Small size fungal pellets favoured more fumaric acid production than large sized fungal pellets.

3.14.3. Citric acid

Citric acid is widely used in food, beverages as well as pharmaceutical industries. It is widely used as an acidifying as well as a flavour enhancing agent. Increase in demand of citric acid leads to search for alternative novel as well as economically viable substrates for the production. Fruit wastes are normally used as animal feed or disposed to soil. Since these wastes are rich in carbohydrates as well as other nutrients, it can be used as a cost-effective substrate for citric acid production. Utilisation of inexpensive substrates is essential for the reduction of production cost of citric acid. Several research and developmental activities are going on in this direction.

Apple pomace ultrafiltration sludge was used as a novel substrate for citric acid production by *Aspergillus niger* NRRL 567 (Dhillon et al., 2011). Various process parameters affecting citric acid production was optimised by response surface methodology. Maximum citric acid production (44.9 g/100 g dry substrate) was observed with initial solid contents of 25 g/L, methanol concentration of 3% (v/v), total solids – 25 g/L and ethanol concentration of 3% (v/v). Utilisation of apple pomace ultrafiltration sludge helped in sequestration of carbon which is an important element of greenhouse gas emissions.

Karthikeyan and Sivakumar 2010 reported citric acid production by *Aspergillus niger* using banana peel as a substrate. Different process parameters affecting fermentation were optimised by adopting a one parameter at a time approach. This is the first report on utilising banana peel as a substrate for citric acid production. The study revealed the potential of banana peel as a suitable substrate for citric acid production.

Utilisation of fruits wastes for the production of citric acid by solid state fermentation using *Aspergillus niger* DS1 was evaluated by Kumar et al., (2003). Maximum citric acid was produced when the moisture content was maintained at 70% level in presence of 4% methanol. Utilisation of fruit processing wastes has dual benefit converting waste to a value added product.

3.14.4. Succinic acid

Succinic acid is a dicarboxylic acid that finds applications as food additives, dietary supplement as well as a precursor for polymers and solvents. Food waste from commercial and industrial sectors increased in the last few decades. Though several research and developmental activities are going on for the disposal as well as decomposition of food waste, it may not be a proper solution. Hence, conversion of these wastes to value added product will lead to an environmental sustainable process. Patsalou et al., (2017) demonstrated the potential of valorisation of citrus peel waste to succinic acid. In this study, citrus peel wastes were pretreated with dilute acid and enzymatically saccharified for the production of sugars that were then fermented by *Actinobacillus succinogenes* for the production of succinic acid. Under optimised conditions, 0.7 g/g of succinic acid was produced. This strategy is a viable alternative to energy intensive chemical strategies of succinic acid production.

Oil palm empty fruit bunch (EFB) is an abundant agricultural residue available in Malaysia. Utilisation of this waste to value added chemicals is a promising strategy. Akthar and Idris (2017) developed a simultaneous saccharification and fermentation strategy for the production of succinic acid from EFB using *Actinobacillus succinogenes* ATCC 55618. Pretreated samples were enzymatically saccharified. Under optimised conditions 33.4 g/L of succinic acid was produced. EFB serves as an alternative, easily available and economically viable substrate for succinic acid production.

A novel biorefinery concept of succinic acid production from fruit and vegetable wastes (FVW) hydrolysis by crude enzyme preparations from *Aspergillus niger* and *Rhizopus oryzae* was developed by Dessie et al. (2018). The hydrolysate was then fermented by *Actinobacillus succinogenes* for the production of succinic acid. Under optimised conditions 27.03 g/L of succinic acid was produced. Lam et al., (2014) studied the economic viability of succinic acid production from bakery waste. The study revealed that fermentative succinic acid production from bakery waste is economically viable.

3.14.5. Lactic acid

Lactic acid is an important organic acid that finds wide applications in food, pharmaceutical and cosmetic industries. It is also used for the production of biopolymer-polylactate (PLA). Decrease in petroleum reserve as well as environmental concerns lead to its production by eco-friendly fermentative strategy. It is one of the most important building blocks derived from sugars. Zhang et al., (2017) carried out high rate lactic acid production from food waste and waste activated sludge by interactive control of pH and incubation temperature. Optimisation was carried out by statistical design experiments and found that interaction effect of alkaline addition and temperature contributes significantly to L-lactic acid production. Optimum pH for lactic acid production decreased with increase of temperature.

Pleissner et al., (2015) reported lactic acid production using mixed restaurant food waste and bakery waste. Enzymatic hydrolysis of the food and bakery wastes were carried out by *Aspergillus awamori* and *Aspergillus oryzae* and the defatted solids were used for the production of lactic acid by *Bacillus coagulans*. The result indicates a green process for lactic acid production.

Nguyen et al., (2013) developed a fermentative strategy for the production of D- and L-lactic acid from waste *Curcuma longa* biomass using *Lactobacillus coryneformis* and *Lactobacillus paracasei* by simultaneous saccharification and co-fermentation. Under optimised conditions 97.13 g/L and 91.61 g/L of D- and L-lactic acid were produced. Results indicate economic lactic acid production using renewable biomass. Kitchen refuse as an effective biomass for lactic acid production was reported by Tashiro et al., (2013). During the process of marine animal resource composting, the dominant bacteria present in it diminishes rapidly and *Bacillus coagulans* become the main microbial source for L-lactic acid production. The study revealed that bacterial consortium from marine animal resource composts produced 34.5 g/L of lactic acid from kitchen refuse with 100% optical purity. This is the first report on achievement of 100% purity of L-lactic acid using microbial consortium.

3.14.6. Propionic acid

Propionic acid is widely used as a preservative and food additive. Currently, most of the propionic acid production takes place through expensive petro-chemical route. Hence, there is a need to develop cost-effective strategies for the production of propionic acid. Several research and developmental activities are going on in this direction. Production of this metabolite by microbial source using cheap as well as easily available waste biomass will be a promising alternative. Piwowarek et al., (2016) developed a strategy for the production of propionic acid using apple pomace. Wild strain of *Propionibacterium freudenreichii* T82 was able to utilise apple pomace as sole carbon source and produced 1.711 g/L of propionic acid after 120 h of incubation. Industrial by-products is a major challenge for manufacturing sites as well as environment. Hence, utilisation of these by-products will be a promising approach to solve these issues.

3.14.7. Gluconic acid

Gluconic acid finds application in different fields like food, pharmaceutical, textile and leather industries. It is an oxidative product of glucose. One of the main limitations of gluconic acid is the production cost. Sharma et al., (2008) developed a solid state fermentation strategy for the production of gluconic acid from sugarcane molasses using *Aspergillus niger* ARNU-4 incorporating tea waste as a novel support. Various process parameters affecting fermentation were optimised. Maximum gluconic acid (76.3 g/L) was observed with 70% moisture level, incubation temperature of 30 °C, inoculum size of 3% and aeration volume of 2.5 L/min. The effect of different inducers on gluconic acid production revealed that addition of 0.5% of yeast extract increased production to 82.2 g/L. This is the first report on utilisation of tea waste as a solid support for the production of gluconic acid utilising waste sugarcane molasses as sole carbon source.

3.15. Pigments

Current increase in interest of using colouring agents leads to increase in cancer rate. Here comes the importance of safe and natural colouring agents and their demand increased during the last decades. Hence, pigment production using microorganisms is a safe strategy but most of the strategies currently available are not economically viable due to high cost of substrates used for fermentation. Agro-industrial residues serve as a low cost substrate for the production of pigments. Panesar et al., (2015) reviewed a variety of agro-industrial residues like molasses, corn steep liquor, bran, whey etc. as a potential carbon, nitrogen and mineral source for the production of pigments. Production of pigments from agro-industrial residues serves as a sustainable and cost effective strategy for pigment production.

Carotenes are unsaturated isoprene derivatives. They find wide applications in feed, pharmaceutical and food industries. They play an important role as cardio-protectant as well as cancer prevention. Several reports are available for the production of carotenoids from *Blakeslea trispora* using synthetic medium and all these strategies are economically non-viable. Nanou and Roukas (2016) developed a submerged fermentation strategy for the production of carotenoids from *Blakeslea trispora* using waste cooking oil. The highest concentration of carotenoids (2021 mg/L) was observed when waste cooking oil was supplemented with 80 g/L of corn steep liquor and 4.0 g/L of butylated hydroxytoluene. Oxidative stress induced by hydroperoxides of waste cooking oil increased the carotenoid production. Cheng and Yang (2016) evaluated carotenoid production using food waste by *Rhodotorula mucilaginosa*. Maximum carotenoid production of 2611 μg/L was observed using molasses as the substrate.

Utilisation of agro-industrial waste for the production of yellowish – orange pigment from *Chryseobacterium artocarpi* CECT 8497 was reported by Aruldass et al., (2016). Pineapple waste medium was used for pigment production. Optimisation was carried out by adopting statistical design experiments. Maximum pigment production (152 mg/L) was observed with liquid pineapple waste concentration of 20% v/v, 12.5 g/L of K_2HPO_4 and 125 g/L of l-tryptophan. The production was three fold higher when compared to nutrient broth. This pigment finds application as a colouring agent in soap manufacture.

Monascus purpureus are known to produce pigments that are a group of fungal metabolites known as azaphilones. These compounds find wide applications in food industry. Red pigment from *Monascus* species are widely used as a food colorant. Several factors affect pigment production like carbon and nitrogen source, agitation, aeration etc. Silveira et al., (2008) reported grape waste as a substrate for cost – effective production of pigment by *Monascus purpureus*. Statistical design experiments were carried out for improved production. Maximum pigment production was reported with 20–22.5 g/L of peptone at any concentration of grape waste. Utilisation of agro-residues serves as an eco-friendly strategy of waste management.

3.16. Quercetin

Quercetin is a flavonoid widely distributed in fruits and vegetables. It is widely used as a supplement in foods and beverages. These compounds are widely used for the treatment of diseases like cancers affecting kidney, colon, breast etc. Onion processing waste is a major waste produced from processed onions. Choi et al., (2015) developed a strategy for the valorisation of onion skin waste to quercetin. The onion skin waste was enzymatically saccharified with a cocktail of cellulase, pectinase and xylanase. Enzymatic saccharification could increase quercetin extraction 1.61 fold. A novel magnetic matrix was used for the easy separation and purification of quercetin.

3.17. Single cell protein

Food waste mixtures serve as an efficient source for the production of value added product-single cell protein (SCP). Aggelopoulos et al., (2014) carried out solid state fermentation of mixed food waste for the production of SCP. *Saccharomyces cerevisiae* and *Kluyveromyces marxianus* were grown on food industry waste. Highest protein and fat were observed with substrate fermented by *Kluyveromyces marxianus* and can be used for livestock feed enrichment.

3.18. Sugars

3.18.1. Glucose

Glucose finds applications to several fine chemicals and fuels. It can be used for the production of fuel in fuel cells, ethanol, levulinic acid as well as hydroxymethyl furfural. Kumar et al., (2016) demonstrated the potential application of a low value potato peel waste under microwave irradiation for the production of glucose. Chemical hydrolysis of potato peel starch was carried out using silicotungstic acid as catalyst under short microwave irradiation. Adopting this strategy 59% of glucose yield was obtained after short microwave irradiation for 15 min. The use of microwave and solid acid catalyst make it a green process for glucose production from potato peel waste.

3.18.2. D-tagatose

Tagatose is a naturally occurring monosaccharide. It is widely used a sweetener. It is sweeter like sucrose but with 38% less calories. Low quantities of tagatose are found in fruits and dairy products. Utilisation of agro-residues for high value products is a promising strategy. Kim et al., (2017) developed a strategy for D-tagatose production from onion waste. Onion juice residue (OJR) was used as source for the production of D-tagatose. Purified L-arabinose isomerase from *Paenibacillus polymyxa* was used for the conversion of OJR to D-tagatose. 0.99 g of D-tagatose was produced from 10 g of OJR. The study revealed the potential of a low value agro-residue, OJR to a high value rare sugar D-tagatose.

3.18.3. D-mannose

D-mannose is a sugar monomer that is widely used as nutrient supplement. Coffee is one of the most consumed beverages. Coffee processing generates a large amount of coffee residue waste (CRW). Disposal of CRW to the environment leads to several environmental issues. CRW contains caffeine, polyphenols, tannins and organic material. Nguyen et al., (2017) developed an integrated process for the production of D-mannose and bioethanol from CRW. The process involves five unit operations like pretreatment, enzymatic hydrolysis, fermentation, decolourization and pervaporation. The CRW was pretreated with ethanol and enzymatically hydrolysed to produce sugars that were then fermented by yeast. Manipulations of fermentation conditions were done in such a way that the yeast would ferment all the glucose and galactose to ethanol, retaining D-mannose in the fermented broth. Under optimised conditions 15.7 g dry weight of D-mannose was produced.

3.19. Vermicompost

Vermicomposting is one of the efficient strategies for management of kitchen waste. Earthworms will convert kitchen waste to high quality compost. Adi and Noor (2009) reported production of vermicompost from coffee grounds and kitchen waste using *Lumbricus rubellus*. Composting was carried out for 49 days after precomposting for three weeks. Different combinational treatments were carried out and the study revealed that treatment with coffee grounds showed higher percentage of nutrient elements. Coffee grounds stabilise kitchen waste and produce high quality vermicompost.

3.20. Vinegar

Vinegar is a mixture of acetic acid and water and is produced by microbial fermentation. Though vinegar has different applications, it is commonly used for food preservation. Roda et al., (2017) reported vinegar production from pineapple waste. Pineapple peels were treated and enzymatically saccharified and fermented with *Saccharomyces cerevisiae* for 7–10 days under aerobic conditions at an incubation temperature of 25 °C. This alcohol medium was used as seed medium for acetic acid fermentation by *Acetobacter aceti* for a period of 30 days at 32 °C to get a concentration of 5% acetic acid. This vinegar is clear and without any post-filtration deposits. The results indicate the potential of pineapple peels as an alternative sustainable feedstock for the production of vinegar.

Effective, eco-friendly and simple strategy for the production of vinegar from olive oil press-mill wastewaters was demonstrated by Leonardis et al., (2018). The study revealed that sugar addition as well as inoculum of selected yeast strains is the crucial factors affecting required acidification. This vinegar shows high content of ash and total phenols when compared to apple or wine vinegars. Olive vinegar shows high percentage of antioxidants indicating its nutraceutical potential.

3.21. Wax esters

Wax esters find applications in candles, lubricants, food as well as cosmetic industries. Papadaki et al., (2017) evaluated food industry wastes and by-product streams for the production of wax esters by three oleaginous yeasts – *Cryptococcus curvatus*, *Rhodosporidium toruloides* and *Lipomyces starkeyi*. Wax esters production was evaluated by lipase catalysed synthesis. Behenyl esters produced showed similar properties like esters derived from palm oil and comparable to natural waxes. The oils were produced by cultivating oleaginous yeast strains in fermentation media derived from confectionary waste streams, cheese whey and wine lees.

3.22. Xanthan gum

Xanthan gum is an important microbial exopolysaccharide that is produced by several microorganisms using glucose or sucrose as sole carbon source. It is first microbial biopolymer produced at an industrial scale. It finds application in many industries including pharmaceutical, food as well as oil industries. In food industries it is widely used as thickener, stabiliser and thickening agent. The use of pure glucose or sucrose as carbon source for the production of xanthan gum makes the process economically non-viable contributing to high cost of xanthan gum. Hence, utilisation of low cost substrate for the production seems to reduce the cost for fermentation.

Li et al., (2016) used kitchen waste as a sole substrate using *Xanthomonas campestris* LRELP-1. The maximal production of xanthan gum of 11.3 g/L was observed using kitchen waste hydrolysate. The study revealed a low cost strategy for the production of xanthan gum as well as an effective strategy of kitchen waste management. Li et al., (2017) reported production of xanthan gum using kitchen waste. In this study the kitchen waste was pretreated with different chemicals and enzymatically hydrolysed and the hydrolysate was used for the production of xanthan gum. A concentration of 4.09–6.46 g/L was observed with kitchen waste hydrolysate.

4. Conclusion and future perspectives

The kitchen and food waste constitute a valuable source of organic carbon which can be utilised for the production of several chemicals and high value compounds. Though several advantages and limitations are there for the conversion of food waste to value added products, still there is a lack of proper technology for efficient conversion. This technological hindrance is mainly due to the heterogeneous nature of the waste. But there exist a huge opportunity for an eco-friendly green process for the production of value-added products from food waste. Fine-tuning of the available technologies and strategies must be done for the proper management of food and kitchen waste. Hence, intense research is to be carried out in this direction to make it economically viable.

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