

1 **Enzyme production from food wastes using a biorefinery concept:**

2 **a review**

3 Esra Uckun Kiran^a, Antoine P. Trzcinski^a, Wun Jern Ng^{a,b} and Yu Liu^{a, b*}

4

5 ^a Advanced Environmental Biotechnology Centre, Nanyang Environment & Water Research

6 Institute, Nanyang Technological University (NTU), Singapore, 637141, Singapore

7 ^b School of Civil and Environmental Engineering, Nanyang Technological University, 50

8 Nanyang Avenue, Singapore, 639798, Singapore.

9 *Corresponding author.

10 Email: CYLiu@ntu.edu.sg

11 Tel: +65 67905254.

12 Fax: +65 6790 6813.

13

14

15 **ABSTRACT**

16 According to FAO, one third of food produced globally for human consumption (nearly 1.3
17 billion tonnes) is lost along the food supply chain. In many countries food waste are currently
18 landfilled or incinerated together with other combustible municipal wastes for possible
19 recovery of energy. However, these two approaches are facing more and more economic and
20 environmental stresses. Due to its organic- and nutrient-rich composition, theoretically food
21 waste can be utilized as a useful resource for the production of enzymes through various
22 fermentation processes. Such conversion of food waste is potentially more profitable than its
23 conversion to animal feed or transportation fuel. Food waste valorisation has therefore
24 gained interest, with value added bio-products such as methane, hydrogen, ethanol, enzymes,
25 organic acids, chemicals, and fuels. The aim of this review is to provide information on the
26 food waste situation with emphasis on Asia-Pacific countries and the state-of-the-art food
27 waste processing technologies to produce enzymes.

28

29

30

31

32 1. Introduction

33 Food waste (FW) is organic waste produced in food processing plants, domestic and
34 commercial kitchens, cafeterias, and restaurants. It accounts for a considerable proportion of
35 municipal solid waste all over the world [1]. According to FAO [2], nearly 1.3 billion tonnes
36 of foods including fresh vegetables, fruits, meat, bakery and dairy products are lost along the
37 food supply chain.

38

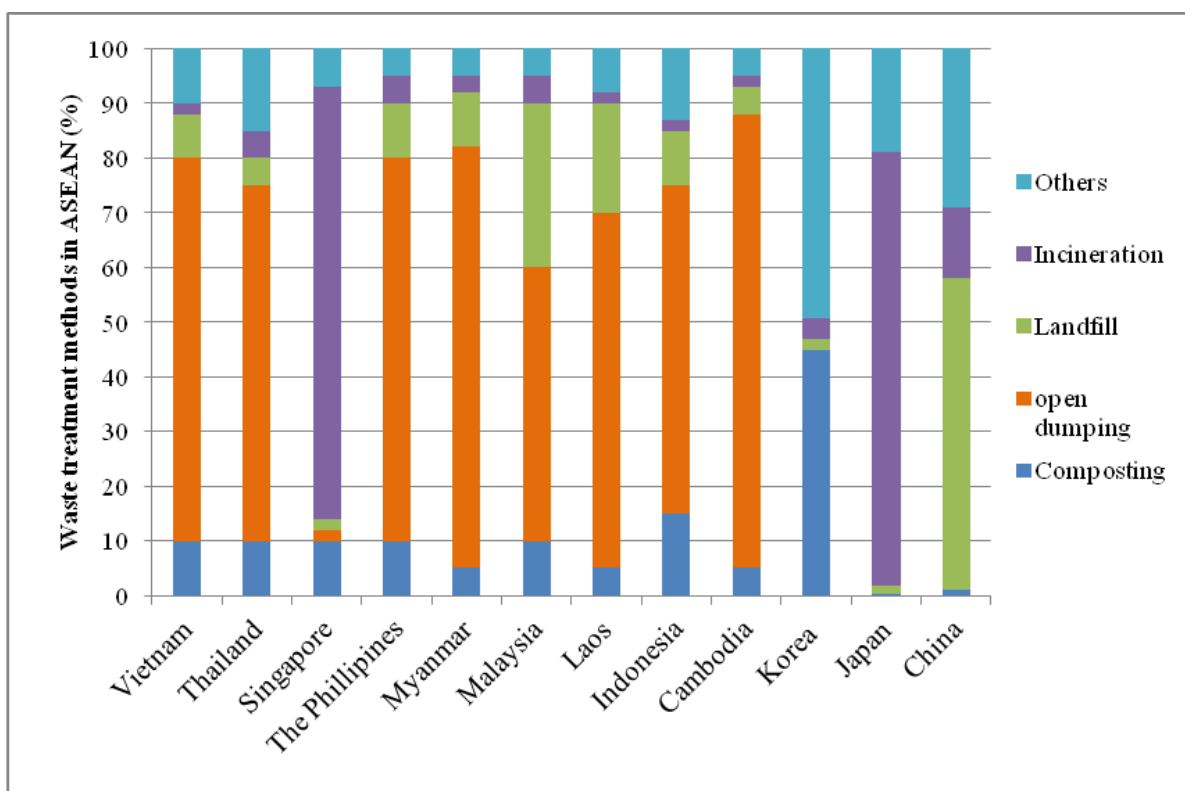
39 The amount of FW is continuing to increase due to the increase in population and economical
40 growth, particularly in Asian countries. The annual amount of urban FW in Asian countries
41 could rise from 278 to 416 million tonnes from 2005 to 2025 [3]. The highest absolute
42 amount per year was in China (82.8 Million tonnes (MT) followed by Indonesia (30.9 MT),
43 Japan (16.4 MT), Philippines (12 MT) and Vietnam (11.5 MT). However, the highest amount
44 of FW produced per capita was in New Zealand and Australia with 280 kg/year, while it was
45 around 120-130 kg in Southeast Asia other than Cambodia (173 kg/year). Although the
46 absolute amount of food waste in China is the highest, the waste production per capita is the
47 lowest (61 kg/year), while the waste production per capita is 120 and 168 kg/year in
48 Singapore and Hong Kong, respectively [4, 5], showing that food wastage seems more
49 prevalent in high-income states.

50

51 Food wastes can be practically dumped, landfilled, incinerated, composted, digested
52 anaerobically and/or used as animal feed. In many Asian countries FW is still dumped with
53 other household waste in landfills or dumpsites (Figure 1). Unfortunately, the capacity of the
54 landfills is mostly surpassed due to a lack of waste management planning, so the
55 environmental pollution (leachate, gas, odors, flies, vermin, and pathogens) poses serious
56 problems [6]. Hence, there is a need for an appropriate management of FWs [7].

57

58 In order to reduce its volume, FW is traditionally incinerated with other combustible
59 municipal wastes for generation of heat or energy, particularly in Japan and Singapore. It is
60 generally favoured over landfilling with regard to overall energy use and emissions of gases
61 contributing to global warming[8].However, it is an inappropriate approach for most low-
62 income countries due to the high capital and operating costs [6]. Moreover, incineration of
63 FW can potentially cause air pollution [9].



64

65 Figure 1. Waste treatment methods in some Asia-Pacific countries.

66

67 Another approach to handle biodegradable FW is composting which results in a valuable soil
68 conditioner and fertilizer [10]. Composting facilities showed a relatively low environmental
69 impact and a high economic efficiency compared to other treatment methods. The primary
70 recycling method in Korea is composting (Figure 1). However, the high moisture content of
71 FW causes remarkable levels of leachate which affects process performance by reducing

72 oxygen availability and weakening the pile strength [11]. In this case, high airflows for
73 aeration or excessive carbon ingredients are necessary for process control, which increase the
74 operational costs. Indeed, compost is more expensive than commercial fertilizers and the
75 available market for compost is not big [12].

76

77 Anaerobic digestion is another alternative which yields methane and carbon dioxide as
78 metabolic end products and therefore could be feasible from an economic and environmental
79 point of view because methane is used as an energy source [8]. Hirai, Murata [13] evaluated
80 the environmental impacts of FW treatment and found that utilising a methane fermentation
81 process prior to incineration reduces approximately 70 kg CO₂eq/tonne waste of the global
82 warming potential, due to the substitution effect. The disadvantages of using FW as animal
83 feed are the variable composition and the high moisture content, which favors microbial
84 contamination [14]. To prevent this, animal feed is generally dried but greenhouse gas
85 emission increases depending on the energy usage during the drying process, which is related
86 to the water content of FW [9].

87

88 FW is mainly composed of carbohydrate polymers (starch, cellulose and hemicelluloses),
89 lignin, proteins, lipids, organic acids (Table 1). Total sugar and protein contents in FW are in
90 the range of 35.5-69% and 3.9-21.9%, respectively. Due to its inherent chemical complexity,
91 alternative treatment methods are currently studied and attention is being directed to
92 production of high value-added products such as biofuels, biodiesel, platform chemicals and
93 enzymes [15-23]. As a comparison, fuel applications (\$200-400/ ton biomass) and organic
94 acids, biodegradable plastics & enzymes applications (\$1000/ton biomass) are usually
95 creating more value compared to generating electricity (\$60-150/ton biomass) and animal
96 feed (\$70-200/ton biomass) [24].

Table 1. Characteristics of mixed food waste.

Origin	pH	Moisture	Total solid	VS/TS	Total sugar	Starch	Cellulose	Lipid	Protein	Ash	References
Dining hall	NR	79.5	20.5	95.0	NR	NR	NR	NR	21.9	NR	Han and Shin [15]
Cafeteria	5.1	84.1	15.9	15.2	NR	NR	NR	NR	NR	NR	Kim, Oh [25]
Cafeteria	5.1	80.0	20.0	93.6	NR	NR	NR	NR	NR	1.3	Kwon and Lee [26]
MSW	NR	85.0	15.0	88.5	NR	NR	15.5	8.5	6.9	11.5	Rao and Singh [27]
Cafeteria	4.6-5	79.1	20.9	93.2	NR	NR	NR	NR	NR	NR	Ramos, Buitron [28]
Cafeteria	NR	75.9	24.1	NR	42.3	29.3	NR	NR	3.9	1.3	Ohkouchi and Inoue [29]
NR	NR	87.6	12.4	89.3	NR	NR	NR	NR	NR	NR	Kim, Oh [30]
Residents	4.9	80.8	19.2	92.7	NR	15.6	NR	NR	NR	NR	Pan, Zhang [21]
Dining hall	NR	80.3	19.7	95.4	59.8	NR	1.6	15.7	21.8	1.9	Tang, Koike [31]
Dining hall	NR	82.8	17.2	89.1	62.7	46.1	2.3	18.1	15.6	NR	Wang, Ma [32]
Restaurant	3.9	80.0	20.0	95.0	70.0	NR	NR	10.0	13.0	NR	Zhang, He [33]
Dining hall	5.6	82.8	17.2	85.0	62.7	46.1	2.3	18.1	15.6	NR	Ma, Wang [34]
Cafeteria	NR	61.3	38.7	NR	69.0	NR	NR	6.4	4.4	1.2	Uncu and Cekmecelioglu [35]
Food court	NR	64.4	35.6	NR	NR	NR	NR	8.8	4.5	1.8	Cekmecelioglu and Uncu [36]
Canteen	NR	81.7	18.3	87.5	35.5	NR	NR	24.1	14.4	NR	He, Sun [23]
Restaurant	NR	81.5	18.5	94.1	55.0	24.0	16.9	14.0	16.9	5.9	Vavouraki, Angelis [22]
Restaurant	NR	81.9	14.3	98.2	48.3	42.3	NR	NR	17.8	NR	Zhang and Jahng [37]

99 Total Solid, Total sugar, Starch, Cellulose, Lipid, Protein and Ash Contents were given in wt% on the basis of dry weight. Volatile solid contents were given as the
100 VS ratio on total solid basis. NR: not reported.

101

102 The critical stage of biomass bioconversion is saccharification, which hampers its

103 commercial use. For an efficient biomass conversion, carbohydrate components of FW

104 should be hydrolyzed to yield high concentrations of oligosaccharides and monosaccharides,

105 which are amenable to fermentation. Hence, there is an increasing interest on the production

106 of biomass saccharifying enzymes, mainly amylases and cellulases [38].

107

108 Commercial enzyme utilization increases the operational cost due to the purchase of these
109 enzymes on a regular basis. In addition, commercial enzymes are generally sold singly.
110 Therefore, mixtures of enzymes would have to be prepared from separate sources. Each
111 commercial enzyme requires different operating conditions for the hydrolysis of their specific
112 substrates. Therefore, the process would either operate sub-optimally with a mix or take a
113 long time to carry out each enzyme step sequentially. However, the cost of enzyme
114 production **could be reduced** either by using low-cost raw materials and/or developing
115 economical processing technologies. **There are remarkable amount of publications on the lab-**
116 **scale production of various industrial enzymes such as proteases, amylases, lignocellulosic**
117 **enzymes and lipases using different types of FW. Therefore, this review summarizes and**
118 **discusses recent industrial enzyme production studies from FW.**

119

120 **2. Enzyme Production**

121 Enzymes are commonly used in many industrial applications due to their great selectivity for
122 the substrates and their biodegradabilities. Besides they act under mild and environmentally
123 friendly conditions. Hence, enzyme production is one of the most important applications,
124 which serves to various industries. **Research is continuing on the production of different**
125 **enzymes in solid-state fermentation (SSF) with the ultimate aims to obtain high activity**
126 **enzymes at lesser cost using low cost substrates and/or by improving economical processing**
127 **technologies.** There are remarkable amount of publications on the production of various
128 enzymes using different agro-industrial waste [39-42]. However, the main problem is the
129 recalcitrant nature, which resulted in low enzyme yields and expensive enzyme production.
130 The recalcitrant nature can be **mitigated** by some pre-treatment steps while the enzyme yields
131 can be enhanced by developing suitable fermentation conditions or by using genetically
132 modified microbial strains [43]. On the other hand, the enzyme production costs can be

133 reduced by developing suitable fermentation processes using FW, which has easily digestible
134 components. There are some publications reporting the production of different enzymes from
135 FW by using both solid and submerged fermentation systems (Tables 2 to 6). Various kinds
136 of FWs were used to produce different enzymes such as proteases, cellulases, amylases,
137 lipases and pectinases particularly by using solid-state fermentation (SSF). SSF has several
138 advantages over submerged fermentation (SmF) as it requires less capital, lower energy, a
139 simple fermentation medium; it has superior productivity and produces less wastewater [44].
140 Moreover, an easy control of bacterial contamination and lower costs of downstream
141 processing make it more attractive. Dos Santos, Gomes [45] have evaluated SSFs efficiency
142 for producing enzymes. It is appropriate for the production of enzymes, especially because of
143 the higher enzyme yields that can be obtained compared to submerged fermentation [46-48].
144 **SSF provides a similar environment to the microorganism's natural environment which**
145 **provides better conditions for its growth and enzymes production [48]** . However, there are
146 only a few reports on SSF bioreactor design in the literature. The large scale production of
147 enzymes using SSF is challenging **because pH**, temperature, aeration, oxygen transfer and
148 moisture content is difficult to control [44, 49].

149

150 **2.1. Amylases**

151 The amylase family has two major classes, namely α -amylase (EC 3.2.1.1) and glucoamylase
152 (GA) (EC 3.2.1.3). α -amylase hydrolyses starch into maltose, glucose and maltotriose by
153 cleaving the 1,4- α -D-glucosidic linkages between adjacent glucose units in the linear amylose
154 chain [51] **while glucoamylase hydrolyses the non-reducing ends of amylose and amylopectin**
155 **to glucose** [52]. Amylases have been widely used in the food, fermentation, textiles and paper
156 industries [51]. They are also used for the pre-treatment of the agroindustrial and organic by-
157 products to improve the bioproduct yield in subsequent processes. Thereby, there is an

158 increasing interest on the production of amylases using cheap feedstocks [49]. High activity
159 amylases can be produced from various kinds of FWs such as kitchen refuse [49], potato peel
160 [47, 53], coffee waste [54] and tomato pomace [55] via the optimization of fermentation
161 using different microbial strains. However, it is not easy to compare the efficiency of the
162 processes as the produced enzymes' activities are defined differently (Table 2). The main
163 advantages of FW utilization for enzyme production are that fermentations do not require
164 harsh pre-treatments and extra nutrient supplements.

165

166 **Table 2.** Amylase production from food wastes.

Residual materials	Microorganism	Pretreatment method	Fermentation mode & vessel type	Fermentation conditions	Duration (day)	Achievements
Potato peel	<i>Bacillus subtilis</i>	Dried, ground, sieved	SSF-250 mL flasks	40°C, pH 7, 65% MC, 10% (v/w) inoculum	2	α -amylase (600 U)
Potato peel	<i>Bacillus licheniformis</i>	Dried, ground, sieved	SSF-250 mL flasks	40°C, pH 7, 70% MC, 10% (v/w) inoculum	2	α -amylase (270 U)
Coffee waste	<i>Neurospora crassa</i> CFR 308	Ground, steamed	SSF-250 mL flasks	28°C, pH 4.6, 60% MC, 1 mm PS, 10 ⁷ spores/g ds,	5	α -amylase (6342 U)
Potato peel	<i>Bacillus firmus</i> CAS 7	Dried, ground, sieved	SmF-250 mL flasks	35°C, pH 7.5, 1% S	2	α -amylase (676 U)
Tomato pomace	<i>Aspergillus awamori</i>	Dried, milled, sieved	SSF-plate-type SSF bioreactor	28°C, pH 5	5	α -amylase (10.9 I)
Bread waste	<i>Bacillus caldolyticus</i> DSM 405	NR	SmF- 1L flask with 100 ml working vol	30°C, pH 7	1	α -amylase (6.7 U)
Pea pulp	<i>Bacillus caldolyticus</i> DSM 405	None	SmF- flasks	70°C, 150 rpm	6	α -amylase (8.6 U/m)
Food waste	<i>Aspergillus niger</i> UV-60	None	SmF-250 mL flasks	30°C, pH 5, 120 rpm, 5% I/S	4	GA (137 U/mL)
Bread waste	<i>Aspergillus oryzae</i>	None	SSF-petri plates	30°C, MC:1.8 (w/w, db), PS:20 mm, 10 ⁶ spore/gdS	6	GA (114 U/gdS)

167 S: substrate, SSF: solid state fermentation, SmF: submerged fermentation, I/S: Inoculum to substrate ratio,
168 ds: dry substrate, MC: moisture content, PS: particle size, ds: dry solid, GA: glucoamylase

169 Wang, Wang [49] investigated the production of glucoamylase from FW by *Aspergillus niger*
170 UV-60 using SmF. They reported that the nutrient supplementation including yeast extract,
171 $(\text{NH}_4)_2\text{SO}_4$, KH_2PO_4 , $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ and CaCl_2 and particle size reduction had
172 no significant influence on the glucoamylase production. Maximum glucoamylase activity of
173 137 U/mL was obtained using 3.75% FW and 5% (v/w, 10^6 spores/mL) inoculum at 30°C,
174 120 rpm for 96h. A reducing sugar concentration of 60.1 g/L could be produced from 10%
175 FW (w/v), within 125 min using the produced crude glucoamylase. Shukla and Kar [47]
176 produced high activity α -amylase from potato peels by SSF using two thermophilic isolates
177 of *Bacillus licheniformis* and *Bacillus subtilis*. Under optimal conditions (40°C, pH 7, using
178 potato peels having 1000 μm particle size with 65-70% moisture content). Alpha-amylase
179 activities obtained by using *B. licheniformis* and *B. subtilis* were 270 and 600 U/mL,
180 respectively. In another study, α -amylase production from potato peels was conducted by
181 SmF using thermophilic isolate of alkaline tolerant *Bacillus firmus* CAS7 strain [53]. Under
182 the optimal conditions (at 35°C, pH 7.5 using 1% of substrate concentrations), 676 U/mL of
183 α -amylase which was optimally active at 50°C and pH 9 was obtained. Murthy, Madhava
184 Naidu(check the references style) [54] used coffee wastes as sole carbon source for the
185 synthesis of α -amylase in SSF using a fungal strain of *Neurospora crassa* CFR 308. α -
186 amylase activity of 4324 U/g dry substrate was obtained using 1 mm particle size, 10^7
187 spores/g dry substrate, 60% moisture content at 28°C, pH 4.6. Steam pre-treatment improved
188 the accessibility of coffee waste and the α -amylase activity of 6342 U/g dry substrate was
189 obtained.

190

191 FW can be used to produce high activity amylases by using suitable microbial strains. In
192 some of the lactic acid production studies from FW, a saccharification step using commercial
193 amylases was conducted prior to the fermentation in order to improve and ease the

194 fermentation process [59, 60]. If the enzyme production step can be integrated to the
195 fermentation system, the process costs could be lowered. In a study of Leung, Cheung [61],
196 waste bread was used as sole feedstock in a biorefinery concept for the production of
197 succinic acid (SA), one of the future platform chemicals of a sustainable chemical industry.
198 Waste bread was used in the SSF of *Aspergillus awamori* and *Aspergillus oryzae* to produce
199 enzyme complexes rich in amylolytic and proteolytic enzymes. The resulting fermentation
200 solids were added directly to a bread suspension to generate a hydrolysate rich in glucose and
201 free amino nitrogen. The bread hydrolysate was used as the sole feedstock for *A.*
202 *succinogenes* fermentations, which led to the production of 47.3 g/L succinic acid with 1.16 g
203 SA/g glucose yield, which is the highest succinic acid yield compared from other FW-derived
204 media reported to date. This consolidated process could be potentially utilised to transform
205 no-value FW into succinic acid.

206

207 **2.2. Lignocellulolytic enzymes**

208 Lignocellulolytic enzymes are mainly produced by several fungi and are composed of
209 cellulases, xylanases and ligninases, which degrade the lignocellulosic materials. Cellulases
210 have many applications in various industries including food, animal feed, brewing and wine
211 making, agriculture, biomass refining, pulp and paper, textile, and laundry [62]. The
212 bioconversion of cellulose to fermentable sugars requires the synergistic action of complete
213 cellulase system comprising of three enzyme classes: endoglucanases (EC 3.2.1.4) which act
214 randomly on soluble and insoluble cellulose chains, exoglucanases (cellobiohydrolases; EC
215 3.2.1.91) which liberate cellobiose from the reducing and non-reducing ends of cellulose
216 chains, and β -glucosidases (EC 3.2.1.21) which liberate glucose from cellobiose [63].
217 Xylanases have many applications in food, feed, pulp and paper, brewing, wine making and
218 textile industries with or without concomitant use of cellulases [64]. The hydrolysis of xylans

219 mainly requires the action of endo- β -1,4-xylanase and β -xylosidase. However, the presence
 220 of other accessory enzymes is needed to hydrolyse substituted xylans [65]. Lignin is an
 221 undesirable polymer for biofuel production as it prevents the accessibility of plant derived
 222 polysaccharides. However, lignin derived materials can be used to develop valuable products
 223 such as dispersants, detergents, drilling mud thinner, surfactants, coagulants and flocculants
 224 (for sewage and waste water treatment), adhesives, graft polymers including polyurethanes,
 225 polyesters, polyamines and epoxies and rubbers [66, 67]. In order to degrade lignin polymers
 226 ligninolytic enzyme systems composed by laccases, lignin peroxidases and Mn-peroxidase
 227 are utilized.

228

229 These enzymes are also used for the pre-treatment of the agroindustrial and organic by-
 230 products to improve the bioproduct yields in subsequent processes [68, 69]. Recent studies on
 231 lignocellulosic enzyme production using different FWs and the achieved enzyme activities
 232 are summarized in Table 3. Since the enzyme activity definitions are different in each study,
 233 it is not an easy task to compare the achievements and detect the best method. However,
 234 generally fungal SSF is the most preferred method due to its advantages over SmF [68-73].
 235 Krishna [71] reported that the total cellulase production from banana waste was 12 fold
 236 higher in SSF than that obtained using SmF. However, Díaz, de Ory [74] reported that the
 237 SmF resulted in higher xylanase production in comparison to SSF due to better aeration.
 238 Umsza-Guez, Díaz [55] demonstrated a clear positive effect of aeration on xylanase and
 239 carboxymethyl cellulase (CMCase) production using SSF in a plate-type bioreactor.

240

241 **Table 3.** Lignocellulosic enzyme production from food wastes.

Residual materials	Microorganism	Pretreatment method	Fermentation mode & vessel type	Fermentation conditions	Duration (day)	Achievements
Banana wastes	<i>Bacillus subtilis</i> (CBTK106)	Dried, ground, acid and alkali pretreatment	SSF-250 mL flasks	35°C, pH 7, 400 μ m PS, 70% MC, 15% (v/w) I/S ratio	3	FPase (2.8 IU/ds), (9.6 IU/g ds), Cel IU/g ds)

Grape pomace	<i>Aspergillus awamori</i>	Dried, milled, sieved	SSF- petri dishes	30°C, 10 g S, 5×10 ⁵ I/S, 60% MC	7	Xylanase (40.4 IU/g ds), Cellulase (9.6IU/g ds)
Apple pomace	<i>Trichoderma sp.</i>	Dried, crushed, sieved	SSF-250 mL flasks	32°C, 70% MC, 10 ⁸ spores/flask	6	Cellulase (5.8 U/g ds)
Banana peel	<i>Trichoderma viride</i> GIM 3.0010	Dried, crushed, sieved	SSF-250 mL flasks	30°C, 65% MC, 10 ⁹ spores/flask	6	FPA(5.6U/g ds), Cellulase (5.8 U/g ds), β-glucosidase (6.21 U/g ds)
Tomato pomace	<i>Aspergillus awamori</i>	Dried, milled, sieved	SSF-plate-type SSF bioreactor	28°C, pH 5	5	Xylanase (195.9 IU/g ds), CMCCase (19.7 IU/g ds)
Carrot, orange, pineapple, potato peels, wheat bran	<i>Aspergillus niger</i> NS-2	Acid/base pretreatment	SSF-250 mL flasks	30°C, pH 7, 1:1.5 to 1:1.75 S/M ratio	4	CMCase (310 U/g ds), β-glucosidase (310 U/g ds) using alkaline pretreatment of wheat bran
Apple pomace	<i>Aspergillus niger</i> NRRL-567	Drying, crushing, sieving	SSF-500 mL flasks	30°C, 1.7-2 mm PS, 75% MC, 10 ⁷ spores/g dS	7	FPase (113.7 IU/g ds), β-glucosidase (172.31 IU/gds), FPA (60.1IU/gds), Xylanase (113.7 IU/gds)
Grape pomace and orange peel	<i>Aspergillus awamori</i>	Dried, milled and sieved	SSF-petri dishes	30°C, pH 5, 70% MC, 4.5×10 ⁸ spores/g S.	15	Exo-PG (3.8 IU/g ds), Cellulase (32.7 IU/gds), CMCCase (19.7 IU/gds)
Potato peel	<i>Aspergillus niger</i>	Dried, ground	SSF	30°C, 10 ⁷ spores/ g dS, 50% MC	3	FPase (0.015 U/mL), β-glucosidase (0.023 U/mL), Xylanase (0.015 U/mL)
Mango Peel	<i>Trichoderma reesei</i>	Alkaline pretreatment	SmF-250mL flasks	30°C, pH 7, 200 rpm	6	Cellulase (7.8 IU/g ds)
Passion fruit waste	<i>Pleurotus pulmonarius</i>	Dried, milled.	SSF-250 mL flasks	28°C in complete darkness	14	MnP (0.22 U/mL), Cellulase (4.76 U/mL), β-Galactosidase (2.96 U/mL), β-glucosidase (6.21 U/mL)
Passion fruit waste	<i>Macrocybe titans</i>	Dried, milled.	SSF-250 mL flasks	28°C in complete darkness	14	Laccase (10.2 U/mL), Cellulase (1.72 U/mL), Endoglucanase (0.27 U/mL)

242 S: substrate, SSF: solid state fermentation, SmF: submerged fermentation, I/S: Inoculum to substrate ratio, DS: dry substrate,
243 S/M: substrate to moisture ratio, MC: moisture content, PS: particle size, ds: dry solid,PG: polygalacturonase, CMCCase:
244 carboxymethylcellulase, MnP: Manganese peroxidase, NR: Not reported.

245

246 The effects of process parameters such as incubation temperature, pH, moisture content,
247 particle size of the substrates, nutrient supplementation, inoculum size and different substrate
248 pre-treatment methods on enzyme production have been investigated. In general, the
249 optimum conditions in SSF depend not only on the microorganism employed, but also greatly
250 on the type of substrate. The incubation time, pH, temperature, particle sizes and water
251 content of the medium should be optimized when the substrate and microorganisms are
252 chosen. Some FWs require extra nutrients [55, 70, 72], while some others can be used as sole

253 nutrient to produce high titers of cellulases [68, 73, 75]. Dhillon, Kaura [70] analysed the
254 effects of different inducers on cellulase and hemicellulase production by *Aspergillus niger*
255 NRRL-567 using apple pomace as a substrate. The higher filter paper cellulase (FPA) and β -
256 glucosidase activities of 133.68 ± 5.44 IU/gram dry substrate (gds) and 60.09 ± 3.43 IU/gds,
257 respectively were observed while using CuSO_4 and veratryl alcohol. Similarly, higher
258 xylanase activity of 1412.58 ± 27.9 IU/gds was observed with veratryl alcohol after 72 h of
259 fermentation time while the higher CMCase activity of 172.31 ± 14.21 IU/g ds was obtained
260 with lactose after 48 h of incubation period. Sun, Ge [72] have also reported that the cellulase
261 production using SSF was markedly improved by supplementing lactose and corn-steep solid
262 to the apple pomace.

263

264 The effects of nutrients and other process parameters on cellulase production from banana
265 waste by *Bacillus subtilis* (CBTK 106) was also evaluated by Krishna [71]. The optimal
266 FPase of 2.8 IU/g dry substrate, CMCase activity of 9.6 IU/g dry substrate and cellobiase
267 activity of 4.5 IU/g dry substrate were obtained at 72 h incubation with media containing heat
268 pretreated banana fruit stalk, $(\text{NH}_4)_2\text{SO}_4$, NaNO_3 and glucose. Saravanan, Muthuvelayudham
269 [69] investigated the cellulase production from mango peel using *Trichoderma reesei* and
270 reported that avicel, soybean cake flour, KH_2PO_4 , and $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ have positive influences
271 on cellulase production. Cellulase activity was to 7.8 IU/mL using the optimum nutrient
272 concentrations of 25.3 g/L avicel, 23.53 g/L soybean cake flour, 4.9 g/L KH_2PO_4 and 0.95
273 g/L $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ which was determined by response surface methodology.

274

275 Díaz, de Ory [74] reported that the cellulase production was inhibited at high concentration of
276 reducing sugars when grape pomace was used as substrate. They avoided this problem by
277 adjusting the nutrients composition of grape pomace by supplementing orange peel, which is

278 a pectin, cellulose and hemicellulose rich substrate inducing cellulase production. The
279 synthesis of xylanase and cellulase increased using the mixed type substrate compared to
280 whole grape pomace. Umsza-Guez, Díaz [55] have reported that the xylanase production
281 from tomato wastes using SSF system is activated by Mg^{2+} , but strongly inhibited by Hg^{2+}
282 and Cu^{2+} .

283

284 The effects of substrate pre-treatments on cellulase and xylanase production have been
285 studied [69, 71]. Bansal, Tewari [68] studied the effects of acid and base pre-treatment on
286 cellulase production from different FWs including carrot peelings, orange peelings, pineapple
287 peelings, potato peelings and wheat bran using SSF. The pretreated substrates are well suited
288 for the organism's growth, producing high titers of cellulases after 96 h without the
289 supplementation of additional nutritional sources. Yields of cellulases were higher in alkali
290 treated substrates compared to acid treated and untreated substrates except in wheat bran. Of
291 all the substrates tested, untreated wheat bran induced the maximum production of enzyme
292 components followed by alkali treated composite kitchen waste and potato peelings. Krishna
293 [71] investigated the effects of acid, alkaline and heat pre-treatment on cellulase production
294 from banana waste using *Bacillus subtilis*. Although cellulase production was not affected by
295 alkali or acid treatment, it increased by 6.84 fold using pressure-cooking under controlled pH.
296 Pressure cooking of plant materials at a controlled pH could result in greater substrate
297 accessibility for microbial growth. Moreover, it did not result in the formation of
298 monosaccharide degradation products, such as furfural and hydroxymethyl furfural, which
299 otherwise inhibit the cellulases [77].

300

301 Besides cellulases and xylanases, ligninases were also produced from FWs by white rot
302 fungi. Zilly, dos Santos Bazanella [76] studied the oxidative and hydrolytic enzymes

303 production by SSF of yellow passion fruit waste using white-rot fungi *Pleurotus ostreatus*,
304 *Pleurotus pulmonarius*, *Macrocybe titans*, *Ganoderma lucidum*, and *Grifola frondosa*. Under
305 the conditions used, the main enzymes produced by the fungi were laccases, pectinases, and
306 aryl- β -D-glycosidases (β -glucosidases, β -xylosidases, and β -galactosidases). The yellow
307 passion fruit waste was as good as wheat bran, which is the most commonly used substrate
308 for white-rot fungi cultivation.

309

310 Biorefineries need to develop their indigenous enzyme production processes along with their
311 existing processes as commercial enzyme production systems are still expensive to
312 incorporate in biorefineries [78]. As can be seen from the studies above, some strains are
313 producing different lignocellulosic enzymes from food wastes simultaneously. These enzyme
314 cocktails can be used to hydrolyse biomass effectively at low cost for their conversion to
315 biofuels, platform chemicals and biodegradable films. To further improve the hydrolysis,
316 different strains can be used to produce enzyme solutions with different hydrolytic activities.
317 Besides, some engineered strains can be used to improve the saccharification yield.

318 **2.3 Pectinolytic enzymes**

319 Pectinolytic enzymes, i.e. pectinases degrade pectin polymers in a sequential and synergic
320 way, by depolymerisation and deesterification reactions. Complete degradation of pectin
321 requires endo- and exo-acting polygalacturonases and pectin- and pectate lyases as well as
322 enzymes that cleave the rhamnogalacturonan chain, the rhamnogalacturonases [79].

323 Pectinases are widely used in food industry particularly for juice and wine production and
324 many other conventional industrial processes, such as textile, plant fiber processing, tea,
325 coffee, oil extraction, treatment of industrial wastewater [46, 80, 81]. The production of
326 pectinases is mainly conducted via fungal SSF particularly by using *Aspergillus* strains [79].
327 **For industrial implementation,** pectinases can be produced from pectin-containing wastes,

328 such as citrus and orange wastes [82-84], apple pomace [85, 86], grape pomace [75] and
 329 many other fruit residues [87] without any harsh pre-treatment owing to the nature of these
 330 substrates and the low moisture content [80, 87]. Hours, Voget [86] investigated the pectinase
 331 production from apple pomace by SSF using *Aspergillus foetidus*. The medium composition,
 332 temperature and type of apple pomace used affected the enzyme production. After 36h
 333 culture at 30°C with organic nitrogen supplemented apple pomace medium, an enzyme
 334 activity of 1,300 U/g was obtained (Table 4).

335

336 **Table 4.** Pectinolytic enzyme production from food wastes.

Residual materials	Microorganism	Pretreatment method	Fermentation mode & vessel type	Fermentation conditions	Duration (day)	Achievements
Apple pomace	<i>Aspergillus foetidus</i> NRRL 341	None	SSF- petri dishes	30°C, pH 4, 10 ³ I/S	2	Pectinase (1300 U/g S)
Citrus waste	<i>Aspergillus foetidus</i> NRRL 341	None	SSF- petri dishes	30°C	2	Pectinase (1641 U/g S)
Apple pomace	<i>Aspergillus niger</i>	None	SSF- 15L horizontal solid state stirred tank reactor	35°C	3	900 AJDA U/mL
Grape pomace	<i>Aspergillus awamori</i>	Milled, sieved	SSF- petri dishes	30°C, 60% MC	1	Exo-PG(40U/g S) U/g S)
Orange bagasse	<i>Botryosphaeria rhodina</i> MAMB-05	Dried, ground	SSF-125 mL flask	28°C	6	Pectinase (32 U/mL) Laccase (46 U/mL)
Orange waste	<i>Aspergillus giganteus</i> CCT3232	NR	SmF-Flask	30°C, pH 6, 120 rpm, 1.10 ⁷ spores/mL	3.5	Exo-PG (48.5 U/mL)
Fruit residues (apple, lemon peel, grape skin & tamarind kernel)	<i>Aspergillus flavipes</i> FP-500	Dried, milled, sieved	SmF-Flask	37°C, pH 3.5-5.5, 150 rpm, 1.10 ⁶ spores/mL	3	Endopectinase (6 U/mL) Pectinlyase (5 U/mL) Exopectinase (4.8 U/mL) Rhamno-galacturonidase (4.8 U/mL)
Fruit residues (apple, lemon peel, grape skin & tamarind kernel)	<i>A. terreus</i> FP-370	Dried, milled, sieved	SmF-Flask	37°C, pH 3.5-5.5, 150 rpm, 1.10 ⁶ spores/mL	3	Endopectinase (3 U/mL) Pectinlyase (33 U/mL) Exopectinase (4.8 U/mL) Rhamno-galacturonidase (4.8 U/mL)
Tomato pomace	<i>Aspergillus awamori</i>	Dried, milled, sieved	SSF-plate-type SSF bioreactor	28°C, pH 5	5	Exo-PG (36.2 IU/g S)

Lemon peel pomace	<i>Aspergillus niger</i> Aa-20	Dried, ground	SSF- column-tray bioreactor	30°C, 70% MC, 194 mL/min AFR, 2–0.7 mm PS	4	Pectinase (2.18 U/g)
Passion fruit waste	<i>Macrocybe titans</i>	Dried, milled.	SSF-250 mL flasks	28°C in complete darkness	14	Pectinase (1.72 U/g)
Orange peel	<i>Aspergillus niger</i> URM5162	Dried, ground	Fixed bed bioreactor	25°C, 3.105 spores/mL	7	Endo-PG (1.18 U/g) Exo-PG (4.11 U/g)

337 S: substrate, SSF: solid state fermentation, SmF: submerged fermentation, I/S: Inoculum to substrate ratio, AFR: air flow
338 rate, DS: dry substrate, MC: moisture content, PS: particle size, ds: dry solid, PG: polygalacturonase, CMC: casein
339 carboxymethylcellulase, NR: Not reported.

340

341 In another study, pectinolytic enzyme production from citrus waste was studied using
342 *Aspergillus foetidus* for SSF [83]. Yeast extract and mineral salt addition improved the
343 activity up to 1,600-1,700 U/g after 36 h of culture. Berovic and Ostroversnik [85] reported
344 that the pectolytic enzyme production from apple pomace using SSF with *Aspergillus niger*
345 was induced and/or improved by supplementing the media with other cheap nutrients such as
346 soya flour, wheat bran, wheat corn and whey. They also mentioned that the highest activity
347 was obtained using 38% moisture content and moisture content is very important in enzyme
348 production. Whereas, Ruiz, Rodriguez-Jasso [46] reported that the 70% moisture content
349 gave the highest pectinase activity using lemon peel pomace. Botella, Diaz [80] evaluated the
350 feasibility of grape pomace for the production of exo-polygalacturonase by *Aspergillus*
351 *awamori* in SSF fermentation. The particle size of the substrate did not influence the enzyme
352 production like it was reported by Hours, Voget [86] while the addition of extra carbon
353 sources and the initial moisture content of the grape pomace were found to have a marked
354 influence on the enzymes yields. In another study, Giese, Dekker [84] carried out the
355 production of pectinases from orange waste by *Botryosphaeria rhodina* MAMB-05 using
356 both SSF and SmF with and without adding nutrients. Orange bagasse with a solid
357 concentration of 16% (w/v) provided good microbial growth and the highest pectinase titre
358 (32 U/mL) was obtained using SSF without adding extra nutrients.

359

360 Aeration is another important parameter affecting the pectinase production. Umsza-Guez,
361 Díaz [55] reported that the forced aeration has negative effects on exo-PG synthesis, reducing
362 to half of its activity in multi-layer packed bead reactor. MacIel, Ottoni [89] obtained the
363 maximum endo- and exo-PG activities of 1.18 U/mL and 4.11 U/mL, respectively, using the
364 reactors without aeration. A system without aeration is advantageous since it is easier to
365 implement and economical.

366

367 The pH value of the medium can also affect the pectinase production. Martínez Sabajanes,
368 Yáñez [87] investigated the effect of different substrates (apple, lemon peel, grape skin &
369 tamarind kernel) and fungi (*Aspergillus flavipes* FP-500 and *Aspergillus terreus* FP-370) on
370 the production of pectinases. The highest activities were obtained using lemon peel. In both
371 strains, acidic pH values and high carbon source concentration favoured exopectinase and
372 endopectinase production, while higher pH values and low carbon source concentration
373 promoted pectin lyase and rhamnogalacturonase production.

374

375 In summary, fruit wastes are superior substrates to produce high titers of pectinolytic
376 enzymes using either SSF or SmF. Process parameters including medium pH, temperature,
377 composition, inoculum size, moisture content and particle size of the substrate and aeration
378 highly depend on the utilized substrate and microbial strain. Statistical experimental designs
379 can be employed to optimize the fermentation conditions by evaluating the effects and
380 interactions of the different parameters that rule a biochemical system.

381

382 There is no industrial scale FW biorefinery facility currently in operation. However, there are
383 some studies reporting the technical advances and engineering challenges of orange and
384 lemon waste biorefineries [90, 91]. Direct utilization of citrus peel as animal feed is the

385 simplest option, requiring little infrastructure or investment, while increasing the value of the
386 waste material significantly [91]. However, citrus peel contains many high value compounds
387 such as pectin and D-limonene [92]. Pectin is frequently used in food processing, while D-
388 limonene is an important essential oil for cosmetics, foods and pharmaceutical industries. D-
389 limonene can be extracted using suitable solvents. The biomass left over after limonene
390 extraction, mainly consists of pectin and lignocellulose, is an excellent source for pectinolytic
391 and lignocellulolytic enzyme production and for the growth of microorganisms to generate
392 high value products such as industrial enzymes, ethanol, methane and single cell proteins.
393 Moreover, the residual biomass i.e. lignin can be used as an energy source.

394

395 **2.4. Proteases**

396 Proteases are also one of the most important commercial enzyme groups because of their
397 wide range use in food, pharmaceutical, detergent, dairy and leather industries [39, 41, 93,
398 94]. Some fungal strains such as *Aspergillus*, *Penicillium* and *Rhizopus* and bacteria of genus
399 *Bacillus* have been reported as the active producers of proteases [39, 57, 95]. Although the
400 protease production from agro-industrial wastes has been studied in detail using both SSF and
401 SmF, the investigations on the utilization of FWs has not been comprehensive. The studies
402 reporting protease production from several FWs are listed in Table 5. Khosravi-Darani,
403 Falahatpishe [95] used a newly isolated alkalophilic *Bacillus* sp. in SmF of date wastes
404 without any pre-treatment. High activity protease production (57420 APU/mL) was obtained
405 at pH 10, 37°C and the enzyme was reported to be thermostable, indicating its possible
406 utilization in industrial applications. Afify, Abd El-Ghany [96] investigated the production of
407 proteases from potato waste in a submerged system using *S. cerevisiae* and studied the
408 utilization of remained solid waste as a biofertilizer for plant development. The highest
409 enzyme activity (360 U/mg) was obtained using a fermentation medium containing 15 g

410 potato waste, at initial pH 6.0, 20°C for 72 h. There are some studies reporting the
411 production of high activity proteases using fishmeal and shrimp wastes. In a study of Gupta,
412 Prasad [93], fishmeal from sardine and pink perch were evaluated as a sole carbon and
413 nitrogen sources in the medium for alkaline protease production by *Bacillus pumilus* MTCC
414 7514. The protease obtained in medium containing only fish meal (4,914 U/mL) was nearly
415 two times higher than that using basal medium (2,646 U/mL). The protease production was
416 enhanced to 6,966 U/mL and 7,047 U/mL when scaled up from flask to 3.7 and 20 L
417 fermenters, respectively, using fish meal as the sole source (10 g/L). The crude protease was
418 found to have dehairing ability in leather processing, which is bound to have great
419 environmental benefits in leather industry. In another study, a powder was prepared from
420 shrimp wastes and tested as growth substrate for the production of protease by *P. aeruginosa*
421 MN7 [97]. *P. aeruginosa* MN7 was found to grow and over-produce proteolytic enzymes
422 (15,000 U/mL) in media containing only SWP as microbial growth substrate. Although there
423 are few reports on protease production from FW, the appreciable protease activities obtained
424 on different FW residues highlighted the potential of these wastes.

425

426 Besides its potential utilization in many industrial applications, proteases produced from FW
427 can be also used for biorefining different biomasses. Koutinas, Malbranque [98] evaluated an
428 oat-based biorefinery for the production of lactic acid as well as other value-added by-
429 products, such as β -glucan and antioxidant-rich oil bodies using *Rhizopus oryzae*. During the
430 process, *Rhizopus oryzae* produced a range of enzymes (glucoamylase, protease,
431 phosphatase) during the hydrolysis of complex macromolecules in oat. The utilization of
432 waste biomass and in-situ produced enzyme cocktails in such a biorefining strategy could
433 lead to significant operating cost reduction as compared to current industrial practices for
434 lactic acid production from pure glucose achieved by bacterial fermentations.

435 **Table 5.** Protease production from food wastes.

Residual materials	Microorganism	Pretreatment method	Fermentation mode & vessel type	Fermentation conditions	Duration (day)	Achievements	References
Date waste	<i>Bacillus sp.</i> 2-5	Heat treatment & filtration	SmF-125 mL flask	37°C, pH 10, 125 rpm	2	57420 APU/mL	[95]
Potato waste	<i>Saccharomyces cerevisiae</i>	NR	SmF- 250 ml flask	28°C	5	360 U/mg	[96]
Fish meal	<i>Bacillus pumilus</i> MTCC 7514	None	SmF-20L bioreactor	30°C, pH 7.5	2	7.05 U/mL	[93]
Waste bread	<i>Aspergillus oryzae</i>	None	SSF-petri plates	30°C, MC:1.8 (w/w, db), PS:20 mm, 10 ⁶ spore/gdS	6	83.2 U/gdS	[58]
Cuttlefish by-products	<i>Vibrio parahaemolyticus</i>	Heat treatment, pressing, grinding, drying at 80°C o/n, powdering	SmF- 250 mL flasks	37°C, pH 8.7, 200 rpm	1	2487 U/mL	[99]
Shrimp waste	<i>Pseudomonas aeruginosa</i> MN7	Heat pretreatment (100°C, 20 min), drying, grinding	SmF- 250 mL flasks	37°C, 200 rpm	<1	15000 U/mL	[97]

436 SmF: submerged fermentation, SSF: solid state fermentation, MC: moisture content, PS: particle size, S: substrate, o/n: overnight, NR: Not reported.

437 **2.5. Lipases**

438 After proteases and carbohydrases, lipases (EC 3.1.1.3) are considered as the third largest
439 group based on total sales volumes [100]. They are widely used for several applications in
440 food, detergent, cosmetics, organic synthesis and pharmaceutical industries. They are
441 catalysing the hydrolysis of triacylglycerols to di- and mono- acylglycerols, fatty acids and
442 glycerol [42, 101, 102]. They are also able to catalyze alcoholysis, acidolysis, aminolysis,
443 esterification and transesterification under certain conditions [103]. Phospholipases are a sub
444 class of lipases that catalyse the hydrolysis of one or more ester and phosphodiester bonds of
445 glycerophospholipids. They vary in site of action on phospholipid which can be used for the
446 modification/production of new phospholipids for some applications in oil refinery, health,
447 food manufacturing, dairy and cosmetics industries [104].

448

449 Most of the research has been concentrated on high activity extracellular lipase production by
450 using both SmF and SSF via a wide variety of microorganisms including bacteria, fungi,
451 yeast and Actinomyces [42, 102, 105, 106]. Several strains of commercial lipase producing
452 fungi are quite dominant, including *Rhizopus*, *Rhizomucor*, *Aspergillus*, *Geotrichum*,
453 *Yarrowia* and *Penicillium* species [107]. Recently, the production of lipase investigated by
454 several researchers using different FWs as substrates [101] or by supplementing FWs as
455 inducer [108, 109]. Alkan, Baysal [101] investigated the production of lipase from melon
456 waste by SSF using *Bacillus coagulans*. The highest lipase production (78.1 U/g) was
457 achieved after 24 h of cultivation with 1% olive oil enrichment at 37°C and pH 7.0 by
458 supplementing sodium dodecyl sulphate (Table 6). The best results were obtained by
459 supplementing starch and maltose (148.9 and 141.6 U/g, respectively), whereas a rather low
460 enzyme activity was found in cultures grown on glucose and galactose (approximately 118.8
461 and 123.6 U/g, respectively). Enzyme was inhibited by Mn^{2+} and Ni^{2+} by 68% and 74%,

462 respectively. By contrast, Ca²⁺ enhanced enzyme production by 5%. In a study of
463 Dominguez, Deive [108] investigated the biodegradation of waste cooking oil and its
464 application as an inducer in lipase production by *Yarrowia lipolytica* CECT 1240. The
465 addition of waste cooking oil to the medium led to a significant augmentation in extracellular
466 lipase production by yeast, compared to oil-free cultures. Papanikolaou, Dimou [109]
467 explored the effects of different *Aspergillus* and *Penicillium* strains on lipid accumulation and
468 lipase production using the waste cooking oil as substrate. In carbon-limited medium, the
469 highest amount of biomass (18 g/L) with a lipid content of 64% was obtain using *Aspergillus*
470 *sp.* ATHUM 3482, while the highest extracellular lipase activity (645 U/mL) was obtained by
471 *Aspergillus niger* NRRL 363. The studies above have indicated the possibility of FWs
472 utilization either as substrates or inducers for lipase production. Lipase production can be
473 further improved using mutant or engineered strains.

474

475 Lipases are also used for biodiesel production from crude oil and fats [112] either in free or
476 immobilized form. Lipase production processes from FW can be integrated in a biodiesel
477 biorefining process to decrease the transesterification cost. Besides lipases, phospholipases
478 are used for oil degumming and improving the efficiency of fatty acid yields [113]. Although
479 there is no report on phospholipase production using FWs, a process for the production of
480 various types of phospholipases from FWs can be developed using suitable strains.

481

482

483 **Table 6.** Lipase production from food wastes.

Substrate	Microorganism	Pretreatment method	Fermentation mode & vessel type	Fermentation conditions	Duration (day)	Achievements	References
Banana waste, melon waste, watermelon waste	<i>Bacillus coagulans</i>	None	SSF-Flasks	37°C, pH 7	1	148.9 U/g S from melon waste	[101]
Waste cooking oil	<i>Y.lipolytica</i> CECT 1240	None	SmF- 5L stirred tank bioreactor with 3L working vol, fb	30°C, 400 rpm	6	0.93U/mL	[108]
Waste cooking olive oil	<i>Aspergillus</i> and <i>Penicillium</i> strains	Filtration	SmF-250 mL flasks	28°C, pH 6, 200 rpm	3	645 U/ mL	[109]
Olive oil cake	<i>Y.lipolytica</i> NRLL Y-1095	Alkaline pretreatment (3% NaOH) 20°C o/n	SSF-150 mL Erlenmeyer flasks	30°C, pH 7, 55% MC	4	40IU/g S	[114]
Tri-substrate (wheat bran, wheat rawa and coconut oil cake)	<i>A.niger</i> MTCC2594	None	SSF-3*1kg tray type bioreactor	30°C, 60% MC	4	745.7 IU/gdS	[115]
Seafood processing waste	<i>Bacillus altitudinis</i>	Drying (80°C o/n)	SSF-Flasks	50°C, pH 8, 80% MC	3	2U/gdS (Esterase)	[116]
Tuna by-products	<i>Rhizopus oryzae</i>	Heat pretreatment (100°C 20 min) and filtration	SmF- 1L flasks	30°C, pH 6, 150 rpm	3	23.5 IU/mL	[117]
Wheat bran with 2% olive oil	<i>Aspergillus flavus</i>	None	SSF-Flasks	29°C, pH 7, 65% MC	4	121.4 U/gdS	[118]
Wheat bran with 2% olive oil	<i>Aspergillus niger</i> J1	None	SmF- 500 mL flasks	30°C, pH 6, 100 rpm	8	1.46 U/mL	[119]
Wheat bran with 2% olive oil	<i>Aspergillus niger</i> J1	None	SSF- flasks	30°C, pH 6, 65% MC	7	1.46 U/mL	[119]

484 S: substrate, ds: dry substrate, SSF: solid state fermentation, SmF: submerged fermentation, fb: fed-batch, *Y. lipolytica*:*Yarrowia lipolytica*, MC: moisture content, o/n:overnight.

485

486

487

488 **3. Conclusions**

489 The management of FWs has posed a serious economic and environmental concern. The
490 publications discussed above indicated that a wide range of high titres industrial enzymes can
491 be produced from various FWs. The produced enzymes can be used for some industrial
492 applications. Moreover, these enzyme production processes can be consolidated with other
493 value-added product development processes to create FW biorefineries.

494

495 So far, all developed biorefinery processes for the conversion of FW into ethanol and other
496 value-added products have only been achieved at bench-top and pilot levels. There is no
497 industrial scale FW biorefinery facility currently in operation. Therefore, it is not possible to
498 conduct an economical analysis for the proposed biorefinery systems. However, considering
499 the cost of defined medium preparation in current commercial enzyme processes, the
500 utilization of low or no cost waste biomass for biorefining could lead to significant reductions
501 in operating costs. However, difficulties and costs associated with the
502 collection/transportation of FW should also be taken into account. Optimization and scale up
503 studies need to be carried out in order to exploit for large-scale applications.

504

505 **ACKNOWLEDGEMENTS**

506 We would like to thank the National Environment Agency (NEA, Singapore) for financial
507 support of this research (Grant no: ETRP 1201 105).

508

509 **REFERENCES**

- 510 1. Lundqvist, J., C. de Fraiture, and D. Molden, *Saving water: From field to fork – curbing losses*
511 *and wastage in the food chain*, in *SIWI Policy Brief*. 2008, Stockholm International Water
512 Institute Stockholm, Sweden.

- 513 2. FAO, *Towards the future we want: End hunger and make the transition to sustainable*
514 *agricultural and food systems*. 2012, Food and agriculture organization of the United Nations
515 Rome.
- 516 3. Melikoglu, M., C.S.K. Lin, and C. Webb, *Analysing global food waste problem: pinpointing the*
517 *facts and estimating the energy content*. Cent. Eur. J. Eng. , 2013. **3**(2): p. 157-164.
- 518 4. National-Environment-Agency. http://app2.nea.gov.sg/topics_wastestats.aspx. 2011 [cited
519 2013 3 February].
- 520 5. Lin, C.S.K., et al., *Food waste as a valuable resource for the production of chemicals,*
521 *materials and fuels. Current situation and global perspective*. Energy and Environmental
522 Science, 2013. **6**(2): p. 426-464.
- 523 6. Ngoc, U.N. and H. Schnitzer, *Sustainable solutions for solid waste management in Southeast*
524 *Asian countries*. Waste Management, 2009. **29**: p. 1982–1995.
- 525 7. Ma, H., et al., *The utilization of acid-tolerant bacteria on ethanol production from kitchen*
526 *garbage*. Renewable Energy 2009. **34**(6): p. 1466–1470.
- 527 8. Othman, S.N., et al., *Review on life cycle assessment of integrated solid waste management*
528 *in some Asian countries*. Journal of Cleaner Production, 2013. **41**: p. 251-262.
- 529 9. Takata, M., et al., *The effects of recycling loops in food waste management in Japan: Based*
530 *on the environmental and economic evaluation of food recycling*. Science of the Total
531 Environment, 2012. **432**: p. 309-317.
- 532 10. Gajalakshmi, S. and S.A. Abbasi, *Solid waste management by composting: State of the art*.
533 Critical Reviews in Environmental Science and Technology, 2008. **38**(5): p. 311-400.
- 534 11. Cekmecelioglu, D., et al., *Applicability of optimized in-vessel food waste composting for*
535 *windrow systems*. Biosystems Engineering, 2005. **91**: p. 479-486.
- 536 12. Aye, L. and E.R. Widjaya, *Environmental and economic analysis of waste disposal options for*
537 *traditional markets in Indonesia*. Waste Management, 2006. **26**: p. 1180-1191.
- 538 13. Hirai, Y., et al., *Life cycle assessment on food waste management and recycling*. Waste
539 Manag Res, 2001. **12**(5): p. 219-228.
- 540 14. Esteban, M.B., et al., *Evaluation of fruit, vegetable and fish wastes as alternative feedstuffs*
541 *in pig diets*. Waste Management, 2007. **27**: p. 193-200.
- 542 15. Han, S.K. and H.S. Shin, *Biohydrogen production by anaerobic fermentation of food waste*.
543 International Journal of Hydrogen Energy 2004. **29**(6): p. 569 – 577.
- 544 16. Sakai, K. and Y. Ezaki, *Open L-lactic acid fermentation of food refuse using thermophilic*
545 *Bacillus coagulans and fluorescence in situ hybridization analysis of microflora*. Journal of
546 Bioscience and Bioengineering, 2006. **101**(6): p. 457-463.
- 547 17. Yang, S.Y., et al., *Lactic acid fermentation of food waste for swine feed*. Bioresource
548 Technology, 2006. **97**(15): p. 1858–1864.
- 549 18. Zhang, C., et al., *The anaerobic co-digestion of food waste and cattle manure*. Bioresource
550 technology, 2013. **129**: p. 170-176.
- 551 19. Zhang, M., et al., *Improved bioethanol production through simultaneous saccharification and*
552 *fermentation of lignocellulosic agricultural wastes by Kluyveromyces marxianus 6556*. World
553 J. Microbiol. Biotechnol. , 2010. **26**(6): p. 1041-1046.
- 554 20. He, Y., et al., *Recent advances in membrane technologies for biorefining and bioenergy*
555 *production*. Biotechnology advances, 2012. **30**(4): p. 817-858.
- 556 21. Pan, J., et al., *Effect of food to microorganism ratio on biohydrogen production from food*
557 *waste via anaerobic fermentation*. International Journal of Hydrogen Energy, 2008. **33**(23):
558 p. 6968-6975.
- 559 22. Vavouraki, A.I., E.M. Angelis, and M. Kornaros, *Optimization of thermo-chemical hydrolysis of*
560 *kitchen wastes*. Waste Management, 2014. **34**(1): p. 167-173.
- 561 23. He, M., et al., *Influence of temperature on hydrolysis acidification of food waste* Procedia
562 Environmental Sciences, 2012. **16**: p. 85-94.

- 563 24. Sanders, J., et al., *Bio-refinery as the bio-inspired process to bulk chemicals*. Macromolecular
564 Bioscience, 2007. **7**(2): p. 105-117.
- 565 25. Kim, J.K., et al., *Statistical optimization of enzymatic saccharification and ethanol*
566 *fermentation using food waste*. Process Biochemistry, 2008. **43**(11): p. 1308-1312.
- 567 26. Kwon, S.H. and D.H. Lee, *Evaluation of Korean food waste composting with fed-batch*
568 *operations I: using water extractable total organic carbon contents (TOCw)* Process
569 Biochemistry 2004. **39**(10): p. 1183–1194.
- 570 27. Rao, M.S. and S.P. Singh, *Bioenergy conversion studies of organic fraction of MSW: kinetic*
571 *studies and gas yield–organic loading relationships for process optimisation*. Bioresource
572 Technology 2004. **95**(2): p. 173–185.
- 573 28. Ramos, C., et al., *Effect of the initial total solids concentration and initial pH on the bio-*
574 *hydrogen production from cafeteria food waste*. International Journal of Hydrogen Energy,
575 2012. **37**(18): p. 13288-13295.
- 576 29. Ohkouchi, Y. and Y. Inoue, *Direct production of L(+)-lactic acid from starch and food wastes*
577 *using Lactobacillus manihotivorans LMG18011*. Bioresource Technology, 2006. **97**: p. 1554–
578 1562.
- 579 30. Kim, J.K., et al., *Effects of temperature and hydraulic retention time on anaerobic digestion of*
580 *food waste*. Journal of Bioscience and Bioengineering, 2006. **102**(4): p. 328-332.
- 581 31. Tang, Y.Q., et al., *Ethanol production from kitchen waste using the flocculating yeast*
582 *Saccharomyces cerevisiae strain KF-7*. Biomass and Bioenergy 2008. **32** (11): p. 1037–1045.
- 583 32. Wang, Q., et al., *Ethanol production from kitchen garbage using response surface*
584 *methodology*. Biochemical Engineering Journal, 2008. **39**(3): p. 604-610.
- 585 33. Zhang, B., et al., *Anaerobic digestion of kitchen wastes in a single-phased anaerobic*
586 *sequencing batch reactor (ASBR) with gas-phased absorb of CO₂*. Journal of Environmental
587 Sciences, 2005. **17**(2): p. 249-255.
- 588 34. Ma, H., et al., *Optimization of the medium and process parameters for ethanol production*
589 *from kitchen garbage by Zymomonas mobilis*. International Journal of Green Energy 2008.
590 **5**(6): p. 480-490.
- 591 35. Uncu, O.N. and D. Cekmecelioglu, *Cost-effective approach to ethanol production and*
592 *optimization by response surface methodology*. Waste Management, 2011. **31**(4): p. 636-
593 643.
- 594 36. Cekmecelioglu, D. and O.N. Uncu, *Kinetic modeling of enzymatic hydrolysis of pretreated*
595 *kitchen wastes for enhancing bioethanol production* Waste Management 2013. **33**(3): p. 735-
596 739.
- 597 37. Zhang, L. and D. Jahng, *Long-term anaerobic digestion of food waste stabilized by trace*
598 *elements*. Waste Management, 2012. **32**(8): p. 1509-1515.
- 599 38. Teeri, T.T., *Crystalline cellulose degradation: new insight into the function of*
600 *cellobiohydrolases*. Trends in Biotechnology, 1997. **15**: p. 160-167.
- 601 39. Chutmanop, J., et al., *Protease production by Aspergillus oryzae in solid-state fermentation*
602 *using agroindustrial substrates*. Journal of Chemical Technology and Biotechnology, 2008.
603 **83**(7): p. 1012-1018.
- 604 40. De Castro, A.M., et al., *Valorization of residual agroindustrial cakes by fungal production of*
605 *multienzyme complexes and their use in cold hydrolysis of raw starch*. Waste and Biomass
606 Valorization, 2011. **2**(3): p. 291-302.
- 607 41. Prakasham, R.S., et al., *Alkaline protease production by an isolated Bacillus circulans under*
608 *solid-state fermentation using agroindustrial waste: Process parameters optimization*.
609 Biotechnology progress, 2005. **21**(5): p. 1380-1388.
- 610 42. Vaseghi, Z., et al., *Production of active lipase by Rhizopus oryzae from sugarcane bagasse:*
611 *Solid state fermentation in a tray bioreactor*. International Journal of Food Science and
612 Technology, 2013. **48**(2): p. 283-289.

- 613 43. Pandey, A., et al., *Biotechnological potential of agro-industrial residues. I: Sugarcane*
614 *bagasse*. *Bioresour Technol*, 2000. **74**(1): p. 69-80.
- 615 44. Couto, S.R. and M.A. Sanromán, *Application of solid-state fermentation to food industry-A*
616 *review*. *Journal of Food Engineering*, 2006. **76**(3): p. 291-302.
- 617 45. Dos Santos, T.C., et al., *Optimisation of solid state fermentation of potato peel for the*
618 *production of cellulolytic enzymes*. *Food Chemistry* 2012. **133**: p. 1299–1304.
- 619 46. Ruiz, H.A., et al., *Pectinase production from lemon peel pomace as support and carbon*
620 *source in solid state fermentation column-tray bioreactor*. *Biochemical Engineering Journal*,
621 2012. **65**: p. 90-95
- 622 47. Shukla, J. and R. Kar, *Potato peel as a solid state substrate for thermostable alpha amylase*
623 *production by thermophilic Bacillus isolates*. *World Journal of Microbiology & Biotechnology*
624 2006. **22**(5): p. 417–422.
- 625 48. Thomas, L., C. Larroche, and A. Pandey, *Current developments in solid-state fermentation*.
626 *Biochemical Engineering Journal*, 2013. **81**: p. 146-161.
- 627 49. Wang, Q., et al., *Glucoamylase production from food waste by Aspergillus niger under*
628 *submerged fermentation*. *Process Biochemistry* 2008. **43**(3): p. 280–286.
- 629 50. Kawa-Rygielska, J., W. Pietrzak, and A. Czubaszek, *Characterization of fermentation of waste*
630 *wheat-rye bread mashes with the addition of complex enzymatic preparations*. *Biomass*
631 *Bioenergy* 2012. **44**: p. 17-22.
- 632 51. Pandey, A., et al., *Advances in microbial amylases*. *Biotechnology and Applied Biochemistry*,
633 2000. **31**(2): p. 135-152.
- 634 52. Anto, H., U.B. Trivedi, and K.C. Patel, *Glucoamylase production by solid-state fermentation*
635 *using rice flake manufacturing waste products as substrate*. *Bioresour Technol*, 2006. **97**(10):
636 p. 1161-1166.
- 637 53. Elayaraja, S., et al., *Thermostable alpha-amylase production by Bacillus firmus CAS 7 using*
638 *potato peel as a substrate*. *African Journal of Biotechnology* 2011. **10**(54): p. 11235-11238.
- 639 54. Murthy, P.S., M. Madhava Naidu, and P. Srinivas, *Production of α -amylase under solid-state*
640 *fermentation utilizing coffee waste*. *Journal of Chemical Technology Biotechnology* 2009.
641 **84**(8): p. 1246–1249.
- 642 55. Umsza-Guez, M.A., et al., *Xylanase production by Aspergillus awamori under solid state*
643 *fermentation conditions on tomato pomace*. *Brazilian Journal of Microbiology*, 2011. **42**(4):
644 p. 1585-1597.
- 645 56. Jamrath, T., et al., *Amylase and protease production by B. caldolyticus*. *Food technology and*
646 *biotechnology*, 2012. **50**(3): p. 355–361.
- 647 57. Jamrath, T., et al., *Production of amylases and proteases by Bacillus caldolyticus from food*
648 *industry wastes*. *Food Technology and Biotechnology* 2012. **50**(3): p. 355-361.
- 649 58. Melikoglu, M., C.S.K. Lin, and C. Webb, *Stepwise optimisation of enzyme production in solid*
650 *state fermentation of waste bread pieces*. *Food and Bioproducts Processing*, 2013. **91**(4): p.
651 638-646.
- 652 59. Kim, K.I., et al., *Production of lactic acid from food wastes*. *Applied Biochemistry and*
653 *Biotechnology - Part A Enzyme Engineering and Biotechnology*, 2003. **107**(105-108): p. 637-
654 647.
- 655 60. Sakai, K., et al., *Making plastics from garbage: A novel process for poly-L-lactate production*
656 *from municipal food waste*. *Journal of Industrial Ecology*, 2004. **7**(3-4): p. 63-74.
- 657 61. Leung, C.C.J., et al., *Utilisation of waste bread for fermentative succinic acid production*.
658 *Biochemical Engineering Journal*, 2012. **65**: p. 10-15.
- 659 62. Kuhad, R.C., R. Gupta, and A. Singh, *Microbial cellulases and their industrial applications*.
660 *Enzyme Research*, 2011. **2011**(1): p. 10.
- 661 63. Jørgensen, H., J.B. Kristensen, and C. Felby, *Enzymatic conversion of lignocellulose into*
662 *fermentable sugars: challenges and opportunities*. *Biofuels Bioproducts Biorefinery*, 2007.
663 **1**(2): p. 119–134.

- 664 64. Khandeparkar, R.D.S. and N.B. Bhosle, *Isolation, purification and characterization of the*
665 *xylanase produced by Arthrobacter sp. MTCC 5214 when grown in solid-state fermentation.*
666 *Enzyme and Microbial Technology*, 2006. **39**(4): p. 732-742.
- 667 65. Uçkun Kiran, E., O. Akpınar, and U. Bakir, *Improvement of enzymatic xylooligosaccharides*
668 *production by the co-utilization of xylans from different origins.* *Food and Bioproducts*
669 *Processing*, 2013. **91**(4): p. 565-574.
- 670 66. Effendi, A., H. Gerhauser, and A.V. Bridgwater, *Production of renewable phenolic resins by*
671 *thermochemical conversion of biomass: A review.* *Renewable and Sustainable Energy*
672 *Reviews*, 2008 **12**(8): p. 2092-2116.
- 673 67. Menon, V. and M. Rao, *Trends in bioconversion of lignocellulose: Biofuels, platform*
674 *chemicals & biorefinery concept.* *Progress in Energy and Combustion Science*, 2012. **38**(4): p.
675 522-550.
- 676 68. Bansal, N., et al., *Production of cellulases from Aspergillus niger NS-2 in solid state*
677 *fermentation on agricultural and kitchen waste residues.* *Waste Management* 2012. **32**(7): p.
678 1341-1346.
- 679 69. Saravanan, P., R. Muthuvelayudham, and T. Viruthagiri, *Application of statistical design for*
680 *the production of cellulase by Trichoderma reesei using mango peel.* *Enzyme Research*, 2012.
681 **2012**: p. 157643-157649.
- 682 70. Dhillon, G.S., et al., *Potential of apple pomace as a solid substrate for fungal cellulase and*
683 *hemicellulase bioproduction through solid-state fermentation.* *Industrial Crops and Products*,
684 2012. **38**(1): p. 6-13.
- 685 71. Krishna, C., *Production of bacterial cellulases by solid state bioprocessing of banana wastes.*
686 *Bioresource Technology* 1999. **69**(3): p. 231-239.
- 687 72. Sun, H., et al., *Cellulase production by Trichoderma sp. on apple pomace under solid state*
688 *fermentation.* *African Journal of Biotechnology*, 2010. **9**(2): p. 163-166.
- 689 73. Sun, H.Y., et al., *Banana peel: A novel substrate for cellulase production under solid-state*
690 *fermentation.* *African Journal of Biotechnology*, 2011. **10**(77): p. 17887-17890.
- 691 74. Díaz, A.B., et al., *Enhance hydrolytic enzymes production by Aspergillus awamori on*
692 *supplemented grape pomace.* *Food and Bioproducts Processing* 2012. **90**(1): p. 72-78.
- 693 75. Botella, C., et al., *Hydrolytic enzyme production by Aspergillus awamori on grape pomace.*
694 *Biochemical Engineering Journal*, 2005. **26**(2-3): p. 100-106.
- 695 76. Zilly, A., et al., *Solid-state bioconversion of passion fruit waste by white-rot fungi for*
696 *production of oxidative and hydrolytic enzymes.* *Food Bioprocess Technology* 2012. **5**(5): p.
697 1573-1580.
- 698 77. Weil, J., et al., *Cellulose pretreatments of lignocellulosic substrates.* *Enzyme and Microbial*
699 *Technology*, 1994. **16**(11): p. 1002-1004.
- 700 78. Chandel, A.K., et al., *The realm of cellulases in biorefinery development.* *Critical Reviews in*
701 *Biotechnology*, 2012. **32**(3): p. 187-202.
- 702 79. Kashyap, D.R., et al., *Applications of pectinases in the commercial sector: A review.*
703 *Bioresource technology*, 2001. **77**(3): p. 215-227.
- 704 80. Botella, C., et al., *Xylanase and pectinase production by Aspergillus awamori on grape*
705 *pomace in solid state fermentation.* *Process Biochemistry* 2007. **42**(1): p. 98-101.
- 706 81. Pedrolli, D.B., et al., *Pectin and pectinases: Production, characterization and industrial*
707 *application of microbial pectinolytic enzymes.* *Open Biotechnology Journal*, 2009. **3**: p. 9-18.
- 708 82. Afifi, M.M., *Effective technological pectinase and cellulase by Saccharomyces cerevisiae*
709 *utilizing food wastes for citric acid production.* *Life Science Journal* 2011. **8**(2): p. 405-413
- 710 83. Garzon, C.G. and R.A. Hours, *Citrus waste: An alternative substrate for pectinase production*
711 *in solid-state culture.* *Bioresource Technology* 1992. **39**(1): p. 93-95.
- 712 84. Giese, E.C., R.F.H. Dekker, and A.M. Barbosa, *Orange bagasse as substrate for the production*
713 *of pectinase and laccase by Botryosphaeria rhodina MAMB-05 in submerged and solid state*
714 *fermentation.* *BioResources*, 2008. **3**(2): p. 335-345.

- 715 85. Berovic, M. and H. Ostroversnik, *Production of Aspergillus niger pectolytic enzymes by solid*
716 *state bioprocessing of apple pomace*. Journal of Biotechnology, 1997. **53**(1): p. 47–53.
- 717 86. Hours, R.A., C.E. Voget, and R.J. Ertola, *Some Factors Affecting Pectinase Production from*
718 *Apple Pomace in Solid-State Cultures*. Biological Wastes 1988. **24**(2): p. 147-157.
- 719 87. Martínez Sabajanes, M., et al., *Pectic oligosaccharides production from orange peel waste by*
720 *enzymatic hydrolysis* International Journal of Food Science and Technology, 2012. **47**(4): p.
721 747-754.
- 722 88. Pedrolli, D.B., et al., *Studies on productivity and characterization of polygalacturonase from*
723 *Aspergillus giganteus submerged culture using citrus pectin and orange waste*. Applied
724 Biochemistry and Biotechnology, 2008. **144**(2): p. 191-200.
- 725 89. Maclel, M., et al., *Production of polygalacturonases by Aspergillus section Nigri strains in a*
726 *fixed bed reactor*. Molecules, 2013. **18**(2): p. 1660-1671.
- 727 90. Rivas-Cantu, R.C., K.D. Jones, and P.L. Mills, *A citrus waste-based biorefinery as a source of*
728 *renewable energy: Technical advances and analysis of engineering challenges*. Waste
729 Management and Research, 2013. **31**(4): p. 413-420.
- 730 91. Ángel Siles López, J., Q. Li, and I.P. Thompson, *Biorefinery of waste orange peel*. Critical
731 Reviews in Biotechnology, 2010. **30**(1): p. 63-69.
- 732 92. Lohrasbi, M., et al., *Process design and economic analysis of a citrus waste biorefinery with*
733 *biofuels and limonene as products*. Bioresource Technology, 2010. **101**(19): p. 7382-7388.
- 734 93. Gupta, R.K., et al., *Scale-up of an alkaline protease from Bacillus pumilus MTCC 7514 utilizing*
735 *fish meal as a sole source of nutrients*. Journal of Microbiology and Biotechnology, 2012.
736 **22**(9): p. 1230–1236.
- 737 94. Potumarthi, R., S. Ch, and A. Jetty, *Alkaline protease production by submerged fermentation*
738 *in stirred tank reactor using Bacillus licheniformis NCIM-2042: Effect of aeration and*
739 *agitation regimes*. Biochemical Engineering Journal 2007. **34**(2): p. 185–192.
- 740 95. Khosravi-Darani, K., H.R. Falahatpishe, and M. Jalali, *Alkaline protease production on date*
741 *waste by an alkalophilic Bacillus sp. 2-5 isolated from soil*. African Journal of Biotechnology
742 2008. **7**(10): p. 1536-1542.
- 743 96. Afify, M.M., T.M. Abd El-Ghany, and M.M. Alawlaqi, *Microbial utilization of potato wastes for*
744 *protease production and their using as biofertilizer*. Australian Journal of Basic and Applied
745 Sciences, 2011. **5**(7): p. 308-315.
- 746 97. Jellouli, K., et al., *Purification, biochemical and molecular characterization of a*
747 *metalloprotease from Pseudomonas aeruginosa MN7 grown on shrimp wastes*. Applied
748 Microbiology and Biotechnology, 2008. **79**(6): p. 989-999.
- 749 98. Koutinas, A.A., et al., *Development of an oat-based biorefinery for the production of L(+)-*
750 *lactic acid by rhizopus oryzae and various value-added coproducts*. Journal of Agricultural
751 and Food Chemistry 2007. **55**(5): p. 1755-1761.
- 752 99. Souissi, N., et al., *Preparation and use of media for protease-producing bacterial strains*
753 *based on by-products from cuttlefish (Sepia officinalis) and wastewaters from marine-*
754 *products processing factories*. Microbiological Research, 2008. **163**(4): p. 473-480.
- 755 100. Contesini, F.J., et al., *Aspergillus sp. lipase: Potential biocatalyst for industrial use*. Journal of
756 Molecular Catalysis B: Enzymatic, 2010. **67**(3-4): p. 163-171.
- 757 101. Alkan, H., et al., *Production of lipase by a newly isolated Bacillus coagulans under solid-state*
758 *fermentation using melon wastes*. Applied Biochemistry and Biotechnology 2007. **136**(2): p.
759 183-192.
- 760 102. Li, N.W., M.H. Zong, and H. Wu, *Highly efficient transformation of waste oil to biodiesel by*
761 *immobilized lipase from Penicillium expansum*. Process Biochemistry 2009. **44**(6): p. 685–
762 688.
- 763 103. Saxena, R.K., et al., *Purification and characterization of an alkaline thermostable lipase from*
764 *Aspergillus carneus*. Process Biochemistry, 2003. **39**(2): p. 239-247.

- 765 104. Ramrakhiani, L. and S. Chand, *Recent progress on phospholipases: Different sources, assay*
766 *methods, industrial potential and pathogenicity*. Appl Biochem Biotechnol, 2011. **164**: p.
767 991-1022.
- 768 105. Gupta, N., V. Shai, and G. R, *Alkaline lipase from a novel strain Burkholderia multivorans:*
769 *Statistical medium optimization and production in a bioreactor*. Process Biochemistry, 2007.
770 **42**(2): p. 518-526.
- 771 106. Rehman, S., et al., *Optimization of process parameters for enhanced production of lipase by*
772 *Penicillium notatum using agricultural wastes*. African Journal of Biotechnology 2011.
773 **10**(84): p. 19580-19589.
- 774 107. Colen, G., R.G. Junqueira, and T. Moraes-Santos, *Isolation and screening of alkaline lipase-*
775 *producing fungi from Brazilian savanna soil*. World Journal of Microbiology and
776 Biotechnology, 2006. **22**(8): p. 881-885.
- 777 108. Dominguez, A., et al., *Biodegradation and utilization of waste cooking oil by Yarrowia*
778 *lipolytica CECT 1240*. European Journal of Lipid Science and Technology 2010. **112**(11): p.
779 1200–1208.
- 780 109. Papanikolaou, S., et al., *Biotechnological conversion of waste cooking olive oil into lipid-rich*
781 *biomass using Aspergillus and Penicillium strains*. Journal of Applied Microbiology 2011.
782 **110**(5): p. 1138–1150.
- 783 110. Zhang, R., et al., *Characterization of food waste as feedstock for anaerobic digestion*.
784 Bioresource technology, 2007. **98**(4): p. 929-935.
- 785 111. Du, G., L.X.L. Chen, and J. Yu, *High-efficiency production of bioplastics from biodegradable*
786 *organic solids*. Journal of Polymers and the Environment, 2004. **12**(2): p. 89-94.
- 787 112. Bajaj, A., et al., *Biodiesel production through lipase catalyzed transesterification: An*
788 *overview*. Journal of Molecular Catalysis B: Enzymatic, 2010. **62**(1): p. 9-14.
- 789 113. Dijkstra, A.J., *Enzymatic degumming*. European Journal of Lipid Science and Technology,
790 2010. **112**(11): p. 1178-1189.
- 791 114. Moftah, O.A.S., et al., *Adding value to the oil cake as a waste from oil processing industry:*
792 *Production of lipase and protease by Candida utilis in solid state fermentation*. Applied
793 Biochemistry and Biotechnology, 2012. **166**(2): p. 348-364.
- 794 115. Edwinoliver, N.G., et al., *Scale up of a novel tri-substrate fermentation for enhanced*
795 *production of Aspergillus niger lipase for tallow hydrolysis*. Bioresource Technology, 2010.
796 **101**: p. 6791–6796.
- 797 116. Esakkiraj, P., et al., *Solid-state production of esterase using fish processing wastes by Bacillus*
798 *altitudinis AP-MSU*. Food and bioproducts processing, 2012. **90**: p. 370-376.
- 799 117. Sellami, M., et al., *Optimization of marine waste based-growth media for microbial lipase*
800 *production using mixture design methodology*. Environmental Technology, 2013. **34**(15): p.
801 2259-2266.
- 802 118. Toscano, L., et al., *Lipase production through solid-state fermentation using agro-industrial*
803 *residues as substrates and newly isolated fungal strains*. Biotechnology & Biotechnological
804 Equipment, 2013. **27**(5): p. 4074-4077.
- 805 119. Falony, G., et al., *Production of Extracellular Lipase from Aspergillus niger by Solid-State*
806 *Fermentation*. Food Technol. Biotechnol., 2006. **44**(2): p. 235-240.

807

808