SUPPLEMENTARY MATERIAL

Systematic evidence mapping to assess the sustainability of bioplastics derived from food waste: Do we know enough?

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A. LIST OF SEARCH TERMS AND STRINGS USED IN THIS SYSTEMATIC EVIDENCE MAP

All search terms from the following list (**Table S1**) were combined with OR Boolean operator forming the search builder *#29*.

Table S1. Search terms related to FLW as 2nd generation feedstock of bioplastics

Search builder	Feedstock search terms
#1	food NEAR/3 waste
#2	"secondary feedstock"
#3	organic NEAR/3 waste
#4	household NEAR/3 waste
#5	(post-consumer OR postconsumer) NEAR/3 waste
#6	industrial NEAR/3 waste
#7	catering NEAR/3 waste
#8	hospitality NEAR/3 waste
#9	"orange peel"
#10	bread or bake* NEAR/3 waste
#11	sugarcane
#12	"animal by-product" OR "animal byproduct"
#13	oil NEAR/3 waste
#14	dairy NEAR/3 waste
#15	butcher NEAR/3 waste
#16	fish NEAR/3 waste
#17	egg*
#18	(fruit OR vegetable) NEAR/3 waste
#19	starch
#20	(coffee OR tea OR cocoa) NEAR/3 waste
#21	brewer* NEAR/3 waste
#22	(wine* or vine*) NEAR/3 waste
#23	liqueur
#24	biomass
#25	whey
#26	agri* NEAR/3 waste
#27	restaurant
#28	biogas

All search terms from the following list (**Table S2**) were combined with OR Boolean operator forming the search builder *#40*.

Table S2. Search terms related to FLW-derived bioplastics

Search builder	Material search terms
#30	(biobased OR bio-based) NEAR/2 (plastic OR polymer*)
#31	bioplastic OR bio-plastic

#32	biodegradable NEAR/3 (plastic OR polymer*)
#33	polyhydroxyalkanoates OR PHA
#34	poly-4-hydroxybutyrate OR P4HB
#35	polyhydroxyvalerate OR PHV
#36	polyhydroxyhexanoate OR PHH
#37	polyhydroxyoctanoate OR PHO
#38	poly-3-hydroxybutyrate OR P3HB
#39	"polyactic acid" OR PLA

All search terms from the following list (**Table S3**) were combined with OR Boolean operator forming the search builder *#51*.

Table S3. Search terms related to sustainability assessment

Search builder	Method search terms
#41	sustainab* NEAR/3 (assessment OR analysis OR evaluation)
#42	environment* NEAR/3 (assessment OR analysis OR evaluation)
#43	"life cycle" OR lifecycle OR life-cycle NEAR/3 (assessment OR analysis OR evaluation)
#44	*economic* NEAR/3 (assessment OR analysis OR evaluation)
#45	socio* NEAR/3 (assessment OR analysis OR evaluation)
#46	social* NEAR/3 (assessment OR analysis OR evaluation)
#47	technological OR technical NEAR/3 (assessment OR analysis OR evaluation)
#48	cost-effectiveness NEAR/3 (assessment OR analysis OR evaluation)
#49	cost-benefit OR COBA NEAR/3 (assessment OR analysis OR evaluation)
#50	LCA OR LCIA OR LCSA NEAR/3 (assessment OR analysis OR evaluation)

After that the search builders *#29*, *#40* and *#51* were combined with AND Boolean operator in WoS and Scopus providing 3,468 number of hits in total.

B. ELIGIBLE STUDIES OF THIS SYSTEMATIC EVIDENCE MAP

Table S4. Eligible studies of this systematic evidence map that investigated the sustainability performance of FLW-derived bioplastics from a single or a multidimensional perspective

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
1	(Albizzati et al., 2021)	FW* in retail sector	Retail	Glucose	PLA	Environmental, economic and social	NA
2	(Albuquerque et al., 2011)	Fermented molasses	Processing	VFAs	PHAs	Technical	France
3	(Amini et al., 2020)	Rice wastewater	Processing	Fructose, glucose, sucrose, and maltose	P3HB-co-P3HV	Technical	Iran
4	(Asunis et al., 2021)	Cheese whey	Processing	VFAs	PHAs	Environmental	Italy
5	(Bastidas-Oyanedel and Schmidt, 2018)	FW*	Consumption	Volatile solids	PLA	Technical and economic	United Arab Emirates
6	(Bátori et al., 2017)	Orange waste	Processing	Pectine	Pectin-cellulose biofilm	Technical	Sweden
7	(Bhatia et al., 2018)	Spent coffee waste	Retail	Coffee waste oil	P(HBco-HHx)	Technical	South Korea

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
8	(Bishop et al., 2022)	FW* (raw and digestate)	Consumption	NA	NA	Environmental	Ireland
9	(Chalermthai et al., 2020)	Dairy waste whey	Processing	Organic acids	Protein-based plastic	Technical and economic	USA
10	(Colombo et al., 2017)	Organic fraction MSW	Consumption	Organic acids	PHAs	Technical	Italy
11	(Colombo et al., 2019)	Cheese whey	Processing	Lactose	PHAs	Technical	Italy
12	(Dinesh et al., 2020)	Rice husk hydrolysate, rice straw hydrolysate and rice mill wastewater	Primary production	Organic acids and sugars	PHB	Technical	India
		Dairy Industry Wastewater	Processing	Organic acids			
13	(Domingos et al., 2018)	Cheese whey	Processing	Carboxylic acids	PHAs	Technical	Italy
14	(Du et al., 2004)	Food scraps anaerobically treated	Consumption	Short-chain fatty acids (cetic, propionic, butyric, and lactic acids)	PHBV	Technical	Hawaii

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
15	(Eshtaya et al., 2013)	Restaurant waste	Consumption	Organic acids	PHB	Technical	Malaysia
16	(Farah et al., 2011)	Kitchen waste	Consumption	Organic acids	PHB	Technical	Malaysia
17	(Follonier et al., 2014)	Nine types of fruit pomace	Processing	Glucose and fatty acids	PHAs	Technical	Switzerland
18	(Gurieff and Lant, 2007)	Food industrial wastewater	Processing	VFAs	PHAs	Environmental and economic	Australia
19	(Hassan et al., 2019)	Waste of corn bran, corncob, wheat, bran, rice bran and sugarcane mollases and dairy waste	Primary production and processing	Sugars	PHB	Technical	Egypt
20	(Hafuka et al., 2011)	Fermented food-waste liquid	Consumption	VFAs	PHB	Technical	Japan
21	(Israni et al., 2020)	Whey	Processing	Lactose	PHAs	Technical	India
22	(Izaguirre et al., 2021)	Organic fraction of MSW**	Consumption	Sugars	P(3HB)	Environmental and economic	Spain
23	(Kamilah et al., 2018)	Palm oil-based waste cooking oil	Consumption	Fatty acids	P(3HB)	Technical	Malaysia
24	(Koller and Braunegg, 2015)	Slaughterhouse and rendering waste	Primary production	Fatty acids	PHB and PHBV	Technical	Austria

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
25	(Koller et al., 2013)	Whey	Processing	Lactose	PHAs	Environmental	Austria
26	(Kovalcik et al., 2018)	Spent coffee grounds	Consumption	Fermentable sugars	PHB	Technical	Czech Republic
27	(Kovalcik et al., 2020)	Grape winery waste	Processing	Glucose and fructose	PHB	Technical	Czech Republic
28	(Kwan et al., 2018)	Food waste (catering and bakery)	Consumption	Glucose	PLA	Technical	Hong Kong
29	(Loh and Chew, 2021)	Empty fruit bunch	Processing	Glucose & xylose	PHAs	Environmental and economic	Malaysia
30	(Możejko et al., 2011)	Waste rapeseed oil	Processing & Consumption	Fatty acids	PHAs	Technical	Poland
31	(Patel et al., 2018)	Corn stover	Primary production	Succinic acid and 1,4-butanediol	Bio-PBS	Environmental	Europe
32	(Pavan et al., 2019)	Citric molasses	Processing	Sucrose	PHB	Economic	Brazil
33	(Pérez et al., 2020a)	Organic fraction of MSW**	Consumption	CH4	PHAs	Economic	Spain
34	(Pérez et al., 2020b)	Organic fraction of MSW**	Consumption	CH4	PHAs	Environmental, economic and social	Spain
35	(Pleissner et al., 2014)	Bakery waste	Consumption	Glucose	PHB	Technical	Hong Kong

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
36	(Rajendran and Han, 2022a)	FW*	Consumption	Glucose	PLA	Technical and economic	(China, India, Brazil, and the USA) - conducted by Republic of Korea
37	(Rajendran and Han, 2022b)	FW*	Consumption	Glucose	PLA	Technical and economic	Republic of Korea
38	(Ratshoshi et al., 2021)	Bagasse and harvesting residues	Primary production	Glucose and xylose	PLA & PBS	Technical and economic	South Africa
39	(Rueda-Duran et al., 2022)	Sugarcane bagasse and coffee cut stems	Primary production	Glucose	PLA	Economic	Colombia
40	(Ryder et al., 2020)	Dairy wastewater	Processing	Caseine	Casein-based bioplastic films	Technical	New Zealand
41	(Saad et al., 2021)	Low-quality animal by-products	Primary production	Fat/protein-emulsions, mineral-fat-mixtures and fat greaves	P(HB-co-HHx)	Technical	Germany
42	(Salgaonkar et al., 2019)	Cassava waste	Primary production	Casava waste hydrolysate	P(3HB-co-3HV)	Technical	India

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
43	(Samer et al., 2022)	Potato peels	Processing	Starch	Starch-based bioplastic	Environmental	Egypt
44	(Sanjuan-Delmás et al., 2021)	Organic fraction of MSW**	Consumption	NA	NA	Environmental, economic and social	Belgium, Germany, Hungary
45	(Shah and Kumar, 2021)	Mixed flour from bread factory	Processing	Glucose, fructose, lactose, sucrose, maltose, and arabinose	PHAs	Technical	India
		Sugarcane molasses	Primary production				
		Mixed fruit pulp	Processing				
		Kitchen wastes	Consumption				
46	(Shahzad et al., 2013)	Slaughtering waste	Primary production	Fatty acids	PHAs	Environmental	NA
47	(Shahzad et al., 2017)	Slaughterhouse and rendering waste (offal and meat and bone meal)	Primary production	Fatty acids	PHAs	Economic	NA
48	(Shahzad et al., 2022)	Slaughtering residues	Primary production	Fatty acids	PHAs	Environmental	Saudi Arabia
49	(Tonini et al., 2021)	FW*	Consumption	NA	PLA	Environmental	NA

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
50	(Tyagi et al., 2018)	Residual sugar from sugarcane bagasse	Primary production	Glucose, fructose, maltose, sucrose	PHA	Technical	India
51	(Ugwu et al., 2012)	Non-edible rice	Primary production	Glucose	PHB	Technical	Japan
52	(Vastano et al., 2015)	Waste frying oils	Processing & Consumption	Fatty acids	PHAs	Technical	Italy
53	(Vastano et al., 2019)	Waste frying oils	Processing & Consumption	Fatty acids	PHAs	Technical	Italy
54	(Reddy and Mohan, 2012)	FW (unfermented and fermented)	Consumption	Fatty acids	P3(HB-co-HV)	Technical	India
55	(Verlinden et al., 2011)	Waste frying oil (rapeseed)	Processing & Consumption	Fatty acids	PHB	Technical	UK
56	(Yu et al., 1998)	Malt wastes from a beer brewery	Processing	Sucrose, lactic acid, butyric acid, valeric acid	PHV and PHB	Technical	Hong Kong
57	(Zhong et al., 2009)	Whey	Processing	Lactose	PHA	Environmental	Singapore
58	(Dionisi et al., 2005)	Olive oil mill effluents	Processing	Anaerobically fermented VFAs	[P(HB-HV)]	Technical	Italy
59	(Munoz and Riley, 2008)	Tequila bagasse	Primary production	Cellulose	PHA	Technical	USA
60	(Povolo et al., 2010)	Cheese whey	Processing	Lactose	PHA	Technical	Italy

No.	Author	FLW type	Stage of food value chain	Carbon source/ composition[1]	Bioplastic type	Sustainability perspective	Country[2]
61	(Hong et al., 2000)	Soy waste	Processing	Glucose	PHB	Technical	NA

*[1] As it is reported from the studies; [2] Refers to the country where the study was conducted – in case that that a specific origin was investigated within the context of sustainability assessment is also included; * Food waste; ** Municipal solid waste*

C. ELIGIBILITY STUDIES FOCUSED ON THE TECHNICAL ASPECT OF FLW-DERIVED BIOPLASTICS

Table S5. Eligible studies that focused on the technical aspect of FLW-derived bioplastics production according to this systematic evidence map.

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
PHV and PHB	Malt wastes from a beer brewery	Processing	Sucrose, lactic acid, butyric acid, valeric acid	Microbial fermentation (Alcaligenes eutrophus)	Hong Kong	The properties of bioplastics and therefore their technical performance can be formulated by selecting appropriate substrates (or combination of them) and microbial strains.	(Yu et al., 1998)
PHB	Waste frying oil (rapeseed)	Processing & Consumption	Fatty acids	Microbial fermentation (Alcaligenes eutrophus)	UK	A feed of waste frying oil could thus achieve more biopolymer (1.2 g/l) than pure vegetable oil (0.62 g PHA /l).	(Verlinden et al., 2011)
PHB	Bakery waste (hydrolysate with seawater)	Consumption	Glucose	Microbial fermentation (*Halomonas boliviensis*)	Hong Kong	Bakery waste forms a nutrient-complete medium for microbial growth and therefore PHB production (maximum PHB production: 2.6 g/l).	(Pleissner et al., 2014)
PHB	Waste of corn bran, corncob, wheat, bran, rice bran, sugarcane,	Primary production and processing	Mollases	Microbial fermentation (*Halomonas boliviensis*)	Egypt	Rice bran was the best carbon source for PHB production compared to other waste streams due to higher production yield (0.31 g/l) and due to the production of PHB with higher thermal stability; Cultural conditions that mostly affect the PHB	(Hassan et al., 2019)

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
	and dairy waste					production are pH, incubation time, and inoculum size	
PHBV	Food scraps anaerobically treated	Consumption	Short-chain fatty acids (acetic, propionic, butyric, and lactic acids)	Microbial fermentation (Ralstonia eutropha)	Hawaii	72.6% (w/w) PHA content obtained from organic solid wastes, which is comparable to the polymer content from glucose fermentation	(Du et al., 2004)
Pectin-Cellulose biofilm	Orange waste	Processing	Pectine	Direct extraction	Sweden	The tensile strength of the films was comparable to conventional plastic; the biodegradability of the films was confirmed under anaerobic conditions	(Bátori et al., 2017)
P(HB-co-HHx)	Low-quality animal by-products	Primary production and processing	Fat/protein-emulsions, mineral-fat-mixtures and fat greaves	Microbial fermentation (*Ralstonia eutropha*)	German y	The efficient production of PHA from animal by-products requires further investigation regarding the C/N ratio and the feeding method (incl., waste pre-treatment processes and hydrolysis for separation of macronutrients)	(Saad et al., 2021)
P(HBco-HHx)	SCG	Processing & Consumption	Coffee oil	Microbial fermentation (*Ralstonia eutropha*)	South Korea	Coffee waste oil is considered a comparable carbon source for PHA production compared to known oils, such as palm oil and waste cooking oil; the	(Bhatia et al., 2018)

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
						fermentation process resulted in 69% w/w of PHA accumulation	
PHAs	Various agro-industrial (i.e., mixed flour from bread factory, sugarcane molasses, and mixed fruit pulp) and kitchen wastes	Whole supply chain	Glucose, fructose, lactose, sucrose, maltose, and arabinose	Microbial fermentation (*Bacillus tropicus*)	India	The higher accumulation of PHAs was achieved by using domestic kitchen waste as carbon substrate (44.5%); The investigation of process parameters optimization showed that higher PHA yield took place under the presence of glucose as sole source of carbon	(Shah and Kumar, 2021)
PHB	Non-edible rice	Primary production	Glucose	Microbial fermentation (*Cupriavidus necator*)	Japan	PHB provided characteristics comparable to those obtainable with other carbon substrates based on its molecular weight distribution () and melting temperature (176oC); Proper implementation of simultaneous saccharification and fermentation process used for PHB production would help in	(Ugwu et al., 2012)

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
						reducing the production cost	
Casein-based bioplastic films	Dairy wastewater	Processing	Caseine	Direct extraction (dissolved air flotation)	New Zealand	Casein-based polymer was found to produce a brittle film, while the incorporation of additional biopolymers is required to enhance its properties	(Ryder et al., 2020)
Medium-chain-length PHAs	Waste frying oils	Processing & Consumption	Fatty acids	Microbial fermentation (*Escherichia coli*)	Italy	The potential exploitation of an E. coli recombinant system based on B. cereus 6E/2 PHA biosynthetic operon for valorisation of WFO into valuable products	(Vastano et al., 2015)
Medium-chain-length PHAs	Waste frying oils	Processing & Consumption	Fatty acids	Microbial fermentation (*Escherichia coli and P. resinovorans*)	Italy	Proper strain designing and process optimization allowed to achieve up to 1.5 g/l of biopolymer; The use of E. coli recombinant strains, although not satisfactory in terms of biopolymer yields, allowed to get a stable PHA composition, whatever was the supplied of waste oils	(Vastano et al., 2019)
Medium-chain-length PHAs	Waste rapeseed oil	Processing & Consumption	Fatty acids	Microbial fermentation (*Pseudomonas strains*)	Poland	The selected strains found to be capable of growing and accumulating PHAs with the use of waste rapeseed oil as a carbon source	(Możejko et al., 2011)

Biopolymer	**Waste type**	**Food supply chain**	**Substrate / carbon source**	**Production method**	**Country**	**Main outcome**	**Ref.**
P(3HB-co-3HV)	Cassava Waste	Primary production	Casava waste hydrolysate	Microbial fermentation (*Halogeometricum borinquense*)	India	The selected strain is an attractive candidate for production of co-polymer of P(3HB-co-3HV) with the use of agro-industrial waste as carbon source; Maximum PHA concentration was estimated at 1.52 g/l	(Salgaonkar et al., 2019)
Medium-chain-length PHAs	Nine types of fruit pomace	Processing and consumption	Glucose and fatty acids	Microbial fermentation (*Pseudomonas resinovorans*)	Switzerland	Solaris grapes provided the best production yield with 21.3 g PHA / l pomace, while apricots provided considerably lower yield estimated at 1.4 g/l	(Follonier et al., 2014)
[P(HB-HV)]	Olive oil mill effluents	Processing	Anaerobically fermented VFAs	Mixed microbial cultures	Italy	Fermentation is an important step in improving the overall performance of the process. Fermentation yield had a range of 25-36% at initial concentration of 36.7 g COD/L and VFA concentration had a range of 9-13 g COD/L including untreated and anaerobically fermented effluents.	(Dionisi et al., 2005)
PHB	Fermented canteen waste	EoL	Organic acids	Microbial fermentation (*Cupriavidus necator)*	Japan	The maximum PHB content in the PHB production reactor was 87%, with continuous feeding system being the most efficient.	(Hafuka et al., 2011)
PHA	Liquid bean curd	Processing	Sucrose	Microbial fermentation (*Alcaligenes Latus)*	Indonesia	Optimum conditions: initial sucrose concentration of 25 gr/l and time of incubation of 60 hours 18	(Kumalaningsih

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
	waste					minute resulting in the production of 2.48 gr/l PHA and the dry cell concentration of 66.56%.	et al., 2011)
PHA	Tequila Bagasse	Primary production	Cellulose	Microbial fermentation (*Saccharophagus degradans*)	USA	*S. degradans* has capabilities to hydrolyze crystalline cellulose and accumulate PHA. The PHA amount produced was ca. 1.5 mg/mL of total biomass.	(Munoz and Riley, 2008)
PHB	Fermented kitchen waste	EoL	Mixture of lactic and acetic acid	Microbial fermentation (*Cupriavidus necator CCGUG 52238*)	Malaysia	In batch fermentation, PHB content in cell mass was 84.54% and PHB yield was 0.38 g/g. By applying fetch-batch fermentation, the PHB productivity was increased 5 times compared to batch fermentation.	(Farah et al., 2011)
PHA	Cheese whey	Processing	Lactose	Microbial fermentation (*Cupriavidus necator DSM 545*)	Italy	The best strategy is to start from excellent PHA producing strains and try to confer them lacZ gene. The recombinant strains produced the polymer directly from lactose.	(Povolo et al., 2010)
[P3(HB-co-HV)]	FW & Fermented FW	Consumption & EoL	Fatty acids	Mixed microbial cultures	India	Integration of biohydrogen production along with PHA during acidogenic process showed increased treatment efficiency. Fermented FW provided higher PHA accumulation (39.6%) than	(Reddy and Mohan, 2012)

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
						unfermented FW (35.6%) due to ready availability of precursors (fatty acids).	
PHB	Soy waste	Processing	Glucose	Microbial fermentation (*Escherichia coli*)	NA	The cell dry weight and PHB content were 3.03 g/L and 27.8%, respectively. More research to improve the consumption of other carbon sources apart glucose in the use of FW as substrate.	(Hong et al., 2000)
PHA	Cheese whey	Processing	Organic acids	Mixed microbial cultures	Italy	PHA production yield estimated at 0.74 ± 0.14 mg COD_{PHA}/mg COD_{acid}), with polymer content of 55-62 g PHA/g VSS. The process could be adopted for a larger scale application.	(Colombo et al., 2019)
PHB	Grape pomace	Agriculture and Processing	Oil and fermentable sugars	Microbial fermentation (*Cupriavidus necator, Halomonas halophila and Halomonas organivorans*)	Czech Republic	*C. necator* found to be the best PHB producer. PHB production yield was 8.3 g/L of biomass with 63% PHB content in cell dry mass.	(Kovalcik et al., 2020)
PHB	SCG	Processing & Consumption	Sugars	Microbial fermentation (*Halomonas halophila*)	Czech Republic	The presence of high content of contaminants accompanied with the substrate inhibit the microbial activity making the detoxification of SCG hydrolysates with sorbent necessary (PHB	(Kovalcik et al., 2018)

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
						production yield: 0.95 g/L; PHB content in cell dry mass: 27%; Cell dry mass 3.52 g/L).	
PHA	Anaerobically treated cheese whey	Processing	VFAs	Pure microbial cultures (*Cupriavidus necator DSMZ 545*)	Italy	The anaerobic fermentation of whey in a PBBR system can be considered a robust process for producing VFAs. An electrodialysis step was proposed for the obtainment of a carboxylic acids concentrated stream. PHA production yield was estimated at 0.60 g PHAs/ g VFAs, while the concentration of VFAs was 63g/L waste.	(Domingos et al., 2018)
PHB	Fermented restaurant waste	Consumption	Organic acids	Microbial fermentation (*recombinant Escherichia coli pnDTM2*)	Malaysia	Optimum concentration (39.4 g/L) and yield (0.39 g/g) of organic acids estimated for waste incubation at 30°C and initial pH 7. The yield of PHB production was comparable with this of utilising pure acids.	(Eshtaya et al., 2013)
PHA	Organic fraction of MSW (OFMSW)	Consumption	Organic acids	Mixed microbial culture (acidogenic process)	Italy	The production of organic acids was 151 g/kg OFMSW and the production yield of PHA was 223 ± 28 g/kg acids. The PHA production was 33.22 ± 4.2 g/kg of fresh OFMSW and 114.4 ± 14.5 g/kg of total solids of OFMSW	(Colombo et al., 2017)

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
P3HB	Whey	Processing	Lactose	Microbial fermentation (B. megaterium Ti3)	India	The production yield of PHA was 2.20 ± 0.11 g/L in 48 h. A positive correlation was found between innate enzymes (protease and lipase) of *B. megaterium Ti3* and PHA production.	(Israni et al., 2020)
PHAs	Residual sugar from bagasse	Primary sector	Glucose, fructose, maltose, sucrose	Microbial fermentation (*ART_MKT2E*)	India	PHA accumulation was 55% for waste incubated at 37°C for 72 hours.	(Tyagi et al., 2018)
P3HB-co-P3HV	Rice wastewater	Processing	Starch	Microbial fermentation (*Azohydromonas lata*)	Iran	Maximum biopolymer content in cell (60%) was achieved when ammonium sulphate used as nitrogen source (C:N:P ratio: 100:4:1). The cell dry mass and production yield were 4.64 and 2.8 g/L respectively. Among various carbon sources, the maximum biopolymer was obtained from fructose (1.4 g l-1), including P (3HV) alone	(Amini et al., 2020)
P(3HB)	Palm oil-based waste cooking oil	Processing & consumption	Fatty acids	Microbial fermentation (*Cupriavidus necator H16*)	Malaysia	The waste substrate is suitable for cell growth and P(3HB) biosynthesis. Biopolymer content in cell mass was 60–80% P(3HB) with dry cell weight of 14–17 g/L.	(Kamilah et al., 2018)

Biopolymer	Waste type	Food supply chain	Substrate / carbon source	Production method	Country	Main outcome	Ref.
P(3HB-co-3HV)	Waste frying oil	Consumption	Fatty acids	Microbial fermentation (Nine *Halomonas* strains)	Czech Republic	*Halomonas hydrothermalis* is an interesting halophilic strain for PHA production of PHA (biopolymer content in cell dry mass: 23.76%, cell dry mass: 1.60 g/L, PHB amount: 0.38 g/L), still optimization of cultivation parameters in bioreactors is needed.	(Pernicova et al., 2019)

D. QUANTITATIVE DATA OBTAINED FROM SUSTAINABILITY ASSESSEMENTS OF FLW-DERIVED BIOPLASTICS

Table S6. Quantitative data obtained from eligible studies that conducted LCA of FLW-derived bioplastics.

						Environmental indicators											
LCA[1]	**FLW**	**Bioplastic type**	**FU[1]**	**Criterion based on different scenarios**	**Scenarios**	**GWP (kg CO2 eq. / FU) [1]**	**NRE (MJ / FU) [1]**	**AP (kg SO2 eq. / FU) [1]**	**FEP (kg P eq. / FU) [1]**	**MEP (kg N eq. / FU) [1]**	**FET (kg 1,4-DB eq. / FU) [1]**	**TET (kg 1,4-DB eq. / FU) [1]**	**MET (kg 1,4-DB eq. / FU) [1]**	**HT (kg 1,4-DB eq. / FU) [1]**	**WC (m³ / FU) [1]**	**ODP (kg CFC11 eq. / FU) [1]**	**Ref. [1]**
Cradle-to-gate	Potato peels	Starch-based bioplastic	1 kg of plastic	Feedstock generation	MAIN: Production of bioplastic from poptato peels	0.354-0.623					0.115-0.119			0.19-0.359			(Samer et al., 2022)
					ALTERNATIVE 1: Production of polypropylene (PP)	2.37					0.234			1.87			
Gate-to-grave (EoL)	NA	Polyester-complexed starch biopolymer	Composting of 1 tn of wet fraction	Type of plastics in the fraction of organic waste for composting	MAIN: Composting of organic waste mixed with fossl-based plastics and bioplastics (compostable and bio-based)	176		36.9	1.34E-02	1.16E-03	1.15E+00	1.01E+02	8.98E+03	7.41E+03	1.42E+00	2.58E-03	(Vinci et al., 2021)
					ALTERNATIVE 1: Composting of organic waste; absence of fossil-based plastics	57		38.1	2.06E-03	1.79E-04	6.25E-01	2.79E+01	2.63E+03	2.07E+03	7.96E-02	2.71E-03	
Gradle-to-grave	Corn stover	Bio-PBS	1 kg of plastic	Feedstock generation	MAIN: Bio-PBS from 2nd generation feedstock (i.e., crop residues)	2.3-2.7	36-47										(Patel et al., 2018)

LCA[1]	FLW	Bioplastic type	FU[1]	Criterion based on different scenarios	Scenarios	GWP (kg CO2 eq. / FU) [1]	NRE (MJ / FU) [1]	AP (kg SO2 eq. / FU) [1]	FEP (kg P eq. / FU) [1]	MEP (kg N eq. / FU) [1]	FET (kg 1,4-DB eq. / FU) [1]	TET (kg 1,4-DB eq. / FU) [1]	MET (kg 1,4-DB eq. / FU) [1]	HT (kg 1,4-DB eq. / FU) [1]	WC (m^3 / FU) [1]	ODP (kg CFC11 eq. / FU) [1]	Ref. [1]
					ALTERNATIVE 1: Bio-PBS from 1st generation feedstock (i.e., edible energy crops)	4.3-4.9	64-76										
					ALTERNATIVE 2: Partly 1st generation bio-PBS (bio-based succinic acid and fossil-based 1,4-butanediol)	5.5-6.1	79-91										
					ALTERNATIVE 3: Partly 2nd generation bio-PBS (bio-based succinic acid and fossil-based 1,4-butanediol)	4.9-5.5	68-80										
					ALTERNATIVE 4: Conventional plastics (PP, PET, PE)	4.2-5	60-75										
Cradle-to-gate	FW in retail sector	PLA	1 kg bioplastic	Feedstock generation	MAIN: 2nd generation PLA production	34											(Albizzati et al., 2021)
					ALTERNATIVE 1: maize-based PLA production (1st generation)	7.1											
				Avoiding conventional	MAIN: 2nd generation PLA	-42											

LCA[1]	FLW	Bioplastic type	FU[1]	Criterion based on different scenarios	Scenarios	Environmental indicators GWP (kg CO2 eq. / FU) [1]	NRE (MJ / FU) [1]	AP (kg SO2 eq. / FU) [1]	FEP (kg P eq. / FU) [1]	MEP (kg N eq. / FU) [1]	FET (kg 1,4-DB eq. / FU) [1]	TET (kg 1,4-DB eq. / FU) [1]	MET (kg 1,4-DB eq. / FU) [1]	HT (kg 1,4-DB eq. / FU) [1]	WC (m^3 / FU) [1]	ODP (kg CFC11 eq. / FU) [1]	Ref. [1]
				FW management option	production avoidng FW landfilling												
					ALTERNATIVE 1: 2nd generation PLA production avoidng AD	30.2											
					ALTERNATIVE 2: 2nd generation PLA production avoidng composting	29.4											
					ALTERNATIVE 3: 2nd generation PLA production avoidng incineration	32.7											
Cradle-to-gate	Cheese whey	PHAs	1 tn of waste	Process improvements	MAIN: Baseline dark fermentation and PHA production	44.8	604		3.84E-02	3.60E-01				2.47E-06	6.95 E+02	1.28E-05	(Asunis et al., 2021)
					ALTERNATIVE 1: Dark fermentation and PHA production (improvements in the PHA production yield: from 7.6 to 9.9 and 17.5 kg PHA/ t whey)	16-29.7											
					ALTERNATIVE 2: Dark fermentation	10.6											

						Environmental indicators											
LCA[1]	**FLW**	**Bioplastic type**	**FU**[1]	**Criterion based on different scenarios**	**Scenarios**	**GWP (kg CO2 eq. / FU)** [1]	**NRE (MJ / FU)** [1]	**AP (kg SO2 eq. / FU)** [1]	**FEP (kg P eq. / FU)** [1]	**MEP (kg N eq. / FU)** [1]	**FET (kg 1,4-DB eq. / FU)** [1]	**TET (kg 1,4-DB eq. / FU)** [1]	**MET (kg 1,4-DB eq. / FU)** [1]	**HT (kg 1,4-DB eq. / FU)** [1]	**WC (m^3 / FU)** [1]	**ODP (kg CFC11 eq. / FU)** [1]	**Ref.** [1]
					and PHA production (water reduction)												
					ALTERNATIVE 3: Dark fermentation and PHA production (improvement in extraction: use of dimethyl carbonate instead of NaOH and NaCl)	21.3											
				Conventional FW management option	MAIN 2: AD (combustion of biogas internally and application of digestate for land use)	-35.7	-713		-9.60E-03	1.13E-02				-2.08E-07	-2.56E+01	-6.88E-06	
Cradle-to-gate	empty fruit bunch	PHA	1 kg of plastic	Different pre-treatment and hydrolysis methods	MAIN: PHA production under chemical pre-treatment and acid hydrolysis	0.33											(Loh and Chew, 2021)
					ALTERNATIVE 1: PHA production under chemical pre-treatment and enzyme hydrolysis	0.29											
					ALTERNATIVE 2: PHA production under water washing	0.29											

LCA[1]	FLW	Bioplastic type	FU[1]	Criterion based on different scenarios	Scenarios	Environmental indicators GWP (kg CO2 eq. / FU) [1]	NRE (MJ / FU) [1]	AP (kg SO2 eq. / FU) [1]	FEP (kg P eq. / FU) [1]	MEP (kg N eq. / FU) [1]	FET (kg 1,4-DB eq. / FU) [1]	TET (kg 1,4-DB eq. / FU) [1]	MET (kg 1,4-DB eq. / FU) [1]	HT (kg 1,4-DB eq. / FU) [1]	WC (m^3 / FU) [1]	ODP (kg CFC11 eq. / FU) [1]	Ref. [1]
					pre-treatment and acid hydrolysis												
					ALTERNATIVE 3: PHA production under water washing pre-treatment and enzyme hydrolysis	0.24											
					ALTERNATIVE 4: PHA production under biological pre-treatment and acid hydrolysis	0.27											
					ALTERNATIVE 5: PHA production under biological pre-treatment and enzyme hydrolysis	0.23											
Cradle-to-grave	Organic waste	PLA	1 kg of plastic	Type of plastic	MAIN: PLA from organic waste (2nd generation) considering the EU-average EoL split for rigid packaging	19											(Toni ni et al., 2021)
					ALTERNATIVE 1: bio-HDPE from sugarcane (1st generation) considering the EU-average EoL split for rigid packaging	2.8											

LCA[1]	FLW	Bioplastic type	FU[1]	Criterion based on different scenarios	Scenarios	Environmental indicators GWP (kg CO2 eq. / FU) [1]	NRE (MJ / FU) [1]	AP (kg SO2 eq. / FU) [1]	FEP (kg P eq. / FU) [1]	MEP (kg N eq. / FU) [1]	FET (kg 1,4-DB eq. / FU) [1]	TET (kg 1,4-DB eq. / FU) [1]	MET (kg 1,4-DB eq. / FU) [1]	HT (kg 1,4-DB eq. / FU) [1]	WC (m^3 / FU) [1]	ODP (kg CFC11 eq. / FU) [1]	Ref. [1]
					ALTERNATIVE 2:recycled HDPE from post-consumer plastic waste considering the EU-average EoL split for rigid packaging	1.75											
					ALTERNATIVE 3: virgin HDPE from fossil fuels (conventional) considering the EU-average EoL split for rigid packaging	2.6											

1 LCA: Life cycle assessment; FU: Functional unit; GWP: Global warming potential; NRE: Non-renewable energy use; AP: Acidification potential; FEP: Freshwater eutrophication potential; MEP: Marine eutrophication potential; FET: Freshwater ecotoxicity; TET: Terrestrial ecotoxicity; MET: Marine ecotoxicity; HT: Human toxicity; WC: Water consumption; ODP: Ozone depletion potential; Ref.: Reference

Table S7. Quantitative data obtained from eligible studies that conducted economic assessment of FLW-derived bioplastics production.

FLW	Bioplastic type	Reactor	Operation time (d/y)	Production processes	FU[1]	Processing capacity (tn of unit / year)	Criterion based on different scenarios	Scenarios	CAPEX (US$ million) [1]	Operating cost (US$ million / year)	Unit production cost (US$ / kg main product)	NPV (US$ million)	ROI (%)[1]	Payback time (y)	Product selling price (US$ / kg)	Ref. [1]
Dairy waste whey	Protein-based plastic	Batch	330	1) Waste pre-treatment (pasteurization and centrifugation); 2) Production of whey protein concentrate (ultrafiltration, diafiltration, and spray drying); 2) Chemical processing (protein dissolution, methacrylation, polymerisation); 4) Plastic making (washing, centrifugation, drum drying)	1 tn of plastics	3,200	Different feedstock source	MAIN: Dairy waste whey	33.563	12.375	3.85	NA	27.1	3.69	7	(Chalermthai et al., 2020)
								ALTERNATIVE 1: Purchased whey protein concentrate	19.132	11.889	3.68	NA	42.2	2.37	7	
OFMSW supplemented with glucose and plum waste juice	P(3HB)	Fed-batch	330	1) thermo-chemical pre-treatment (i.e., grinding, addition of H2SO4 solution, and drying) and an enzymatic hydrolysis of OFMSW; 2) fermentation with *Burkholderia sacchari DSM 17165*: glucose and sugar-rich plum waste juice were also added as feed to enhance productivity	1 tn of processing waste	330	Different fermentation medium	MAIN: Use of enzymatic hydrolysate from OFMSW (and more extensive pre-treatment)	7.419	2.158	48	-18.213	-17	N/A	4	(Izaguirre et al., 2021)

FLW	Bioplastic type	Reactor	Operation time (d/y)	Production processes	FU[1]	Processing capacity (tn of unit / year)	Criterion based on different scenarios	Scenarios	CAPEX (US$ million) [1]	Operating cost (US$ million / year)	Unit production cost (US$ / kg main product)	NPV (US$ million)	ROI (%)[1]	Payback time (y)	Product selling price (US$ / kg)	Ref. [1]
				during cultivation; 3) P(3HB) extraction-separation												
Basal medium supplemented with glucose and plum waste juice				1) Less extensive pre-treatment (i.e., blending, filtration and sterilisation); 2) fermentation with Burkholderia sacchari DSM 17165: a basal medium that contained glucose and salts using plum waste juice as feed ; 3) P(3HB) extraction-separation				ALTERNATIVE 1: Use of basal medium	5.549	1.546	28	-12.163	-14	N/A	4	
Food waste (catering and bakery waste)	PLA	Batch	346	1) Pre-treatment to convert food waste into powder; 2) Fungal hydrolysis; 3) Lactic acid fermentation; 4) Ultrasonic solvent extraction; 5) Lactide synthesis and purification; 6) Ring opening polymerisation	1 tn FLW	83,000	Different product type	MAIN: Production of PLA	116.53	37.797	3.56	202.07	17.2	6.6	3.33	(Kwan et al., 2018)
								ALTERNATIVE 1: Production of lactic acid	96,769	26.641	1.07	234.80	22.9	5.1	2.07	
								ALTERNATIVE 2: Production of lactide (intermediate for PLA polymerisation)	104,576	32.416	2.27	104.76	11.1	9	0.94	
Processed food waste	PLA	NA	330	1) Milling and drying; 2) Oil extraction; 3) Biodiesel production; 4) Lactic acid production; 5) Lactic acid purification; 6) Lactide production; 7) PLA production	1 kg of plastic	50 tn of FW/ day	Country of production	MAIN: Integrated processes of biodiesel and PLA production in the USA	47.32	12.782	4.54	26.902	17.11	5.84	4.29	(Rajendran and Han, 2022a)
								ALTERNATIVE 1: Integrated processes of biodiesel and PLA production in Brazil	48.217	15.027	5.06	18.271	15.12	6.62	4.75	

FLW	Bioplastic type	Reactor	Operation time (d/y)	Production processes	FU[1]	Processing capacity (tn of unit / year)	Criterion based on different scenarios	Scenarios	CAPEX (US$ million) [1]	Operating cost (US$ million / year)	Unit production cost (US$ / kg main product)	NPV (US$ million)	ROI (%)[1]	Payback time (y)	Product selling price (US$ / kg)	Ref. [1]
								ALTERNATIVE 2: Integrated processes of biodiesel and PLA production in India	45.065	13.651	5.48	1.456	12.42	8.05	5.35	
								ALTERANTIVE 3: Integrated processes of biodiesel and PLA production in China	41.891	12.252	6.51	-12.532	8.35	11.98	6.53	
Processed food waste	PHAs	NA	330	1) Milling and drying; 2) Enzyme hydrolysis; 3) Fermentation; 4) Distillation; 5) Separation and purification	1 kg of plastic	50 tn of FW/ day	Change the solid loading in hydrolysis	MAIN: Integrated processes of biofuels (i.e, biohydrogen, bioethanol, and 2,3-butanediol) and PHAs production	42.834	13.876	20.95	4.471	13.68	7.31	4.83	(Rajendran and Han, 2022 b)
								ALTERNATIVE: Integrated processes of biofuels (i.e, biohydrogen, bioethanol, and 2,3-butanediol) and PHAs production increasing solid loading 30%				13.25			2.41	
Biogas from OFMSW	PHAs	Fed-batch	NA	1) Biogas desulfurization; 2) methanotrophic culture growth; 3) subsequent PHA accumulation; 4) extraction and purification	1 kg of plastic	300 tn/d	Biogas exploitation	MAIN: Biogas production and combustion for CHP generation	5.7	0.367		0.766	6.7	16		(Pérez et al., 2020 b)
								ALTERNATIVE 1: Biogas bioconversion into PHAs	7.4	5.1		> 0 (similar to the MAIN)	6.3	17	8.6	
								ALTERNATIVE 2: A combination of MAIN & ALTERNATIVE 1	7.8			> 0 (similar to the MAIN)	6.3	17	4.2	

FLW	Bioplastic type	Reactor	Operation time (d/y)	Production processes	FU[1]	Processing capacity (tn of unit / year)	Criterion based on different scenarios	Scenarios	CAPEX (US$ million) [1]	Operating cost (US$ million / year)	Unit production cost (US$ / kg main product)	NPV (US$ million)	ROI (%)[1]	Payback time (y)	Product selling price (US$ / kg)	Ref. [1]
Offal material, biodiesel, and meat and bone meal	PHA	Batch	333	ANIMPOL process (hydrolysis, rendering, biodiesel production and the biotechnological fermentation process)	1 tn of plastics	10000	Market value of waste (offal)	MAIN: PHA production from waste animal processing industry (offal has no market value (i.e., waste))	8.95	*51.7*	1.41	NA		3.5	4	(Shahzad et al., 2017)
								ALTERNATIVE: PHA production from waste animal processing industry (offal has market value: 1.3 €/kg)			1.64	NA		3.75		
Sugarcane bagasse	PLA		208	1) Steam explosion pre-treatment; 2) Hydrolysis and fermentation; 3) Gypsum free process; 4) Reactive distillation; 5) Lactide synthesis and recovery; 6) PLA synthesis and recovery	1 tn of plastics produced	150000	Biopolymer type	MAIN 1: Production of PLA from 2nd generation feedstock							3.87	(Ratshoshi et al., 2021)
								ALTERNATIVE 1.1: Production of PLA from 1st generation feedstock							3.32	
								ALTERNATIVE 1.2: Production of PLA from 1st and 2nd generation feedstock				1600			2.97	
	PBS			1) Dilute acid pre-treatment; 2) Enzymatic hydrolysis and fermentation (succinic acid and 1,4-butanediol); 3) Filtration; 4)				ALTERNATIVE 1: PBS production from 2nd generation feedstock							7.138	
								ALTERNATIVE 2.1: Production of PBS from 1st generation feedstock				764			2.98	

FLW	Bioplastic type	Reactor	Operation time (d/y)	Production processes	FU[1]	Processing capacity (tn of unit / year)	Criterion based on different scenarios	Scenarios	CAPEX (US$ million) [1]	Operating cost (US$ million / year)	Unit production cost (US$ / kg main product)	NPV (US$ million)	ROI (%)[1]	Payback time (y)	Product selling price (US$ / kg)	Ref. [1]
				Evaporation and distillation; 5) PBS synthesis and recovery				ALTERNATIVE 2.2: Production of PBS from 1st and 2nd generation feedstock							3.92	
Empty fruit bunch	PHA		330	1) Pre-treatment; 2) Hydrolysis; 3) Fermentation; 4) Recovery; 5) Purification	9000 tonnes of PHA	9000	Different pre-treatment and hydrolysis methods	MAIN: PHA production under chemical pre-treatment and acid hydrolysis	35.7258	4.8048		NA		7.01		(Loh and Chew, 2021)
								ALTERNATIVE 1: PHA production under chemical pre-treatment and enzyme hydrolysis	30.7758	3.9248		NA		5.15		
								ALTERNATIVE 2: PHA production under water washing pre-treatment and acid hydrolysis	30.844	3.9578		NA		5.19		
								ALTERNATIVE 3: PHA production under water washing pre-treatment and enzyme hydrolysis	26.4836	3.2318		NA		3.97		
								ALTERNATIVE 4: PHA production under biological pre-treatment and acid hydrolysis	29.4514	3.3418		NA		4.49		
								ALTERNATIVE 5: PHA production under biological pre-treatment and enzyme hydrolysis	25.2912	2.7412		NA		3.53		

FLW	Bioplastic type	Reactor	Operation time (d/y)	Production processes	FU[1]	Processing capacity (tn of unit / year)	Criterion based on different scenarios	Scenarios	CAPEX (US$ million) [1]	Operating cost (US$ million / year)	Unit production cost (US$ / kg main product)	NPV (US$ million)	ROI (%)[1]	Payback time (y)	Product selling price (US$ / kg)	Ref. [1]
Citric molasses	PHB	fed-batch	330	1) Pre-treatment; 2) Centrifugation; 3) Spray drying; 4) Extraction; 5) Filtration; 6) Precipitation; 7) Dring, biomass rinsing and solvent recovery	1 kg of plastic	2000	Different extraction pre-treatment process	MAIN: PHB production using Ultrasonication process	35.44	8.93	4.46	-22.27		17.6		(Pavan et al., 2019)
								ALTERNATIVE 1: PHB production using High temperature process	33.12	8.57	4.28	-17.48		14.1		
								ALTERNATIVE 2: PHB production using High pressure process	33.85	8.55	4.28	-18.14		12.9		
								ALTERNATIVE 1: PHB production without pre-treatment	36.02	9.45	4.72	-26.33		23.9		

[1] CPAEX: Capital investment cost; ROI: Return on investment; FU: Functional unit; NPV: Net present value; Ref.: References

E. INFLUENTIAL FACTORS ON THE ECONOMIC PERFORMANCE OF PHAs PRODUCTION FROM FLW

There are economic assessments of FLW-derived bioplastics that investigated the production of PHAs providing insights mainly into the production method using microbial cultures with a focus on fermentation parameters such as method, medium and microbial culture. Among submerged fermentation and solid-state fermentation – two of the most popular methods widely used in PHAs production – the latter is more cost-effective due to low water requirements, less pre-treatment and cheap cultivation media (Dutt Tripathi et al., 2021). The successful valorisation of crude whey in terms of economic aspect by using innate enzymes has been recently reported leading to the avoidance of waste pre-treatments and commercial enzymes costs (Israni et al., 2020).

The fermentation medium (i.e., sources of carbon, nitrogen, and other nutrients that meet the nutritional requirements of the microorganisms (Lekha and Lonsane, 1997)) has influence on the waste pre-treatment requirements, raw materials and energy use and the feedstock to product yield and therefore on the economic performance (Izaguirre et al., 2021). Specifically, the carbon to nitrogen (C/N) ratio is a critical parameter to the production yield since it affects the biopolymer accumulation in the microorganisms (Bhatia et al., 2018, Bhatia et al., 2021) (ratio of PHA weight to dry cell weight (Tyagi et al., 2018)) as well as phosphorous that might be more influential on biopolymer production compared to nitrogen as reported by a study on PHA production from rice wastewater (Amini et al., 2020). The source of nitrogen has influence on the productivity of catalytic biomass during growth phase and therefore the process recovery time, which in turn affects the selling price of biopolymer, e.g., inorganic nitrogen sources for cultivation such as ammonia are less efficient than hydrolysing complex organic nitrogen sources (Koller et al., 2005, Shahzad et al., 2017).

The agitation speed affects also the production yield, i.e., slower agitation decreases the cell growth, while higher agitation decreases the biopolymer accumulation (Bhatia et al., 2021). The effect of feeding regimens on production yields was investigated by (Hafuka et al., 2011) reporting that continuous feeding systems provide higher PHB production compared to one-pulse and intermittent feeding systems, while (Farah et al., 2011) reported a 5-fold increase of PHB production from fermented FW in fetch-batch fermentation (intermittent feeding) compared to batch fermentation. Furthermore, the method of hydrolysis may affect the production yield and consequently the economic performance of PHA production (Loh and Chew, 2021). For example, enzyme hydrolysis found to provide higher yields compared to acid hydrolysis for the production of PHA from empty fruit bunch (Loh and Chew, 2021).

High-performance microbial strains (Pagliano et al., 2017) and/or mixed microbial cultures using AD (i.e., more than one type of microorganisms) (Nielsen et al., 2017, Bastidas-Oyanedel and Schmidt, 2018, Gurieff and Lant, 2007) can improve the economic performance of the plants that produce

FWL-derived PHAs. Mixed microbial cultures are able to treat complex substrates compared to pure culture that are most costly (Brigham and Riedel, 2018, Bastidas-Oyanedel and Schmidt, 2018, Nielsen et al., 2017) due to high requirements for sterilization, aeration and agitation (Nielsen et al., 2017, Bhatia et al., 2021). However, in mixed microbial cultures biopolymer quality can vary due to various types of microorganisms (Brigham and Riedel, 2018), while mixed microbial cultures provide nearly 10 times lower production yields than pure cultures since bacterial growth might be inhibited by the production of the organic acids during fermentation (Nielsen et al., 2017, Albuquerque et al., 2011).

The bioconversion of FLW into bioplastics (i.e., PHAs) with the use of AD can be conducted using either an open system of mixed microbial cultures or an indirect coupling approach where volatile fatty acids (VFAs) are produced in a mixed culture and then are transferred through evaporation and ion exchange to a pure culture fermentation for biopolymer production (Nielsen et al., 2017). These two different approaches affect the techno-economic performance since the mixed culture is cheaper but provides low production yields and therefore profits, while the pure culture is more expensive but provided considerably higher production yields (Nielsen et al., 2017), i.e., microbial mixed cultures have lower storage capacity and growth rate of PHAs than pure cultures, while the dispersion of PHA content in cells is higher in mixed cultures lowering the extraction yield (Serafim et al., 2008).

PHA production through biogas bioconversion in waste treatment plants can be considered a realistic alternative to biogas use for CHP from economic perspective (Pérez et al., 2020b, Rostkowski et al., 2012, Pérez et al., 2020a, Gurieff and Lant, 2007). The biogas bioconversion into PHAs takes places through a fetch-batch strategy by which a mineral medium (e.g., $NaNO_3$) is supplied to the methanotrophic bacteria cultivation leading to biomass concentration in leachates followed by a nutrient-limiting stage where PHA accumulation occurs (Pérez et al., 2020b, Pérez et al., 2020a). This strategy can be rapidly implemented in the existing AD infrastructure (i.e., dry anaerobic digesters at industrial scale) (Colombo et al., 2017). Although, the capital and operational cost for biogas bioconversion is higher than biogas combustion due to high requirements of energy and raw materials, the economic performance of these processes can be comparable due to the higher sales revenues of PHA production (Pérez et al., 2020b). A techno-economic assessment reported that large scale production of PHB from CH_4 through methanotrophic fermentation and acetone-water solvent extraction can be competitive highlighting that thermophilic methanotrophs have the potential to reduce the production cost compared to mesophilic methanotrophs that require cooling of bioreactors through refrigeration (Levett et al., 2016). Optimising the operating conditions of bioreactor and biomass moisture content could support the design and economic development of CH_4 bioconversion (Levett et al., 2016).

REFERENCES

Albizzati, P. F., Tonini, D. & Astrup, T. F. 2021. High-value products from food waste: An environmental and socio-economic assessment. *Science of The Total Environment,* 755**,** 142466.

Albuquerque, M. G. E., Martino, V., Pollet, E., Avérous, L. & Reis, M. A. M. 2011. Mixed culture polyhydroxyalkanoate (PHA) production from volatile fatty acid (VFA)-rich streams: Effect of substrate composition and feeding regime on PHA productivity, composition and properties. *Journal of Biotechnology,* 151**,** 66-76.

Amini, M., Sobhani, S., Younesi, H., Abyar, H., Salamatinia, B. & Mohammadi, M. 2020. Evaluating the feasibility of poly (3-hydroxybutyrate-co-3-hydroxyvalerate) Co-biopolymer production from rice wastewater by Azohydromonas lata. *Applied Food Biotechnology,* 7**,** 73-83.

Asunis, F., De Gioannis, G., Francini, G., Lombardi, L., Muntoni, A., Polettini, A., Pomi, R., Rossi, A. & Spiga, D. 2021. Environmental life cycle assessment of polyhydroxyalkanoates production from cheese whey. *Waste Management,* 132**,** 31-43.

Bastidas-Oyanedel, J.-R. & Schmidt, J. E. 2018. Increasing Profits in Food Waste Biorefinery—A Techno-Economic Analysis. 11**,** 1551.

Bátori, V., Jabbari, M., Åkesson, D., Lennartsson, P. R., Taherzadeh, M. J. & Zamani, A. 2017. Production of Pectin-Cellulose Biofilms: A New Approach for Citrus Waste Recycling. *International Journal of Polymer Science,* 2017**,** 9732329.

Bhatia, S. K., Kim, J.-H., Kim, M.-S., Kim, J., Hong, J. W., Hong, Y. G., Kim, H.-J., Jeon, J.-M., Kim, S.-H., Ahn, J., Lee, H. & Yang, Y.-H. 2018. Production of (3-hydroxybutyrate-co-3-hydroxyhexanoate) copolymer from coffee waste oil using engineered Ralstonia eutropha. *Bioprocess and Biosystems Engineering,* 41**,** 229-235.

Bhatia, S. K., Otari, S. V., Jeon, J.-M., Gurav, R., Choi, Y.-K., Bhatia, R. K., Pugazhendhi, A., Kumar, V., Rajesh Banu, J., Yoon, J.-J., Choi, K.-Y. & Yang, Y.-H. 2021. Biowaste-to-bioplastic (polyhydroxyalkanoates): Conversion technologies, strategies, challenges, and perspective. *Bioresource Technology,* 326**,** 124733.

Bishop, G., Styles, D. & Lens, P. N. L. 2022. Land-use change and valorisation of feedstock side-streams determine the climate mitigation potential of bioplastics. *Resources, Conservation and Recycling,* 180**,** 106185.

Brigham, C. J. & Riedel, S. L. 2018. The potential of polyhydroxyalkanoate production from food wastes. *Applied Food Biotechnology,* 6**,** 7-18.

Chalermthai, B., Ashraf, M. T., Bastidas-Oyanedel, J.-R., Olsen, B. D., Schmidt, J. E. & Taher, H. 2020. Techno-Economic Assessment of Whey Protein-Based Plastic Production from a Co-Polymerization Process. *Polymers,* 12**,** 847.

Colombo, B., Favini, F., Scaglia, B., Sciarria, T. P., D'Imporzano, G., Pognani, M., Alekseeva, A., Eisele, G., Cosentino, C. & Adani, F. 2017. Enhanced polyhydroxyalkanoate (PHA) production from the organic fraction of municipal solid waste by using mixed microbial culture. *Biotechnology for Biofuels,* 10**,** 201.

Colombo, B., Villegas Calvo, M., Pepè Sciarria, T., Scaglia, B., Savio Kizito, S., D'Imporzano, G. & Adani, F. 2019. Biohydrogen and polyhydroxyalkanoates (PHA) as products of a two-steps bioprocess from deproteinized dairy wastes. *Waste Management,* 95**,** 22-31.

Dinesh, G. H., Nguyen, D. D., Ravindran, B., Chang, S. W., Vo, D.-V. N., Bach, Q.-V., Tran, H. N., Basu, M. J., Mohanrasu, K., Murugan, R. S., Swetha, T. A., Sivapraksh, G., Selvaraj, A. & Arun, A. 2020. Simultaneous biohydrogen (H2) and bioplastic (poly-β-hydroxybutyrate-PHB) productions under dark, photo, and subsequent dark and photo fermentation utilizing various wastes. *International Journal of Hydrogen Energy,* 45**,** 5840-5853.

Dionisi, D., Carucci, G., Papini, M. P., Riccardi, C., Majone, M. & Carrasco, F. 2005. Olive oil mill effluents as a feedstock for production of biodegradable polymers. *Water Research,* 39**,** 2076-2084.

Domingos, J. M. B., Puccio, S., Martinez, G. A., Amaral, N., Reis, M. A. M., Bandini, S., Fava, F. & Bertin, L. 2018. Cheese whey integrated valorisation: Production, concentration and

exploitation of carboxylic acids for the production of polyhydroxyalkanoates by a fed-batch culture. *Chemical Engineering Journal,* 336**,** 47-53.
Du, G., Chen, L. X. L. & Yu, J. 2004. High-Efficiency Production of Bioplastics from Biodegradable Organic Solids. *Journal of Polymers and the Environment,* 12**,** 89-94.
Dutt Tripathi, A., Paul, V., Agarwal, A., Sharma, R., Hashempour-Baltork, F., Rashidi, L. & Khosravi Darani, K. 2021. Production of polyhydroxyalkanoates using dairy processing waste – A review. *Bioresource Technology,* 326**,** 124735.
Eshtaya, M. K., Nor 'Aini, A. R. & Hassan, M. A. 2013. Bioconversion of restaurant waste into Polyhydroxybutyrate (PHB) by recombinant E. coli through anaerobic digestion. *International Journal of Environment and Waste Management,* 11**,** 27-37.
Farah, N. O., Norrsquo, Aini, A. R., Halimatun, S. H., Tabassum, M., Phang, L. Y. & Mohd, A. H. 2011. Utilization of kitchen waste for the production of green thermoplastic polyhydroxybutyrate (PHB) by Cupriavidus necator CCGUG 52238. *African Journal of Microbiology Research,* 5**,** 2873-2879.
Follonier, S., Goyder, M. S., Silvestri, A.-C., Crelier, S., Kalman, F., Riesen, R. & Zinn, M. 2014. Fruit pomace and waste frying oil as sustainable resources for the bioproduction of medium-chain-length polyhydroxyalkanoates. *International Journal of Biological Macromolecules,* 71**,** 42-52.
Gurieff, N. & Lant, P. 2007. Comparative life cycle assessment and financial analysis of mixed culture polyhydroxyalkanoate production. *Bioresource Technology,* 98**,** 3393-3403.
Hafuka, A., Sakaida, K., Satoh, H., Takahashi, M., Watanabe, Y. & Okabe, S. 2011. Effect of feeding regimens on polyhydroxybutyrate production from food wastes by Cupriavidus necator. *Bioresource Technology,* 102**,** 3551-3553.
Hassan, M. A., Bakhiet, E. K., Hussein, H. R. & Ali, S. G. 2019. Statistical optimization studies for polyhydroxybutyrate (PHB) production by novel Bacillus subtilis using agricultural and industrial wastes. *International Journal of Environmental Science and Technology,* 16**,** 3497-3512.
Hong, K., Leung, Y. C., Kwok, S. Y., Law, K. H., Lo, W. H., Chua, H. & Yu, P. H. F. 2000. Construction of recombinant Escherichia coli strains for polyhydroxybutyrate production using soy waste as nutrient. *Applied Biochemistry and Biotechnology,* 84**,** 381.
Israni, N., Venkatachalam, P., Gajaraj, B., Varalakshmi, K. N. & Shivakumar, S. 2020. Whey valorization for sustainable polyhydroxyalkanoate production by Bacillus megaterium: Production, characterization and in vitro biocompatibility evaluation. *Journal of Environmental Management,* 255**,** 109884.
Izaguirre, J. K., Barañano, L., Castañón, S., Santos, J. A. L., Cesário, M. T., da Fonseca, M. M. R., Alkorta, I. & Garbisu, C. 2021. Economic and environmental assessment of bacterial poly(3-hydroxybutyrate) production from the organic fraction of municipal solid waste. *Bioresources and Bioprocessing,* 8**,** 39.
Kamilah, H., Al-Gheethi, A., Yang, T. A. & Sudesh, K. 2018. The Use of Palm Oil-Based Waste Cooking Oil to Enhance the Production of Polyhydroxybutyrate [P(3HB)] by Cupriavidus necator H16 Strain. *Arabian Journal for Science and Engineering,* 43**,** 3453-3463.
Koller, M., Bona, R., Braunegg, G., Hermann, C., Horvat, P., Kroutil, M., Martinz, J., Neto, J., Pereira, L. & Varila, P. 2005. Production of Polyhydroxyalkanoates from Agricultural Waste and Surplus Materials. *Biomacromolecules,* 6**,** 561-565.
Koller, M. & Braunegg, G. 2015. Biomediated production of structurally diverse poly (hydroxyalkanoates) from surplus streams of the animal processing industry. *Polimery,* 60**,** 298-308.
Koller, M., Sandholzer, D., Salerno, A., Braunegg, G. & Narodoslawsky, M. 2013. Biopolymer from industrial residues: Life cycle assessment of poly(hydroxyalkanoates) from whey. *Resources, Conservation and Recycling,* 73**,** 64-71.
Kovalcik, A., Kucera, D., Matouskova, P., Pernicova, I., Obruca, S., Kalina, M., Enev, V. & Marova, I. 2018. Influence of removal of microbial inhibitors on PHA production from spent coffee grounds employing Halomonas halophila. *Journal of Environmental Chemical Engineering,* 6**,** 3495-3501.

Kovalcik, A., Pernicova, I., Obruca, S., Szotkowski, M., Enev, V., Kalina, M. & Marova, I. 2020. Grape winery waste as a promising feedstock for the production of polyhydroxyalkanoates and other value-added products. *Food and Bioproducts Processing,* 124**,** 1-10.

Kumalaningsih, S., Hidayat, N. & Aini, N. 2011. Optimization of polyhydroxyalkanoates (PHA) production from liquid bean curd waste by Alcaligenes latus bacteria. *Journal of Agriculture and Food Technology,* 1**,** 63-67.

Kwan, T. H., Hu, Y. & Lin, C. S. K. 2018. Techno-economic analysis of a food waste valorisation process for lactic acid, lactide and poly(lactic acid) production. *Journal of Cleaner Production,* 181**,** 72-87.

Lekha, P. K. & Lonsane, B. K. 1997. Production and Application of Tannin Acyl Hydrolase: State of the Art. *In:* NEIDLEMAN, S. L. & LASKIN, A. I. (eds.) *Advances in Applied Microbiology.* Academic Press.

Loh, Y. Z. & Chew, I. M. L. 2021. Mitigating plastic pollution through better process design: an opportunity from biomass to bioplastic. *Biomass Conversion and Biorefinery*.

Możejko, J., Przybyłek, G. & Ciesielski, S. 2011. Waste rapeseed oil as a substrate for medium-chain-length polyhydroxyalkanoates production. *European Journal of Lipid Science & Technology,* 113**,** 1550-1557.

Munoz, L. A. & Riley, M. R. 2008. Utilization of cellulosic waste from tequila bagasse and production of polyhydroxyalkanoate (PHA) bioplastics by Saccharophagus degradans. *Biotechnology and Bioengineering,* 100**,** 882-888.

Nielsen, C., Rahman, A., Rehman, A. U., Walsh, M. K. & Miller, C. D. 2017. Food waste conversion to microbial polyhydroxyalkanoates. *Microbial biotechnology,* 10**,** 1338-1352.

Pagliano, G., Ventorino, V., Panico, A. & Pepe, O. 2017. Integrated systems for biopolymers and bioenergy production from organic waste and by-products: a review of microbial processes. *Biotechnology for Biofuels,* 10**,** 113.

Patel, M. K., Bechu, A., Villegas, J. D., Bergez-Lacoste, M., Yeung, K., Murphy, R., Woods, J., Mwabonje, O. N., Ni, Y. & Patel, A. D. 2018. Second-generation bio-based plastics are becoming a reality–Non-renewable energy and greenhouse gas (GHG) balance of succinic acid-based plastic end products made from lignocellulosic biomass. *Biofuels, Bioproducts & Biorefining,* 12**,** 426-441.

Pavan, F. A., Junqueira, T. L., Watanabe, M. D. B., Bonomi, A., Quines, L. K., Schmidell, W. & de Aragao, G. M. F. 2019. Economic analysis of polyhydroxybutyrate production by Cupriavidus necator using different routes for product recovery. *Biochemical Engineering Journal,* 146**,** 97-104.

Pérez, V., Lebrero, R. & Muñoz, R. 2020a. Comparative Evaluation of Biogas Valorization into Electricity/Heat and Poly(hydroxyalkanoates) in Waste Treatment Plants: Assessing the Influence of Local Commodity Prices and Current Biotechnological Limitations. *ACS Sustainable Chemistry & Engineering,* 8**,** 7701-7709.

Pérez, V., Mota, C. R., Muñoz, R. & Lebrero, R. 2020b. Polyhydroxyalkanoates (PHA) production from biogas in waste treatment facilities: Assessing the potential impacts on economy, environment and society. *Chemosphere,* 255**,** 126929.

Pernicova, I., Kucera, D., Nebesarova, J., Kalina, M., Novackova, I., Koller, M. & Obruca, S. 2019. Production of polyhydroxyalkanoates on waste frying oil employing selected Halomonas strains. *Bioresource Technology,* 292**,** 122028.

Pleissner, D., Lam, W. C., Han, W., Lau, K. Y., Cheung, L. C., Lee, M. W., Lei, H. M., Lo, K. Y., Ng, W. Y., Sun, Z., Melikoglu, M. & Lin, C. S. K. 2014. Fermentative Polyhydroxybutyrate Production from a Novel Feedstock Derived from Bakery Waste. *BioMed Research International,* 2014**,** 819474.

Povolo, S., Toffano, P., Basaglia, M. & Casella, S. 2010. Polyhydroxyalkanoates production by engineered Cupriavidus necator from waste material containing lactose. *Bioresource Technology,* 101**,** 7902-7907.

Rajendran, N. & Han, J. 2022a. Integrated polylactic acid and biodiesel production from food waste: Process synthesis and economics. *Bioresource Technology,* 343**,** 126119.

Rajendran, N. & Han, J. 2022b. Techno-economic analysis of food waste valorization for integrated production of polyhydroxyalkanoates and biofuels. *Bioresource Technology,* 348**,** 126796.

Ratshoshi, B. K., Farzad, S. & Görgens, J. F. 2021. Techno-economic assessment of polylactic acid and polybutylene succinate production in an integrated sugarcane biorefinery. *Biofuels, Bioproducts & Biorefining,* 15**,** 1871-1887.

Reddy, M. V. & Mohan, S. V. 2012. Influence of aerobic and anoxic microenvironments on polyhydroxyalkanoates (PHA) production from food waste and acidogenic effluents using aerobic consortia. *Bioresource Technology,* 103**,** 313-321.

Rueda-Duran, C.-A., Ortiz-Sanchez, M. & Cardona-Alzate, C. A. 2022. Detailed economic assessment of polylactic acid production by using glucose platform: sugarcane bagasse, coffee cut stems, and plantain peels as possible raw materials. *Biomass Conversion and Biorefinery*.

Ryder, K., Ali, M. A., Billakanti, J. & Carne, A. 2020. Evaluation of Dairy Co-product Containing Composite Solutions for the Formation of Bioplastic Films. *Journal of Polymers and the Environment,* 28**,** 725-736.

Saad, V., Gutschmann, B., Grimm, T., Widmer, T., Neubauer, P. & Riedel, S. L. 2021. Low-quality animal by-product streams for the production of PHA-biopolymers: fats, fat/protein-emulsions and materials with high ash content as low-cost feedstocks. *Biotechnology Letters,* 43**,** 579-587.

Salgaonkar, B. B., Mani, K. & Bragança, J. M. 2019. Sustainable Bioconversion of Cassava Waste to Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) by Halogeometricum borinquense Strain E3. *Journal of Polymers and the Environment,* 27**,** 299-308.

Samer, M., Hijazi, O., Mohamed, B. A., Abdelsalam, E. M., Amer, M. A., Yacoub, I. H., Attia, Y. A. & Bernhardt, H. 2022. Environmental impact assessment of bioplastics production from agricultural crop residues. *Clean Technologies and Environmental Policy,* 24**,** 815-827.

Sanjuan-Delmás, D., Taelman, S. E., Arlati, A., Obersteg, A., Vér, C., Óvári, Á., Tonini, D. & Dewulf, J. 2021. Sustainability assessment of organic waste management in three EU Cities: Analysing stakeholder-based solutions. *Waste Management,* 132**,** 44-55.

Serafim, L. S., Lemos, P. C., Albuquerque, M. G. E. & Reis, M. A. M. 2008. Strategies for PHA production by mixed cultures and renewable waste materials. *Applied Microbiology and Biotechnology,* 81**,** 615-628.

Shah, S. & Kumar, A. 2021. Production and characterization of polyhydroxyalkanoates from industrial waste using soil bacterial isolates. *Brazilian Journal of Microbiology,* 52**,** 715-726.

Shahzad, K., Kettl, K.-H., Titz, M., Koller, M., Schnitzer, H. & Narodoslawsky, M. 2013. Comparison of ecological footprint for biobased PHA production from animal residues utilizing different energy resources. *Clean Technologies and Environmental Policy,* 15**,** 525-536.

Shahzad, K., Narodoslawsky, M., Sagir, M., Ali, N., Ali, S., Rashid, M. I., Ismail, I. M. I. & Koller, M. 2017. Techno-economic feasibility of waste biorefinery: Using slaughtering waste streams as starting material for biopolyester production. *Waste Management,* 67**,** 73-85.

Shahzad, K., Rehan, M., Rashid, M. I., Ali, N., Summan, A. S. & Ismail, I. M. I. 2022. Sustainability Evaluation of Polyhydroxyalkanoate Production from Slaughterhouse Residues Utilising Emergy Accounting. 14**,** 118.

Tonini, D., Schrijvers, D., Nessi, S., Garcia-Gutierrez, P. & Giuntoli, J. 2021. Carbon footprint of plastic from biomass and recycled feedstock: methodological insights. *Iinternationa Journal of Life cyce Assessment* 26**,** 221-237.

Tyagi, P., Saxena, N. K. & Sharma, A. 2018. Production of polyhydroxyalkanoates (PHA) from a non-lignocellulosic component of sugarcane bagasse: fueling a biobased economy. *Biofuels, Bioproducts and Biorefining,* 12**,** 536-541.

Ugwu, C. U., Tokiwa, Y. & Aoyagi, H. 2012. Utilization of Broken Rice for the Production of Poly(3-hydroxybutyrate). *Journal of Polymers and the Environment,* 20**,** 254-257.

Vastano, M., Casillo, A., Corsaro, M. M., Sannia, G. & Pezzella, C. 2015. Production of medium chain length polyhydroxyalkanoates from waste oils by recombinant Escherichia coli. *Engineering in Life Sciences,* 15**,** 700-709.

Vastano, M., Corrado, I., Sannia, G., Solaiman, D. K. Y. & Pezzella, C. 2019. Conversion of no/low value waste frying oils into biodiesel and polyhydroxyalkanoates. *Scientific Reports,* 9**,** 13751.

Verlinden, R. A. J., Hill, D. J., Kenward, M. A., Williams, C. D., Piotrowska-Seget, Z. & Radecka, I. K. 2011. Production of polyhydroxyalkanoates from waste frying oil by Cupriavidus necator. *AMB Express,* 1**,** 11.
Vinci, G., Ruggieri, R., Billi, A., Pagnozzi, C., Di Loreto, M. V. & Ruggeri, M. 2021. Sustainable Management of Organic Waste and Recycling for Bioplastics: A LCA Approach for the Italian Case Study. 13**,** 6385.
Yu, P. H., Chua, H., Huang, A. L., Lo, W. & Chen, G. Q. 1998. Conversion of food industrial wastes into bioplastics. *Applied Biochemistry and Biotechnology,* 70**,** 603-614.
Zhong, Z. W., Song, B. & Huang, C. X. 2009. Environmental Impacts of Three Polyhydroxyalkanoate (PHA) Manufacturing Processes. *Materials and Manufacturing Processes,* 24**,** 519-523.