sustainability

MDPI

Supplementary Materials

Assessment of Dehydration as a Commercial-Scale Food Waste Valorization Strategy

Table S1. Full list of parameters tested.

Number	Parameter
1	pH (liquid)
2	moisture content
3	total volatile solids
4	total solids
5	dry matter (DM)
6	crude protein (CP)
7	soluble protein (SP)
8	acid detergent fiber (ADF)
9	neutral detergent fiber (a NDF)
10	lignin
11	fat
12	total mineral content (ash)
13	non-fiber carbohydrates (NFC)
14	relative feed value (RFV)
15	total digestible nutrients (TDN)
16	net energy for lactation (NE l)
17	net energy for maintenance (NE m)
18	net energy for gain (NE g)
19	metabolizable energy (ME)
20	digestible energy (DE)
21	calcium (Ca)
22	phosphorus (P)
23	magnesium (Mg)
24	potassium (K)
25	sodium (Na)
26	iron (Fe)
27	zinc (Zn)
28	copper (Cu)
29	manganese (Mn)
30	molybdenum (Mo)
31	sulfur (S)
32	starch
33	water soluble carbs (WSC)
34	gross energy
35	pH (solids)
36	carbon (C)
37	nitrogen (N)

Table S2. Measured density of output materials from five sources.

	Trial #	Mass (g)	Volume (mL)	Density (g/cm³)	Average Density (g/cm³)	Density (kg/m³)	Average Density (kg/m³)	Density (lb/gal)	Average Density (lb/gal)
Cafeteria	1	77.7	90	0.86	0.86	863.3	857.3	7.2	7.1
	2	79.7	90	0.89		885.6		7.4	
	3	82.3	100	0.82		823.0		6.9	
Hospital	1	75.9	100	0.76	0.79	759.0	785.9	6.3	6.5
	2	86.6	110	0.79		787.3		6.6	
	3	56.8	70	0.81		811.4		6.8	
Grocery	1	70.8	100	0.71	0.77	708.0	766.7	5.9	6.4
	2	79.2	100	0.79		792.0		6.6	
	3	56.0	70	0.80		800.0		6.7	
Food Bank	1	63.6	70	0.91	0.87	908.6	871.1	7.6	7.3
	2	78.3	90	0.87		870.0		7.2	
	3	96.0	115	0.83		834.8		7.0	
Restaurant	1	53.3	60	0.89	0.88	888.3	880.6	7.4	7.3
	2	77.7	90	0.86		863.3		7.2	
	3	71.2	80	0.89		890.0		7.4	
		Averages			**0.83**	**832.3**		**6.9**	

Table S3. Total solids and total volatile solids triplicate measurement data for output (dehydrated food waste).

Sample	W-crucible (g)	W-sample (g)	W-dry (g)	W-incinerate (g)	TS%	TVS%
C1	89.2528	19.6208	108.5924	90.5987	98.57	91.71
C2	22.7067	10.2012	32.7771	23.3914	98.72	92.01
C3	25.5851	10.4811	35.9025	26.4072	98.44	90.59
R1	87.5001	19.8464	107.4082	90.2429	100.31	86.49
R2	26.4075	10.2001	36.0738	27.9144	94.77	79.99
R3	25.7424	9.7673	35.0584	27.1524	95.38	80.94
H1	92.5443	21.3700	113.3571	93.8995	97.39	91.05
H2	26.4582	10.2235	36.4173	27.4020	97.41	88.18
H3	29.2732	10.5342	39.5283	30.2027	97.35	88.53
G1	83.5070	20.6590	103.7980	84.9054	98.22	91.45
G2	16.6255	4.6041	21.1487	16.8538	98.24	93.28
G3	25.5114	10.0998	35.4259	26.3819	98.17	89.55
F1	90.7917	21.1278	110.4638	93.0828	93.11	82.27
F2	89.4702	20.6015	108.3214	91.7193	91.50	80.59
F3	25.4197	11.1169	35.8282	26.9926	93.63	79.48

Table S4. Total solids and total volatile solids triplicate measurement data for input.

(raw food waste)

Sample	W-crucible (g)	W-sample (g)	W-dry (g)	W-incinerate (g)	TS%	TVS%
C1	89.2566	22.1700	96.1085	89.6402	30.91	29.18
C2	22.7063	14.8689	27.2453	22.9687	30.53	28.76
C3	25.5780	14.7530	30.0612	25.8297	30.39	28.68
R1	87.5141	20.6639	92.6818	88.6175	25.01	19.67
R2	26.4048	11.7820	29.3927	27.1072	25.36	19.40
R3	25.7382	13.8778	29.3181	26.5926	25.80	19.64
H1	92.5367	20.4600	97.7266	92.743	25.37	24.36
H2	26.4545	13.9333	30.0008	26.6054	25.45	24.37
H3	29.2711	11.9465	32.2955	29.3957	25.32	24.27
G1	83.5010	21.9330	89.8044	83.7943	28.74	27.40
G2	16.6240	8.8765	19.1578	16.7425	28.55	27.21
G3	25.5048	14.0549	29.5596	25.6968	28.85	27.48
F1	90.7843	23.6557	93.4977	91.0573	11.47	10.32
F2	89.4679	18.8922	91.2045	89.6683	9.19	8.13
F3	25.4170	10.6998	26.5089	25.5333	10.20	9.12

Table S5. Data collection for five sources of food waste processed through Ecovim-66.

Source	Input Composition	Input Mass (kg)	Output Composition	Output Mass (kg)	% Mass Reductio n	pH (liquid)	kWh/cycle	Notes
Cafeteria	50/50 pre-consumer to post-consumer food waste	22.68	Smooth.	6.99	69%	3.16	24.59	Quite homogeneous output, looks like coffee grounds.
Restaurant	Mostly post-consumer some prep; many citrus rinds.	-	Citrus rinds did not break down, fibrous material remained as well.	3.45	-	3.06	20.26	Condensate water color was quite yellow.
Hospital	Mostly patient tray waste, some prep (about 1/8), very wet and mixed with Municipal Solid Waste (MSW) off trays. Paper napkins, etc. were too wet to remove.	22.68	Some materials did not break down, but overall quite smooth.	4.58	80%	3.25	23.02	Very wet, dish room empties liquids into bags, too. Tried to separate out as best we could. Some non-organics present, did not break down.
Grocery	Pre-waste many totes, pineapple, pizza, salad bar, prep, baked bread, meat/seafood, pasta combos	22.68	Smooth, coffee-like consistency.	6.44	72%	3.22	23.72	Resembles soil.
Food Bank	Various canned goods—beans, beets, beef broth, corn, purees, asparagus, string beans, artichokes, etc.	22.68	Smooth.	2.90	91%	2.97	24.85	Very wet input, but zero contamination

Table S6. Parameter analytical methods.

No.	Parameter	Test Location	Method
1	pH (liquid)	RIT	The food waste was centrifuged and pH of the supernatant was measured using a Mettler Toledo SevenCompact pH meter.
2	moisture content	Dairy One	Calculated from dry matter value and initial sample weight.
3	total volatile solids	RIT	U.S. Environmental Protection Agency (EPA), Method 1684, "Total, Fixed, and Volatile Solids in Water, Solids, and Biosolids," EPA-821-R-01-015, January 2001.
4	total solids	RIT	U.S. Environmental Protection Agency (EPA), Method 1684, "Total, Fixed, and Volatile Solids in Water, Solids, and Biosolids," EPA-821-R-01-015, January 2001.
5	dry matter (DM)	Dairy One	Two step oven—initial at 60 °C for 4 h, grind, then residual moisture determination in oven at 135 °C for 2 h.
6	crude protein (CP)	Dairy One	Dry, 1 mm ground samples analyzed by combustion using a CN628 Carbon/Nitrogen Determinator. Liquid samples analyzed using a TruMac N Macro Determinator.
7	soluble protein (SP)	Dairy One	Cornell Sodium Borate-Sodium Phosphate Buffer Procedure. Soy products incubated at 39 °C. All other samples incubated at ambient temperature. Residue containing insoluble protein analyzed using Leco TruMac N Macro Determinator.
8	acid detergent fiber (ADF)	Dairy One	ANKOM Technology Method 12 – Acid Detergent Fiber in Feeds – Filter Bag Technique (for A2000 and A2000l), 05/19/2017. Solutions as in AOAC 973.18—Fiber (Acid Detergent) and Lignin (H2SO4) in Animal Feed. Samples individually weighed at 0.5 g into filter bags and digested for 75 min as a group of 24 in 2 L of ADF solution in ANKOM A2000 Digestion Unit. Samples are rinsed three times with boiling water for 5 min in filter bags followed by a 3-min acetone soak and drying at 105 °C for 2 h.
9	neutral detergent fiber (a NDF)	Dairy One	ANKOM Technology Method 13—Neutral Detergent Fiber in Feeds—Filter Bag Technique (for A2000 and A2000l), 05/19/2017 Solutions as in Van Soest, P.J., J.B. Robertson, and B.A. Lewis. 1991. Methods for Dietary Fiber, Neutral Detergent Fiber, and Nonstarch Polysaccharides in Relation to Animal Nutrition. J.Dairy Science 74:3583-3597. Samples individually weighed at 0.5g into filter bags and digested for 75 min as a group of 24 in 2 L of NDF solution in ANKOM A2000 Digestion Unit. Four ml Alpha Amylase and 20g sodium sulfite are added at the start of digestion. Samples are rinsed three times with boiling water for 5 min. Four ml Alpha Amylase is added to the first two rinses. Water rinses are followed by a 3-min acetone soak and drying at 105 °C for 2 h.
10	lignin	Dairy One	ANKOM Technology Method 9—Method for Determining Acid Detergent Lignin in the DaisyII Incubator—01/24/2017. Solution as in AOAC 973.18—Fiber (Acid Detergent) and Lignin (H2SO4) in Animal Feed. ADF performed as above and residue digested as a group of 24 in 72% w/w sulfuric acid for 3 h in ANKOM DaisyII Incubator at ambient temperature.
11	fat	Dairy One	AOAC 2003.05—Crude Fat in Feeds, Cereal Grains, and Forages. Dairy One Forage Lab, Equi-Analytical, Zooquarius Analytical Procedures Page 3 of 10. Extraction by Soxtec HT6 System using anhydrous diethyl ether. Crude fat residue determined gravimetrically after drying.
12	total mineral content (ash)	Dairy One	AOAC Method 942.05—Ash of Animal Feed. Ignition at 600 °C for 2 h.

13	non fiber carbohydrates (NFC)	Dairy One	NFC is calculated as 100%—(CP% + (NDF% − NDICP%) + Fat% + Ash%).
14	relative feed value (RFV)	Dairy One	RVF is an index for ranking forages based on digestibility and intake potential. RFV is calculated from ADF and NDF. A RFV of 100 is considered the average score and represents an alfalfa hay containing 41% ADF and 53% NDF on a dry matter basis.
15	TDN	Dairy One	Sum of digestible protein, digestible NSC, digestible NDF, and 2.25X digestible fat
16	net energy for lactation (NE l)	Dairy One	Energy requirements are determined for maintenance, growth or gain, lactation, reproduction, and activity level. Energy values are not measured, rather they are predicted using equations and relationships with other nutrients. Dairy One uses a multiple component summative approach for its ruminant energy prediction system.
17	net energy for maintenance (NE m)	Dairy One	
18	net energy for gain (NE g)	Dairy One	
19	metabolisable energy (ME)	Dairy One	
20	digestible energy (DE)	Dairy One	
21	calcium (Ca)	Dairy One	Samples digested using CEM Microwave Accelerated Reaction System (MARS6) with MarsXpress Temperature Control using 50ml calibrated Xpress Teflon PFA vessels with Kevlar/fiberglass insulating sleeves then analyzed by ICP using a Thermo iCAP 6300 Inductively Coupled Plasma Radial Spectrometer. Sample weights—0.5 g for forages, ingredients, byproducts (1.0 g for Co or Cr); 0.5 g for grain mixes; 0.2 g for mineral mixes; Manure—0.5 g dried, ground or 2–10g wet sample. Samples first pre-digested at ambient temperature 10 minutes with 8mL nitric acid (HNO_3) and 2 mL hydrochloric acid (HCl) and then an additional 10 min with 1mL 30% hydrogen peroxide (H_2O_2). After pre-digestion complete, samples digested in two stages: Stage one—10-min ramp to 135 °C and held for 3 minutes at 1500W. Stage two—12-minute ramp to 200 °C and held for 15 min at 1600W. Vessels brought to 50-mL volume, aliquot used for analysis.
22	phosphorus (P)	Dairy One	
23	magnesium (Mg)	Dairy One	
24	potassium (K)	Dairy One	
25	sodium (Na)	Dairy One	
26	iron (Fe)	Dairy One	
27	zinc (Zn)	Dairy One	
28	copper (Cu)	Dairy One	
29	manganese (Mn)	Dairy One	
30	molybdenum (Mo)	Dairy One	
31	sulfur (S)	Dairy One	
32	starch	Dairy One	YSI 2950D-1 or 2700 SELECT Biochemistry Analyzers Samples are pre-extracted for sugar by incubation in 40 °C water bath and filtration on Whatman 41 filter paper. Residues are thermally solubilized using an autoclave, then incubated with glucoamylase enzyme to hydrolyze starch to produce dextrose (glucose). Prepared samples injected into sample chamber of YSI Analyzer where dextrose diffuses into a membrane containing glucose oxidase. The dextrose is immediately oxidized to hydrogen peroxide and D-glucono-4-lactone. The hydrogen peroxide is detected amperometrically at the platinum electrode surface. The current flow at the

			electrode is directly proportional to the hydrogen peroxide concentration, and hence to the dextrose concentration. Starch is determined by multiplying dextrose by 0.9.
33	water soluble carbs (WSC)	Dairy One	Samples incubated with water in a 40 °C bath for 1 h extracting water soluble carbohydrates composed of simple sugars and fructan. WSC determined using a Thermo Scientific Genesys 10S Vis Spectrophotometer after acid hydrolysis with sulfuric acid and colorimetric reaction with potassium ferricyanide.
34	gross energy	Dairy One	Gross energy (gross calorific value) of solid and liquid materials expressed as calories per gram (cal/g) using an IKA C2000 basic Calorimeter System. Instrument is set to IKA’s dynamic mode with an outer vessel temperature set at 25 °C and calibrated with benzoic acid. Analysis time is 7–12 min. Dried samples weighed into polyethylene bags. Oil type samples weighed into gelatin capsules. Samples placed in a crucible, then ignited in an oxygen rich atmosphere in a sealed decomposition vessel where the increase in temperature of the system is measured. Dairy One Forage Lab, Equi-Analytical, Zooquarius Analytical Procedures Page 5 of 10. The specific gross calorific value of the sample is calculated from the weight of the sample, the heat capacity of the calorimeter determined from calibration standards, and the increase in temperature of the water within the inner vessel of the measuring cell.
35	pH (solids)	Dairy One	H Feed and Forage—15 g wet sample placed into 250-mL beaker. 200mL deionized water added, stirred, and allowed to stabilize for five minutes. Analyzed using Thermo Orion Combination Sure-Flow pH Electrode and Thermo Orion 410 A meter. Calibrated with buffers referenced to NIST SRMs. pH 4 buffer contains potassium hydrogen phthalate and pH 7 buffer contains sodium phosphate dibasic and potassium phosphate monobasic.
36	carbon (C)	Dairy One	Dry, 1mm ground samples analyzed using a Leco CN628 Carbon/Nitrogen Determinator. Leco Application Note—“Carbon/Nitrogen in Soil and Plant Tissue” Form No. 203-821-442 11/14—Rev1 Leco Corporation, 300 Lakeview Avenue, St. Joseph, MI 49085. www.leco.com
37	nitrogen (N)	Dairy One	Nitrogen (N) is calculated by dividing the measured C:N into C, which are both metrics given in the carbon (C) parameter above.

Table S7. Optimal ranges.

Fertilizer	**5-5-5 NPK is a commonly accepted concentration in the gardening community. Selected the acceptable range of pH from [30]. We chose 5.5 as the starting point as that is where the majority of crops grown start.**
Compost	C:N ratio and moisture content came from Dickson et al. [17]. pH was taken from Cooperbrand [18]; we slightly adjusted the upper limit down to 8.5 from 9.0.
Biochar	Joseph et al. [22] was used to determine the optimal moisture content percentage.
Fish Feed	Craig et al. [23] is where all six optimal ranges came from.
Cattle Feed	Optimal ranges were taken from *Nutrient requirements of beef cattle* [25,27,28].
Pelletized Fuel	Chandrasekaran et al. [29] was used as the reference for the optimal range.

Table S8. Measured output sample parameters.

Output samples (all in %)	Crude protein (DM basis)	TN/TKN	carbon	DM	TOC
Food bank	22.8	3.64	46	93	42.78
Grocery	21.7	3.47	53	97.1	51.46
Restaurant	21.1	3.37	49.3	95.3	46.98
Cafeteria	19.1	3.05	52	97.6	50.75
Hospital	20.2	3.23	50.5	95.6	48.27
Juice Processor	25	4	51	79.8	40.69
Tofu Processor	27.3	4.368	51.7	99.4	51.38
Avg. (excluding food processors)	21.0	3.4	50.2	95.7	48.1
Avg. (including processors)	22.5	3.6	50.5	94.0	47.5

References

1. Rethink food waste through economics and data. A roadmap to reduce U.S. food waste by 20 percent. Available online: https://www.refed.com/downloads/ReFED_Report_2016.pdf (accessed on 13 December 2016).
2. Lin, C.S.K.; Pfaltzgraff, L.A.; Herrero-Davila, L.; Mubofu, E.B.; Abderrahim, S.; Clark, J.H.; Koutinas, A.A.; Kopsahelis, N.; Stamatelatou, K.; Dickson, F. et al. Food waste as a valuable resource for the production of chemicals, materials and fuels: Current situation and global perspective. *Energy Environ. Sci.* **2013**, *6*, 426–464.
3. Hegde, S.; Lodge, J.S.; Trabold, T.A. Characteristics of food processing wastes and their use in sustainable alcohol production. *Renew. Sustain. Energy Rev.* **2018**, *81*, 510–523.
4. Xu, F.; Li, Y.; Ge, X.; Yang, L.; Li, Y. Anaerobic digestion of food waste: Challenges and opportunities. *Bioresour. Technol.* **2018,** *247*, 1047–1058.
5. Pinacho, A.; García-Encina, P.A.; Sancho, P.; Ramos, P.; Márquez, M.C. Study of drying systems for the utilization of biodegradable municipal solid wastes as animal feed. *Waste Manag.* **2006**, *26*, 495–503.
6. San Martin, D.; Ramos, S.; Zufía, J. Valorisation of food waste to produce new raw materials for animal feed. *Food Chem.* **2016**, *198*, 68–74.
7. Hall, M. Techno-environmental analysis of generating animal feed from wasted food products. Master's thesis, Rochester Institute of Technology, Rochester, New York, July 2016.
8. Sotiropoulos, A.; Malamis, D.; Loizidou, M. Dehydration of domestic food waste at source as an alternative approach for food waste management. *Waste Biomass Valoriz.* **2015**, *6*, 167–176.
9. Sotiropoulos, A.; Bava, N.; Valta, K.; Vaakalis, S.; Panaretou, V.; Novacovic, J.; Malamis, D. Household food waste dehydration technique as a pretreatment method for food waste minimization. *Int. J. Environ. Waste Manag.* **2016**, *17*, 273–286.
10. Sotiropoulos, A.; Malamis, D.; Michailidis, P.; Krokida, M.; Loizidou, M. Research on the drying kinetics of household food waste for the development and optimization of domestic waste drying technique. *Environ. Technol.* **2016**, *37*, 929–939.
11. Balaskonis, A.; Vakalis, S.; Sotiropoulos, A. Comparison of 3 household food waste dryers in the context of food waste prevention and bioeconomy. *SN Appl. Sci.* **2019**, *1*, 648. doi:10.1007/s42452-019-0667-1
12. Karthikeyan, O.P.; Trably, E.; Mehariya, S.; Bernet, N.; Wong, J.W.; Carrere, H. Pretreatment of food waste for methane and hydrogen recovery: A review. *Bioresour. Technol.* **2018**, *249*, 1025-1039.

13. Sotiropoulos, A.; Vourka, I.; Erotokritou, A.; Novakovic, J.; Panaeetou, V.; Vakalis, S.; Thanos, T.; Moustakas, K.; Malamis, D. Combination of decentralized waste drying and SSF techniques for household biowaste minimization and ethanol production. *Waste Manag.* **2016**, *52*, 353–359.
14. Ecovim. Available online: http://www.ecovimusa.com/products/ (accessed on 5 January 2017).
15. *Handbook of plant nutrition*. Barker, A.V., Pilbeam, D.J., Eds.; CRC press: Boca Raton, FL, USA, 2015.
16. Longstroth, M. Soil test before you plant blueberries. Available online: https://www.canr.msu.edu/news/soil_test_before_you_plant_blueberries (accessed on 17 January 2017).
17. Dickson, N.; Richard, T.; Kozlowski, R. *Composting to reduce the waste stream-A guide to small scale food and yard waste composting*; Northeast Regional Agricultural Engineering Service: Ithaca, NY, USA, 1991.
18. Cooperband, L. The art and science of composting. Available online: https://www.cias.wisc.edu/wp-content/uploads/2008/07/artofcompost.pdf (accessed on 23 January 2017).
19. Vakalis, S.; Sotiropoulos, A.; Moustakas, K.; Malamis, D.; Vekkos, K.; Baratieri, M. Thermochemical valorization and characterization of household biowaste. *J. Environ. Manag.* **2017**, *203*, 648–654.
20. *Biochar for environmental management: Science, technology and implementation*, 2nd ed.; Lehmann, J., Joseph, S. Eds.; Routledge: London, UK, 2015.
21. Ahmed, I.I.; Gupta, A.K. Pyrolysis and gasification of food waste: Syngas characteristics and char gasification kinetics. *Appl. Energy* **2010**, *87*, 101–108.
22. Joseph, S.; Taylor, P.; Cowie, A. Basic Principles and Practice of Biochar Production and Kiln Design. Available online: https://biochar.international/guides/basic-principles-of-biochar-production/#introduction (accessed on 25 January 2017).
23. Craig, S.; Helfrich, L.A.; Kuhn, D.; Schwarz, M.H. Understanding fish nutrition, feeds, and feeding. Available online: https://fisheries.tamu.edu/files/2019/01/FST-269.pdf (accessed on 7 November 2016)
24. Rust, M.; Barrows, F.T.; Hardy, R.W.; Lazur, A.M. Naughten, K.; Silverstein, J.T. Available online: https://spo.nmfs.noaa.gov/sites/default/files/tm124.pdf (accessed on 7 November 2016)
25. *Nutrient requirements of beef cattle*, 8th ed.; National Academies Press: Washington, DC, USA, 2016.
26. Hall, J.B. Nutrition and feeding of the cow-calf herd: Production cycle nutrition and nutrient requirements of cows, pregnant heifers and bulls. Available online: https://www.pubs.ext.vt.edu/400/400-012/400-012.html (accessed on 10 November 2016)
27. Hilton, W.M. Merck Vet Manual. Available online: https://www.merckvetmanual.com/management-and-nutrition/nutrition-beef-cattle/nutritional-requirements-of-beef-cattle (accessed on 13 December 2016).
28. University of Georgia Extension. Mineral Supplements for Beef Cattle. Available online: https://secure.caes.uga.edu/extension/publications/files/pdf/B%20895_4.PDF (accessed on 11 January 2017).
29. Chandrasekaran, S.R.; Hopke, P.K.; Rector, L.; Allen, G.; Lin, L. Chemical composition of wood chips and wood pellets. *Energy Fuels* **2012**, *26*, 4932–4937.
30. Mosaic. Soil PH. Available online: https://www.cropnutrition.com/nutrient-management/soil-ph (accessed on 13 January 2017).