sustainability

MDPI

Suplementary material

Neural Network for AI-Driven Prediction of Larval Protein Yield: Establishing the Protein Conversion Index (PCI) for Sustainable Insect Farming

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Table S1. Data base

Moisture (%)	Crude protein (%)	Carbohydrates (%)	Ash (%)	Fat (%)	Larval crude protein (%)	Reference
56,4	17,57	9,37	3,36	13,3	41,9	[1]
88,9	1,24	8,94	0,65	0,27	37,65	[1]
53,7	7,45	23,15	6,81	8,89	42,2	[1]
36	15,49	31,42	5,12	11,97	44,4	[1]
51,3	8,81	8,96	3,94	26,98	46,2	[1]
57,6	10,35	15,18	3,01	13,86	39,9	[1]
62,2	5,9	6,92	3,55	21,43	37,9	[1]
45,1	11,42	19,49	10,54	13,45	38,4	[1]
11,53	28,3	51,21	4,19	4,77	41,9	[1]
36,03	15,3	32,87	7,55	8,24	23,19	[2]
19,6	13,88	16,14	0,93	49,45	21,71	[2]
37,46	7,12	28,76	6,75	19,91	24,34	[2]
51,3	14,15	27,83	4,56	2,16	37,3	[2]
82	9,61	0,36	1,08	6,95	44,2	[3]
88,9	1,37	8,06	0,56	1,12	41,3	[3]
75,7	5,42	13,37	1,73	3,79	39,2	[3]
85,5	4,05	5,42	1,02	4,02	44,1	[3]
58,8	7,33	24,72	0	9,15	39,6	[3]
62,3	12,29	13,72	2,66	9,03	42,8	[3]
68,8	7,55	11,86	4,68	7,11	41,6	[3]
78,1	8,5	6,79	3,29	3,33	39,1	[3]
82,5	3,82	6,81	3,05	3,83	39,6	[3]
91,7	2,32	1,49	0	4,48	40	[3]
71,3	4,22	5,74	9,66	9,08	42,6	[3]
10,76	26,97	52,13	3,94	6,21	41,3	[3]
80	7,52	4,7	6,24	1,48	49,5	[4]
68,3	9,8	15,66	2,22	4,03	51,5	[4]

71,3	5,91	20,52	1,29	0,98	43,4	[4]
68,9	8,12	18,6	1,34	3,05	59,8	[4]
4,89	69,73	0,99	14,84	9,55	34,94	[5]
2,64	41,6	8,92	18,87	27,97	34,83	[5]
2,32	73,26	1,92	13,18	9,32	34,47	[5]
3,45	49,52	6,7	27,46	12,87	34,29	[5]
6,75	58,28	18,87	13,99	2,11	55,1	[6]
82,28	1,41	13,6	2,26	0,44	38,98	[6]
65,9	4,54	20,26	2,76	6,55	42,2	[7]
75,9	7,04	10,48	1,79	4,79	43,54	[7]
82,28	3,58	6,34	1,36	6,44	39,52	[7]
86,6	0,4	8,9	4	0,1	28,72	[8]
92,3	2	2,4	3,1	0,2	55,05	[8]
89,5	1,2	5,6	3,5	0,2	49,72	[8]
29,3	10,75	33,43	5,86	20,67	38,27	[9]
24,42	13,74	41,06	7,63	13,15	48,93	[9]
19,79	10,8	44,32	5,24	19,85	44,52	[9]
25,07	15,04	32,07	6,17	21,65	32,97	[9]
9	7,74	40,95	7,55	34,76	52,3	[10]
13,7	18,99	49,3	8,72	9,29	37,2	[10]
7	29,02	47,71	5,49	10,79	44,6	[10]
10,38	26,38	49,34	3,33	10,58	40,3	[10]
67,03	2,04	29,8	1,13	0	62,3	[11]
61,67	6,93	19,56	1,2	10,63	38,93	[11]
60,2	7,87	27,76	2,07	2,1	55,31	[11]
68,6	2,58	27,11	1,71	0	52,2	[11]
64,23	2,46	18,22	13,52	1,57	39	[11]
65,67	9,13	14,6	1,2	9,4	55,1	[11]
64,27	5,67	22,42	5,5	2,14	53,1	[11]
91,73	0,98	5,7	0,75	0,84	41,88	[12]
59,85	6,78	14,37	2,85	16,14	41,44	[13]
65,25	15,67	9,9	3,16	6,02	43,9	[14]
65,25	15,67	12,16	2,78	4,14	46,3	[14]
11,83	9,26	0,79	6,63	71,49	53,29	[14]
37,89	7,06	1,01	7,09	46,96	45,8	[14]
17,35	8,79	2,73	9	62,13	47,15	[14]
39,93	6,79	4,17	6,23	42,88	48,16	[14]
10,4	7,85	1,54	4,93	75,28	43,98	[14]
35,06	5,68	3,86	5,28	50,12	45,3	[14]
12,52	7,63	0,76	7,22	71,87	45,82	[14]
35,22	5,98	1,06	5,22	52,52	50,34	[14]
11,83	9,26	0,79	6,63	71,49	53,29	[14]
37,89	7,06	1,01	7,09	46,96	45,8	[14]
17,35	8,79	2,73	9	62,13	47,15	[14]
39,93	6,79	4,17	6,23	42,88	48,16	[14]
10,4	7,85	1,54	4,93	75,28	43,98	[14]

35,06	5,68	3,86	5,28	50,12	45,3	[14]
12,52	7,63	0,76	7,22	71,87	45,82	[14]
35,22	5,98	1,06	5,22	52,52	50,34	[14]
66,3	2,76	15,54	1,48	13,92	28	[15]
65,91	3,68	14,93	1,54	13,94	39,1	[15]
65,52	4,62	14,31	1,62	13,93	42,7	[15]
65,13	5,58	13,66	1,73	13,89	44,8	[15]
4,9	16,07	57,9	4,66	16,47	37,6	[16]
13,07	14,33	63,42	4,7	4,48	41,1	[16]
6	13,35	38,26	4,79	37,6	30,2	[17]
83,23	3,59	10,39	0,89	1,9	30,12	[18]
73,8	4,11	16,19	1,18	4,72	43,1	[19]
74,2	4,52	10,97	2,97	7,35	41,2	[19]
87,3	1,09	5,7	1,37	4,53	39,9	[19]
75,7	5,98	0,17	7,27	10,89	42,2	[19]
7,9	15,66	45,87	12,43	18,14	52,8	[20]
81,7	7,17	1,37	0,76	9	51,2	[20]
5,1	28	16,42	5,12	45,36	53,4	[20]
84,2	2,5	1,77	0,65	10,88	54,1	[20]
11,57	26,82	52,3	3,67	5,64	37,4	[21,22]
12,38	25,31	53,04	3,33	5,94	39,9	[21,22]
12,1	24,07	55,48	2,66	5,69	40,6	[21,22]
9,91	24,97	55,04	4,63	5,44	39,8	[21,22]
9,17	28,51	49,78	3,92	8,61	45,7	[21,22]
19,51	17,82	54,82	4,67	3,18	31,7	[21,22]
18,24	18,25	57,53	3,34	2,64	29,9	[21,22]
18,79	15,51	59,42	3,5	2,78	31,8	[21,22]
18,66	17,64	55,65	3,83	4,21	44,6	[21,22]
64,2	4,2	27,91	3,69	0	34,43	[23]
76,79	4,65	17,03	0,92	0,6	52,96	[23]

Table S2. Layer 1 Weights (W1)

Neuron	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5
Neuron 1	-2.0724	-2.7289	5.5386	2.8684	-3.5536
Neuron 2	10.1698	-5.5078	3.5189	-3.6035	4.5868
Neuron 3	-1.1233	1.0295	-4.0393	-4.1591	5.3534
Neuron 4	4.0477	-0.2156	0.0479	-0.8541	0.9371

Table S3. Layer 2 Weights (W2)

Neuron	Weight 1	Weight 2	Weight 3	Weight 4
Neuron 1	-2.3069	-8.9110	2.5015	2.6267
Neuron 2	-0.1823	-4.9254	2.6223	-0.8652
Neuron 3	-4.5113	-0.0883	-3.7903	0.7029
Neuron 4	-6.0148	2.1865	-5.5467	-1.1866

Table S4. Output layer (W3)

Neuron	Weight 1	Weight 2	Weight 3	Weight 4
Neuron 1	3.3567	-6.4333	10.8760	-6.3423

Table S5. Biases for Each Layer

Layer	Bias for Neuron 1	Bias for Neuron 2	Bias for Neuron 3	Bias for Neuron 4
Layer 1 (b1)	1.6040	-7.3382	-0.1595	-2.5531
Layer 2 (b2)	5.0689	3.0887	1.2361	3.5187
Layer 3 (b3)	2.0630			

References

1. Hosseindoust, A.; Ha, S.H.; Mun, J.Y.; Kim, J.S. A Metanalysis to Evaluate the Effects of Substrate Sources on the Nutritional Performance of Black Soldier Fly Larvae: Implications for Sustainable Poultry Feed. *Poult Sci* 2024, *103*, 103299, doi:10.1016/J.PSJ.2023.103299.
2. Taufek, N.M.; Mohamad Zulkifli, N.F.N.; Hamizah, A.N. Upcycling of Food Waste Generated from the Fresh Market by Utilising Black Soldier Fly Larvae: Influence on Growth, Bioconversion, and Nutritional Composition. *J Environ Manage* 2024, *349*, 119467, doi:10.1016/J.JENVMAN.2023.119467.
3. Lalander, C.; Diener, S.; Zurbrügg, C.; Vinnerås, B. Effects of Feedstock on Larval Development and Process Efficiency in Waste Treatment with Black Soldier Fly (Hermetia Illucens). *J Clean Prod* 2019, *208*, 211–219, doi:10.1016/J.JCLEPRO.2018.10.017.
4. Eggink, K.M.; Lund, I.; Pedersen, P.B.; Hansen, B.W.; Dalsgaard, J. Biowaste and By-Products as Rearing Substrates for Black Soldier Fly (Hermetia Illucens) Larvae: Effects on Larval Body Composition and Performance. *PLoS One* 2022, *17*, doi:10.1371/JOURNAL.PONE.0275213.
5. Arena, R.; Manuguerra, S.; Curcuraci, E.; Cusimano, M.; Lo Monaco, D.; Di Bella, C.; Santulli, A.; Messina, C.M. Fisheries and Aquaculture By-Products Modulate Growth, Body Composition, and Omega-3 Polyunsaturated Fatty Acid Content in Black Soldier Fly (Hermetia Illucens) Larvae. *Frontiers in Animal Science* 2023, *4*, doi:10.3389/fanim.2023.1204767.
6. Nyakeri, E.M.; Ogola, H.J.; Ayieko, M.A.; Amimo, F.A. An Open System for Farming Black Soldier Fly Larvae as a Source of Proteins for Smallscale Poultry and Fish Production. *J Insects Food Feed* 2017, *3*, 51–56, doi:10.3920/JIFF2016.0030.
7. Hosseindoust, A.; Ha, S.H.; Mun, J.Y.; Kim, J.S. Quality Characteristics of Black Soldier Flies Produced by Different Substrates. *Insects 2023, Vol. 14, Page 500* 2023, *14*, 500, doi:10.3390/INSECTS14060500.
8. Jucker, C.; Erba, D.; Leonardi, M.G.; Lupi, D.; Savoldelli, S. Assessment of Vegetable and Fruit Substrates as Potential Rearing Media for Hermetia Illucens (Diptera: Stratiomyidae) Larvae. *Environ Entomol* 2017, *46*, 1415–1423, doi:10.1093/EE/NVX154.
9. Adebayo, H.A.; Kemabonta, K.A.; Ogbogu, S.S.; Elechi, M.C.; Obe, M.T. Comparative Assessment of Developmental Parameters, Proximate Analysis and Mineral Compositions of Black Soldier Fly (Hermetia Illucens) Prepupae Reared on Organic Waste Substrates. *Int J Trop Insect Sci* 2021, *41*, 1953–1959, doi:10.1007/S42690-020-00404-4/TABLES/4.
10. Tschirner, M.; Simon, A. Influence of Different Growing Substrates and Processing on the Nutrient Composition of Black Soldier Fly Larvae Destined for Animal Feed. *J Insects Food Feed* 2015, *1*, 249–259, doi:10.3920/JIFF2014.0008.

11. Naser El Deen, S.; van Rozen, K.; Elissen, H.; van Wikselaar, P.; Fodor, I.; van der Weide, R.; Hoek-van den Hil, E.F.; Rezaei Far, A.; Veldkamp, T. Bioconversion of Different Waste Streams of Animal and Vegetal Origin and Manure by Black Soldier Fly Larvae Hermetia Illucens L. (Diptera: Stratiomyidae). *Insects* 2023, *14*, doi:10.3390/INSECTS14020204.
12. Meneguz, M.; Schiavone, A.; Gai, F.; Dama, A.; Lussiana, C.; Renna, M.; Gasco, L. Effect of Rearing Substrate on Growth Performance, Waste Reduction Efficiency and Chemical Composition of Black Soldier Fly (Hermetia Illucens) Larvae. *J Sci Food Agric* 2018, *98*, 5776–5784, doi:10.1002/JSFA.9127.
13. Ebeneezar, S.; Linga Prabu, D.; Tejpal, C.S.; Jeena, N.S.; Summaya, R.; Chandrasekar, S.; Sayooj, P.; Vijayagopal, P. Nutritional Evaluation, Bioconversion Performance and Phylogenetic Assessment of Black Soldier Fly (Hermetia Illucens, Linn. 1758) Larvae Valorized from Food Waste. *Environ Technol Innov* 2021, *23*, 101783, doi:10.1016/J.ETI.2021.101783.
14. Fitriana, E.L.; Jayanegara, A.; Astuti, D.A.; Laconi, E.B. Growth Performance and Nutrient Composition of Black Soldier Fly Larvae Reared on Solid-State Fermentation Substrates with Various White Rot Fungi. *Biodiversitas* 2022, *23*, 4894–4905, doi:10.13057/BIODIV/D230959.
15. Lopes, I.G.; Lalander, C.; Vidotti, R.M.; Vinnerås, B. Using Hermetia Illucens Larvae to Process Biowaste from Aquaculture Production. *J Clean Prod* 2020, *251*, 119753, doi:10.1016/J.JCLEPRO.2019.119753.
16. Opoku, O.; Hamidu, J.A.; Adjei-Mensah, B.; Quaye, B.; Sasu, P.; Benante, V.; Amankrah, M.A.; Donkoh, A.; Atuahene, C.C. Alternative Organic Wastes as Substrates and Its Impact on Growth, Proximate Chemical and Mineral Composition of Black Soldier Fly (Hermetia Illucens) Larvae for Subsistent Animal Feed. *J Appl Anim Res* 2023, *51*, 564–572, doi:10.1080/09712119.2023.2249545.
17. Jing Lim, J.; Seng Liew, C.; Raksasat, R.; Merican, Z.M.A.; Kiatkittipong, K.; Alaaeldin Abdelfattah, E.; Mohamad, M.; Bashir, M.J.K.; Karabo Obed Ntwampe, S.; Lim, J.W. Cellulase Pretreated Palm Decanter Cake for Feeding of Black Soldier Fly Larvae in Triggering Bioaccumulation of Protein and Lipid into Biodiesel Productions. *Sustainable Energy Technologies and Assessments* 2022, *53*, 102485, doi:10.1016/J.SETA.2022.102485.
18. Montevecchi, G.; Macavei, L.I.; Zanelli, E.; Benassi, G.; Pinotti, G.; D'Arco, S.; Buffagni, S.; Masino, F.; Maistrello, L.; Antonelli, A. Seasonal Variability of the HO.RE.CA. Food Leftovers Employed as a Feeding Substrate for Black Soldier Fly (Hermetia Illucens L.) Larvae and Effects on the Rearing Performance. *Sustain Chem Pharm* 2023, *33*, 101061, doi:10.1016/J.SCP.2023.101061.
19. Spranghers, T.; Ottoboni, M.; Klootwijk, C.; Ovyn, A.; Deboosere, S.; De Meulenaer, B.; Michiels, J.; Eeckhout, M.; De Clercq, P.; De Smet, S. Nutritional Composition of Black Soldier Fly (Hermetia Illucens) Prepupae Reared on Different Organic Waste Substrates. *J Sci Food Agric* 2017, *97*, 2594–2600, doi:10.1002/JSFA.8081.
20. Bava, L.; Jucker, C.; Gislon, G.; Lupi, D.; Savoldelli, S.; Zucali, M.; Colombini, S. Rearing of Hermetia Illucens on Different Organic By-Products: Influence on Growth, Waste Reduction, and Environmental Impact. *Animals (Basel)* 2019, *9*, doi:10.3390/ANI9060289.
21. Chia, S.Y.; Tanga, C.M.; Osuga, I.M.; Mohamed, S.A.; Khamis, F.M.; Salifu, D.; Sevgan, S.; Fiaboe, K.K.M.; Niassy, S.; van Loon, J.J.A.; et al. Effects of Waste Stream Combinations from Brewing Industry on Performance of Black Soldier Fly, Hermetia Illucens (Diptera: Stratiomyidae). *PeerJ* 2018, *2018*, e5885, doi:10.7717/PEERJ.5885/SUPP-8.
22. Chia, S.Y.; Tanga, C.M.; Osuga, I.M.; Cheseto, X.; Ekesi, S.; Dicke, M.; van Loon, J.J.A. Nutritional Composition of Black Soldier Fly Larvae Feeding on Agro-Industrial by-Products. *Entomol Exp Appl* 2020, *168*, 472–481, doi:10.1111/EEA.12940.
23. Palma, L.; Fernández-Bayo, J.; Putri, F.; VanderGheynst, J.S. Almond By-Product Composition Impacts the Rearing of Black Soldier Fly Larvae and Quality of the Spent Substrate as a Soil Amendment. *J Sci Food Agric* 2020, *100*, 4618–4626, doi:10.1002/JSFA.10522.