ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 9 Number 1, 2013
http://dx.doi.org/10.11118/actaun201361010077

VORACIOUS LARVAE *HERMETIA ILLUCENS* AND TREATMENT OF SELECTED TYPES OF BIODEGRADABLE WASTE

Markéta Kalová, Marie Borkovcová

Received: December 10, 2012

Abstract

KALOVÁ MARKÉTA, BORKOVCOVÁ MARIE: *Voracious larvae Hermetia illucens and treatment of selected types of biodegradable waste.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 1, pp. 77–83

This report is focused on the ability of larvae *Hermetia illucens* (Diptera: Stratiomyidae) to consume different types of biodegradable waste. Waste was selected in groups 02, 19 a 20 according to the Waste Catalogue (in Decree No. 381/2001 Coll., Czech Republic). Experiments were carried out in 14 BioPods Plus that are especially designed for insect *Hermetia illucens* (HI) in order to consume waste. The experiments were measured in laboratory conditions (relatively constant temperature and humidity). The highest weight reduction of waste material (by 66.53% of the original mass) was reached in waste plant tissues. Weight reduction for food scraps – highly problematic kind of waste – was calculated by 46.04%. Worst results were achieved with compost tea from garden waste – larvae reduced the initial amount of waste by only 8.47%. Firstly grubs finished their life cycle after 35 days in catering waste, together with waste plant tissues, quality culled biodegradable municipal waste and poorly culled biodegradable municipal waste. The experiment was finished in 35 days.

black soldier fly, waste management, strategy of municipal waste

From a perspective of a waste manager, advantageous features of *Hermetia illucens* (HI) (Linnaeus, 1758) is no preferences of animal or vegetable origin of consumed material. Neither is there a necessity to separate waste of vegetable origin for composting technology nor the waste of animal origin for processing of biogas as traditional ways are required.

It is known that *Hermetia illucens* larvae are used for reducing weight of food waste (Zheng *et al.*, 2012; Jeon *et al.*, 2011) and for reducing weight of manure (Li *et al.*, 2011; Yu *et al.*, 2011; Myers *et al.*, 2008; Newton *et al.*, 2005). For very favourable results, the usage of HI for the treatment of biowaste is discussed not only in states, where the incidence of HI is natural (Diener *et al.*, 2009) but also in states where you will need to use controlled breeding (Holmes *et al.*, 2012), as in the case of Czech Republic. Thus, if we assume that the use of HI will be possible in Czech Republic, then we need to find out which other types of biodegradable waste could be effectively weight–reduced by larvae of *Hermetia illucens*, and this was the aim of this research.

MATERIALS AND METHODS

Material: For experiments we used insect that is commonly recognized as a forensic indicator for determination post mortem interval: *Hermetia illucens* (Linnaeus, 1758). Biological classification is to Insecta: Diptera: Stratiomyidae. Often this insect is called Black soldier fly. Larvae were bought from commercial breeding MD Terraristik Ammerweg (Germany) where they are offered as a feed for pets (reptile, amphibian, insect). This insect is not widespread but is common in warmer regions of the Czech Republic. Incidence of *Hermetia illucens* in Europe is shown from Second World War as majority non–original kinds of Diptera from North America (Roques, 2010) thus Black soldier fly is not original kind in the Czech Republic. Larvae were delivered in packages of 120 pieces in breeding substrate (millet), the size of the larvae at delivery was 0.5 mm in average (from 0.2 to 0.7 mm).

Experimental spaces: Experiments were carried out in 2012 in biological laboratory without special equipment at the Department of Zoology, Fisheries, Hydrobiology and Apiculture, Mendel University in Brno, Czech Republic, where the relatively standard humidity and temperature were ensured.

Experimental containers: BioPod Plus (Prota Culture™ LLC, USA) is especially designed according to typical behaviour of *Hermetia illucens* in order to consume waste. Larvae (grubs) consume waste in the body of BioPod Plus, consequently climb after migration ramp to the harvest bucket, when grubs want to become pupae.

Pupae can be either a feeding or can emerge adults who in appropriate temperature conditions mates and they sit on the lid BioPod Plus where adults lay their eggs. New small larvae hatched from eggs crawl holes in the lid for the waste which closes a development cycle of HI.

Measuring of temperature and humidity: We used sensors type Minikin TH and TT (EMS Brno, Czech Republic) to measure laboratory conditions (temperature and humidity). These sensors work permanently and they save values every ten minutes as we set. Average temperature was 27.2 °C and average humidity 45.2%.

Experimental methodology: Principle of methodology was to compare several types of biodegradable waste from perspective of possible involvement of HI for treatment. For this purpose it was in groups 02, 19 and 20 (Waste Catalogue in Decree No. 381/2001 Coll., Czech Republic) selected 14 types of waste (Table I). 10 kilograms of type of waste were added to each experimental pod and 240 pieces larvae (two commercially supplied boxes) of size 0.2 to 0.7 millimeters were added. The experiment was terminated on the day when the first adults began to hatch. First adults started to hatch after 35 days from beginning of experiment. In this moment experiments were stopped. This experiment was for the purpose of statistical evaluation repeated 5 times. Always at the end of the experiment consideration of waste residues was performed. Residues were taken from BioPod on the device for weighing. Grubs, pupae and adults were measured after finishing the experiment, from each pod or harvest bucket 30 specimen were taken and measured. All results were statistic evaluated by one–way analysis of the variance–ratio test, including post–hoc Tukey's test.

RESULTS AND DISCUSSION

During the 35 days of testing, larvae have reached different stages of development: larvae, pupae or adults. Based on this objective criterion, wastes were divided into three groups, and average decrease of waste was calculated for each of them (Table III). Group 1 included the experimental containers 1, 9, 10 and 14, where the larvae reached the stage of "adults". The average reduction in this group was 48%, unconsumed remnants were 52%. HI in group 2 reached developmental stages of "pupae", and the average waste reduction in this group was 18% of the original weight. In group 3, the larvae almost did not evolve, and did not even reach the stage of pupae. This group included experimental containers no. 6, 7 and 8. The average reduction of residues in this group was 14%. Detailed results for each type of waste are given in Table II–III. The highest reduction of waste material (on 33.47% of the original mass) was reached in waste plant tissues. Slightly worse results were seen in the groups: quality culled biodegradable municipal waste, catering waste garden waste, food scraps and poorly culled biodegradable municipal waste. Reduction was at 53.96% of the original mass for food scraps and 65.02% for poorly culled biodegradable municipal waste. For other types of waste was reduced to only 82.03% of the original mass waste (waste from rain drains) or even just 97.81% (Garden waste, 20 02 01).

Different reduction may be influenced by many factors. Jeon *et al.* (2011) reported that a significant factor is amount and composition of bacteria in the digestive tract of the larvae HI. Yu *et al.* (2011) have even proven impact on growth and development of larvae HI after inoculating poultry manure with bacteria from HI larvae. The actual weight reduction may not be the only indicator of positivity using larvae HI processing biological waste. Popa and Green (2012) demonstrated an increase in ammonia (NH_4^+) concentration five–to sixfold relative to unprocessed leachate by larvae.

The best results were achieved in those BioPods which contained pasty fraction of waste since the start of experiment. Larvae could consume significantly less waste where to liquefaction occurred gradually. The second highest reduction (at 53.96% of the original mass) was conducted in food scraps that were sufficiently moist and without hard parts.

Temperature and humidity are important conditions for living, growth and activities of insects generally. For insects *Hermetia illucens* ideal temperature range is between 27 and 37 °C which guarantees 74–97% survival (Tomberlin *et al.*, 2009). Larvae *Hermetia illucens* consume also waste in low temperature conditions but not very quickly because their behaviour is generally slower. The lowest temperature for satisfactory consuming waste was determined on value 21 °C.

Optimum value of moisture varies according to the different stages of the development cycle HI. Particularly after the larvae leave the stage larvae posfeeding their food source, they are exposed to ambient humidity which value significantly affects the pupation and emergence of adults (Holmes *et al.*, 2012).

The average humidity was 45.2% in our experiments. These average values were sufficient

I: *Overview of selected types of biodegradable waste and classification according to Waste Catalogue (in Decree No. 381/2001 Coll., Czech Republic)*

Serial number of attempt	Classification according Waste Catalogue (in Decree No. 381/2001 Coll.)		Types of biodegradable waste	Example of specific waste
	02	Wastes from primary production from agriculture, horticulture, hunting, fishing and food production and processing		
	02 01	Wastes from agriculture, horticulture, forestry, hunting and fishing		
1	02 01 03	Waste plant tissues	Waste plant tissues	Core of apple, peel of melon, potato
2			Garden waste	Grass
3			Compost tea	Liquid fraction from plant tissues
4	02 01 06	Animal faeces, urine and manure (including spoiled straw), effluent, collected separately and treated off-site	Chicken droppings - hen manure	Excrements of free-range hens
5			Cow manure	Excrements of cows with straw
	19	Waste from processing equipment (use and disposal) of waste, sewage treatment		
6	19 06 04	Digestate from anaerobic treatment of municipal waste	Offprint from processing biogas	Dried part of digestate from processing biogas
7	19 08	Wastes from waste water treatment	Waste from rain drains	Waste from rain receivers from treatment of waste water
8	19 08 05	Sludges from treatment of urban waste water	Sludges from treatment of waste water	Sludges from treatment of waste water
	20	Municipal wastes (household waste and similar commercial, industrial wastes and wastes from offices) including separately collected fractions		
9	20 01	Separately collected fractions (except in the subgroup of 15 01)	Quality culled biodegradable municipal waste	Vegetable and fruit, grass, peel of potato, onion
10	20 01 08	Biodegradable waste from kitchens and canteen	Catering waste	Bacon, potato, rice, pasta, fruit, rolls, vegetable, bread
11			Food scraps	Potato, rice, pasta, dumplings
	20 02	Waste from gardens and parks (including cemetery waste)		
12	20 02 01	Biodegradable waste	Garden waste	Grass
13			Compost tea	Liquid fraction
	20 03	Other municipal wastes		
14	20 03 01	Mixed municipal waste	Poorly culled biodegradable municipal waste	Bread, bones from fish, butter, fruit, vegetable, cakes, plastic bag

II: *Weight reduction of selected types of waste materials after 35 days; intensity of consuming and stage of life cycle after 35 days of observation. One-way analysis of the variance-ratio test, including post-hoc Tukey's test; A, B, C – means marked with different letters within developmental stages of material consumed differ at $P < 0.05$*

Number in Waste Catalogue	Serial number of attempt	Types of waste materials	Weigh of remains [g]	Reduction of waste weight after 35 days [g]	Standard deviation	How much% of original weight remained	Stage of life cycle *Hermetia illucens* under 5 weeks of consuming	Score size / stage of development	Homogeneous group, the significance level 0.05	Size of grubs, pupa and adults [mm]
02 01 03	1	Waste plant tissues	3 347	6653	668,2	33.47	Adults flaying out	1	B	3
	2	Garden waste	8 758	1242	123,9	87.58	Medium pupa	2	A	2.7–3.5
	3	and water, consequently compost tea [ml]	9 153	847	83,7	91.53	Swimming grubs	2	A	1.7–2.7
02 01 06	4	Chicken droppings (hen manure)	8 320	1680	183,6	83.20	Medium pupa	2	A	2.7–3.5
	5	Cow manure	9 025	974	142,6	90.25	Small pupa	2	A	1.0–2.7
19 06 04	6	Offprint from processing biogas (dried part of digestate)	9 125	875	83,8	91.25	Small grubs	3	A	1.0
19 08	7	Waste from rain drains	8 203	1797	180,1	82.03	Small, medium grubs	3	A	1.0–1.7
19 08 05	8	Sludges from treatment of waste water	8 448	1552	147,7	84.48	Small grubs	3	A	0.5–1.0
20 01	9	Quality culled biodegradable municipal waste	5 525	4475	1093,1	55.25	Adults flaying out	1	B	3
20 01 08	10	Catering waste	5 411	4589	428,1	54.11	Mating adults, extremely large pupa	1	B	3.5
	11	Food scraps	5 396	4604	431,7	53.96	Large pupa	2	C	3.0–3.5
20 02 01	12	Garden waste	8 781	1219	122,8	87.81	Large pupa	2	C	3.0–3.5
	13	and water, consequently compost tea [ml]	8 306	1694	192,6	83.06	Swimming grubs	2	A	1.7–2.7
20 03 01	14	Poorly culled biodegradable municipal waste	6 502	3498	346,2	65.02	Adults flying out	1	B	3

for development of flies and their consuming of waste. Some larvae finished their life cycle after 35 days in these conditions. It was in catering waste, together with waste plant tissues; quality culled biodegradable municipal waste and poorly culled biodegradable municipal waste. In other types of waste, however, development took place at the same temperature and humidity, development was significantly slower, which was evident from the size of the larval stages and their behaviour (the size of the larvae at the end of the experiment and their behavioural activities are in Tab. II). Development of *Hermetia illucens* larvae at warm 27.8 °C temperature subsequent completion of the life cycle can require an additional 55 days (Lord *et al.*, 1994).

From our observation, however, the development of the larvae of *Hermetia illucens* depends not only on temperature, but also on different types and amount of decaying materials and the proportion of liquid food components. The life cycle of *Hermetia illucens* did not finish in these pods: offprint from processing biogas, waste from rain drains, sludges from treatment of waste water. Reasons may be the moisture of materials and the amount of suitable nourishment. In pods with "poorly culled biodegradable municipal waste" grubs did not climb to migration ramp to the harvest bucket because waste material was an obstacle for moving to the migration ramp. Swimming larvae in compost tea is really surprising because there is no reference in any literature. Aerobic conditions are necessary for swimming because of breathing.

Pupae and consequently adults are suitable for making other generation of *Hermetia illucens*. There is a possibility to use pupae and adults as a feed for fish (Sealey *et al.*, 2011; Kroeckel *et al.*, 2012), reptiles and other pets. Other potential area where insects *Hermetia illucens* could be used is a prevention of waste production.

This option is interesting from the perspective of municipal waste management that is inherent problematic for further use of the material (composting, processing into biogas) as required by the current wording of the Act No. 185/2001 Coll. (Czech Republic), which provides landfilling as a last level of hierarchy of waste management.

CONCLUSIONS

In our experiments larvae *Hermetia illucnes* consumed various decaying material. The best results were in waste plant tissues, where waste material was reduced by 66.53%. The largest pupae were after consuming catering waste, food scraps, waste plant tissues, manure, poorly and quality culled biodegradable municipal waste. These waste materials are suitable for consuming by larvae *Hermetia illucens*. Life cycle of *Hermetia illucens* did not finish in these pods: offprint from processing biogas, waste from rain drains, sludges from treatment of waste water. Reasons may be the moisture of materials and the amount of suitable nourishment.

It was also observed that in the setting of appropriate temperature the larvae are able to complete their life cycle when they are close to

III: *Dividing of waste into groups by final level of HI development cycle after 35 days*

	final level of development cycle	Serial number of attempt	Types of waste materials	reduction of waste weight after 35 days [g]	Weigh of remains [g]
1	adults	1	Waste plant tissues	6 653	
		9	Quality culled biodegradable municipal waste	4 475	
		10	Catering waste	4 589	
		14	Poorly culled biodegradable municipal waste	3 498	
			averagely	4 804	5 196
2	pupae	2	Garden waste	1 242	
		3	Compost ea	847	
		4	Chicken droppings hen manure)	1 680	
		5	Cow manure	974	
		11	Food scraps	4 604	
		12	Garden waste	1 219	
		13	Compos tea	1 694	
			averagely	1 751	8 249
3	grubs	6	Offprint from processing biogas (dried part of digestate)	875	
		7	Waste from storm drains	1 797	
		8	Sludges from treatment of waste water	1 552	
			averagely	1 408	8 592

suitable places to lay eggs. The larvae that hatch from eggs may be used for another experiments and thereby reach a cyclical supply of larvae to consume other waste materials.

SUMMARY

This report is focused on the ability of larvae *Hermetia illucens* (Diptera: Stratiomyidae) to consume waste. Different types of biodegradable waste were selected in groups 02, 19 a 20 according to the Waste Catalogue (in Decree No. 381/2001 Coll., Czech Republic). These groups include also typically problematic waste as sewage sludge, poorly culled biodegradable municipal waste or biodegradable waste from kitchens and canteen. Experiments were carried out in fourteen BioPods that are especially designed for insect *Hermetia illucens* in order to consume waste. The experiments were measured for five weeks in laboratory conditions (relatively constant temperature and humidity).

The highest reduction (by 66.53%) was calculated in garden waste and second highest reduction (by 46.04%) for food scraps.

There was a difference between intensity of consuming and stage of life cycle after 35 days of observation. Firstly grubs finished their life cycle in catering waste, after grubs finished their life cycle in food scraps, waste plant tissues, poorly and quality culled biodegradable municipal waste, garden waste, cow and hen manure. Life cycle of *Hermetia illucens* did not finish in these pods: offprint from processing biogas, waste from rain drains, sludges from treatment of waste water. Reasons may be the moisture of materials and the amount suitable nourishment.

Acknowledgement

This report was supported by the IGA – Internal Grant Agency Faculty of Agronomy MENDELU No. IP 14/2012.

REFERENCES

DIENER, S., ZURBRÜGG, C. and TOCKNER, K., 2009: Conversion of organic material by black soldier fly larvae: Establishing optimal feeding rates. *Waste Management and Research,* 27, 603–610.

HOLMES, L. A., VANLAERHOVEN, S. L. and TOMBERLIN, J. K., 2012: Relative humidity effects on the life history of hermetia illucens (Diptera: Stratiomyidae). *Environmental Entomology,* 41, 971–978.

JEON, H., PARK S., CHOI J., JEONG G., LEE S. B., CHOI Y., LEE S. A., 2011: The Intestinal Bacterial Community in the Food Waste–Reducing Larvae of Hermetia illucens. *Current Microbiology*. 2011, roč. 62, č. 5, s. 1390–1399. ISSN 0343-8651. DOI: 10.1007/s00284–011–9874–8. Available at: http://www.springerlink.com/index/10.1007/s00284–011–9874–8.

LI, Q., ZHENG, L., QIU, N., CAI, H., TOMBERLIN, J.,K. and YU, Z., 2011: Bioconversion of dairy manure by black soldier fly (Diptera: Stratiomyidae) for biodiesel and sugar production. *Waste Management,* 31, 1316–1320.

LORD, W. D., GOFF, M. L., and ATKINS, T. R., 1994: Black Soldier Fly Hermetia illucens (Diptera: Stratiomyidae) As a Potential Measure of Huan Postmorten Interval: Observation a nad Case Histories. Journal of Forensic Sciences, JFSCA, Vol. 39, No. 1, January 1994, 215–222.

MYERS, H. M., TOMBERLIN, J. K., LAMBERT, B. D., KATTES, D., 2008: Development of the Black Soldier Fly (Diptera: Stratiomyidae) Larvae Fed Dairy Manure. *Environmental Entomology,* 37, 11–15.

NEWTON, L., SHEPPARD, C., WATSON, D. W., BURTLE, G., DOVE, R., 2005: Using the black soldier fly, *Hermetia illucens*, as a value–added tool for the management of swine manure. *Waste Management Programs*. North Carolina State University. Available at: http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase2report05/cd,web%20files/A2.pdf.

POPA, R. and GREEN, T. R., 2012: Using black soldier fly larvae for processing organic leachates. *Journal of Economic Entomology,* 105, 374–378.

ROQUES A. (ed), 2010: *Alien terrestrial arthropods of Europe.* 4. Pensoft, 2010. 558 s. Database online [cit. 2012–11–09]. Available at: http://pensoftonline.net/biorisk/index.php/journal.

SEALEY, W. M., GAYLORD, T. G., BARROWS, F. T., TOMBERLIN, J. K., MCGUIRE, M. A., ROSS, C. and ST–HILAIRE, S., 2011: Sensory Analysis of Rainbow Trout, Oncorhynchus mykiss, Fed Enriched Black Soldier Fly Prepupae, Hermetia illucens. *Journal of the World Aquaculture Society,* 42, 34–45.

TOMBERLIN, J. K., ADLER, P. H., MYERS, H. M., 2009: Development of the Black Soldier Fly (Diptera: Stratiomyidae) in Relation to Temperature. *Environmental Entomology*, 38, 930–934.

YU, G., CHENG, P., CHEN, Y., LI, Y., YANG, Z., CHEN, Y. and TOMBERLIN, J. K., 2011: Inoculating poultry manure with companion bacteria influences growth and development of black soldier fly (Diptera: Stratiomyidae) larvae. *Environmental Entomology*, 40, 30–35.

ZHENG, L., HOU, Y., LI, W., YANG, S., LI, Q. and YU, Z., 2012: Biodiesel production from rice straw and restaurant waste employing black soldier fly assisted by microbes. *Energy*, 47, 225–229.

Address

Mgr. Ing. Markéta Kalová, doc. Ing. Marie Borkovcová, Ph.D., Department of Zoology, Fisheries, Hydrobiology and Apiculture, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, e-mail: marketa.kalova@mendelu.cz, marie.borkovcova@mendelu.cz