Can the environmental impact of livestock feed be reduced by using waste-fed housefly larvae?

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ABSTRACT

The livestock sector is searching for alternative protein sources, because of the expected increase in demand for animal products. Insects are such a protein source. Use of insects may reduce environmental impact as they have potential to turn organic waste into high quality insect-based feed products. The aim of this study was to explore the environmental impact of using common housefly larvae fed on organic waste as livestock feed. Data were obtained from a testing site, that is designing a rearing place of 20 tons of larvae meal per day. Results showed that larvae meal has a GWP of 770 g CO_2-eq, energy use of 9,329 MJ and land use of 32 m^2 per kg dry matter meal. Compared with soybean meal, larvae meal results in lower land use and a higher GWP due to its high energy use. To conclude, larvae production has potential to make livestock diets more sustainable.

Keywords: insects, house fly, larvae, LCA, environment

1. Introduction

A growing and more prosperous world population is demanding for more animal proteins, especially in developing countries (Godfray et al. 2010; Eisler et al. 2014). Livestock production, however, already and will continue to poses a severe pressure on the environment via their emissions to air, water and soil (Tilman et al. 2001; Steinfeld et al. 2006). Moreover, livestock also increasingly competes for scarce resources, such as land, water, and fossil energy (Steinfeld et al. 2006; Godfray et al. 2010). The current sector, for example, uses about 70% of the agricultural land (Steinfeld et al. 2006), mainly for pasture and production of feed crops. Land is scarce and expansion of the area for livestock production leads to deforestation in the tropics, i.e. 80% of new croplands are replacing forest, resulting in losses of ecosystem services, biodiversity and increased carbon emissions (Foley et al. 2007; Gibbs et al. 2010; Foley et al. 2011). Similarly, about 15% of the anthropogenic emissions of greenhouse gases result from livestock production (Gerber et al. 2013), mostly resulting from production and utilization of feed (De Vries and De Boer 2010).

So, there is an urgent need for efficient production of feed for livestock. Using insects as a protein source in livestock feed potentially enables such efficient production, i.e. by more efficient use of natural resources and low emissions to air, water and soil. According to a recent publication of the FAO insects as feed can emerge as an especially relevant issue in the twenty-first century (Van Huis et al. 2013).

Insects possess favorable characteristics: 1) They are highly nutritious and have value as a protein source for livestock (Veldkamp et al. 2012). Insect-based feed products, therefore, can replace conventional feed ingredients with a high environmental impact, like fishmeal and soybean meal (SBM). 2) Insects have a low feed conversion ratio and can be consumed as a whole (no residual materials i.e. no bones or feathers). 3) Insects may offer the possibility to reduce the environmental impact of livestock production. In contrast with feed cultivation, the production of insects is not necessarily land intensive (Van Huis et al. 2013). A further environmental benefit of the use of insects lays in their capability to turn organic waste streams, such as manure, household waste or formal food products, into high quality insect-based feed products (Veldkamp et al. 2012; Van Huis et al. 2013). By feeding waste-fed insects, livestock can be fed less food products that are directly edible by humans, thus reducing the competition for land. As an example, around 70% of the cereal grains used in developed countries is fed to livestock (Eisler et al. 2014). With a rather inefficient feed conversion ratio of livestock – for chicken 1.6, for pigs 2.5 and cattle 5.1 per kg dry matter feed/kg product (Šebek and Temme 2009) – more people could be supported from the same amount of land if they did not consume meat from livestock fed with cereals (Godfray et al. 2010).

Feeding waste-fed insects to livestock, therefore, might be an effective strategy to transform inedible waste streams for livestock and humans into high quality food products, such as meat, milk, and eggs. Already in 1970, Calvert et al. showed that housefly larvae (*Musca domestica L.*) can be used for biodegradation of chicken manure, while Ocio et al. (1979) showed that larvae can grow on municipal organic waste. As tons of manure and food waste are produced in western countries –according to the FAO one third of the food is never consumed (Gustavsson et al. 2011)- feeding insects organic waste streams seems a promising solution for the environment.

To our knowledge no study quantified the reduction of the environmental impact of livestock production by including waste-fed insects in livestock feed. The aim of this study, therefore, was to explore if the environmental impact of livestock production can be reduced by using larvae of the common housefly fed on organic waste streams as livestock feed. Environmental impacts included were land and energy use, and emission of greenhouse gases. Data were obtained from a commercially-exploited testing site that designs a rearing place for 20 tons of larvae meal per day. The larvae were fed with a substrate of poultry manure and food waste.

2. Methods

Life cycle assessment (LCA) is an internationally accepted and standardized holistic method (ISO14040 1997; ISO14041 1998; ISO14042 2000; ISO14043 2000) to evaluate the environmental impact during the entire production chain (Guinée et al. 2002; Bauman and Tillman 2004). An attributional LCA was performed to assess the environmental impact, as we aimed, to analyze the environmental impact of larvae meal in a status quo situation.

2.1. Goal and scope definition

Figure 1 illustrates the production chain of the larvae meal. The system consists of four stages: egg production, larvae production, substrate/feed production for larvae and processing of larvae in order to produce larvae meal. In the egg production stage, pupae are brought into a cage and will eclose into flies within 2 days. Feed of the flies consists of sugar, milk powder and egg powder. Flies are kept at a temperature of 25 degrees Celsius. Female flies start to lay eggs after 7 days in an oviposition substrate, consisting of milk powder, yeast, fiber, vegetable oil and vitamins. Drinking water is provided by a nozzle system and water is used for cleaning. The output of the egg production consists of eggs with the oviposition-substrate. The larvae production stages starts with mixing eggs with the oviposition-substrate with larvae-substrate. Subsequently, larvae are kept at a temperature of 27 degrees Celsius and are full grown after 5 days. The larvae-substrate consists of 195 ton food waste, 65 ton laying hen manure and 1 ton premix. Per 4 kilograms of substrate, one kilogram of larvae is produced. After harvesting the larvae, the cage is cleaned with water. Harvesting of the larvae is performed by shutting off the ventilation, which makes the larvae crawl to the surface of the substrate when oxygen levels drop. Per day 65 ton of live larvae are produced resulting in 20 ton of larvae meal with a dry matter (DM) content of 88%. Besides the larvae meal, 159 ton larvae manure is produced. The larvae manure is not a waste product as it can have different application e.g. as fertilizer. The environmental impact related to the larvae manure was not included in this study. Larvae meal was compared with fishmeal and SBM as both products are protein rich. The functional unit to calculate the impact of larvae meal is one kilogram DM of larvae meal.

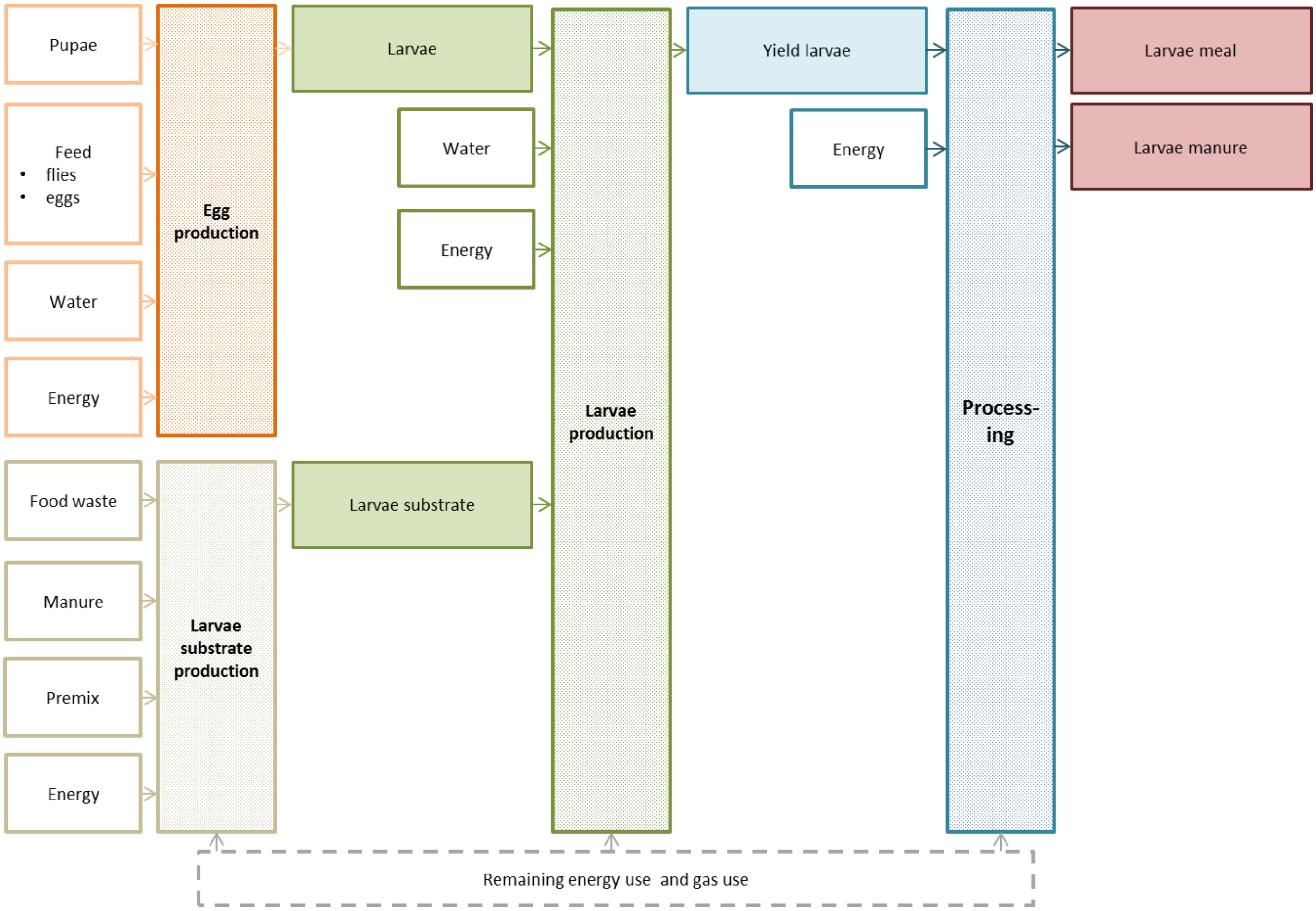

Figure 1. Stages in the production chain of larvae meal

2.2. Data collection

The model, based on experimental studies, is developed by four companies in the Netherlands (an animal nutrition company, Denkavit, two waste processing companies, AEB and SITA and an insect rearing company, Jagran). All data were provided by those four companies and a summary of the data is presented in table 1.

2.3. Measuring environmental impact

The impact categories greenhouse gas (GHG) emissions, energy use (EU) and land use (LU) were assessed. Emission of GHGs, EU and LU were assessed because the livestock sector contributes significantly to both climate change and LU worldwide (Steinfeld et al. 2006) and earlier results of Oonincx and De Boer (2012) demonstrated that insect production is related to high energy use. The following GHGs were included: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These GHGs were summed up based on their equivalence weighing factors in terms of CO_2 (100 years' time horizon): i.e. 1 for CO_2, 25 for CH_4, and 298 for N_2O (Forster et al. 2007). Land use was expressed in m^2 per year per kg dm of larvae meal and energy use was expressed in MJ per kg dm of larvae meal. For both, parameters of GHGs, EU and LU and quantitative input data a sensitivity analyses was performed. In case of multifunctional processes, economic allocation was used. Economic allocation is the partitioning of the environmental impact between co-products based on the relative economic value of the outputs (Guinée et al. 2002).

A summary of the input and output data required to maintain the production of larvae meal together with the related impact factors is provided in table 1. The GWP, EU and LU related to the feed for the flies and egg substrate were based on Vellinga et al. (2013) for the production of feed ingredients and on EcoinventCentre

(2007) for the production of tap water. Environmental impact from production of feed ingredients included impacts from cultivation (e.g. fertilizers, pesticides, machinery, energy, emissions related to direct and indirect N_2O and CO_2 emissions from liming and urea fertilization) impacts from drying and processing, and impacts from transport up to the farm gate.

The emissions related to the substrate for the larvae were based on IPCC (2006). According to IPCC, emissions of methane from organic waste occur only after several months. As food waste was used for 4 days only during the larvae production process, we assumed that emissions from organic waste were negligible. During the handling and storage of laying hen manure CH_4 and direct and indirect N_2O were emitted. As there were no specific data available of the use of manure for insect rearing, we assumed emissions for using manure were equal to emissions emitted on a laying hen farm. For CH_4 a tier 2 approach was used based on country specific data of Coenen et al. (2013) and IPCC default values (an organic matter content of 0.35 kg per kg manure, maximum CH_4 producing potential of 0.34 m^3 CH_4 per kg organic matter and a methane conversion factor of 0.015). For direct N_2O emissions a tier 2 approach was used based on country specific data of Coenen et al. (2013) (0.8 kg N excretion per laying hen per year, 18.9 kg manure per laying hen per year and a default emission factor of 0.01). For indirect N_2O emissions a tier 1 approach was used based on IPCC default values (volatilisation 40% and an emission factor of 0.01). The GWP, EU and LU for transportation of food waste and manure over an average of 65 km per day were included, based on Eco-invent (2007). The GWP, EU and LU related to the production of electricity and gas were based on Eco-invent (2007). Electricity was assumed to be substituted with marginal Dutch electricity, i.e. 28% coal-based, 67% natural gas-based, and 5% wind-based electricity (EcoinventCentre 2007). The GWP, EU and LU related to SBM and fishmeal were based on Vellinga et al.(2013).

Table 1. Input data and related global warming potential (GWP), energy use (EU) and land use (LU) data for the environmental impact of producing one ton dry matter larvae meal.

Ingredients	**Unit**	**Amount** /ton (DM)	**GWP** (g CO_2)	**EU** (MJ)	**LU** (m^2)
Feed flies	kg	1	3,808	12.2	1.34
Substrate eggs	kg	17	1,351	3.9	0.34
Food waste	kg	11,079	11	0.2	0.00
Manure	kg	3,693	42	0.2	0.00
Premix	kg	57	1,362	3.9	0.34
Water	kg	10,309	0	0.0	0.00
Electricity	kWh	378	753	11.8	0.01
Gas	kWh	183	586	11.2	0.00

3. Results

Producing larvae meal resulted in a GWP of 770 kg CO_2-eq, an EU of 9,329 MJ and a LU of 32 m^2 per ton DM larvae meal. Figure 2 shows the GWP, EU and LU for different production phase including a sensitivity range of 30%. The egg production phase contain processes like feed and water use. The larvae production phase contains processes like water and substrate use. The electricity for the building contained the complete electricity use and gas for the building contained the complete gas use. The gas for drying the larvae is in this business model obtained from residual heat from a waste incineration plant in which the larvae production is situated. The largest part of the GWP was caused by the feed for the larvae (44%), whereas an additional 37% resulted from the use of electricity and 14% form the use of gas. Electricity and gas use, however, explained the majority of the EU (70%), whereas production of vitamins and minerals in larvae feed explained the majority of the LU.

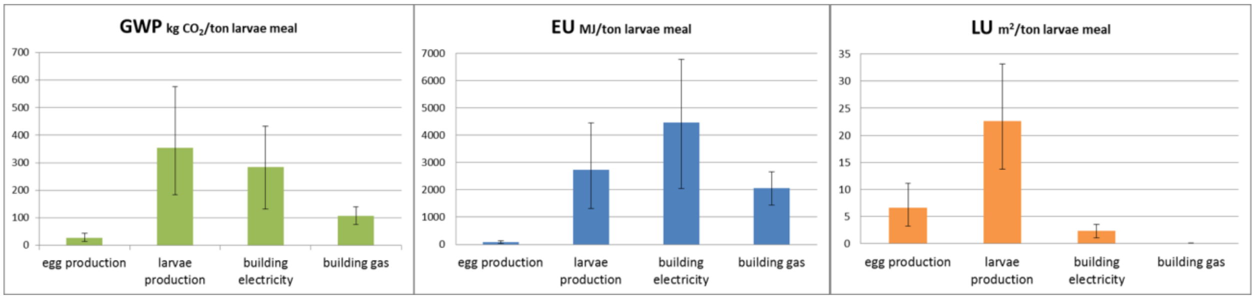

Figure 2. Global warming potential (GWP), energy use (EU) and land use (LU) of each phase of larvae meal per ton dry matter larvae meal, including a sensitivity range of 30%

To compare larvae meal with other protein rich ingredients a comparison of the nutrient content is of importance. Table 2 shows the nutrient content of larvae meal (based on analysis of the commercially-exploited testing site), fishmeal and SBM (CVB 2010).

Table 2. Nutrient content (%) of larvae meal, fishmeal and soybean meal (SBM)

	Larvae meal	**SBM**	**Fishmeal**
Dry matter	88.0	87.5	92.7
Crude protein	47.9	46.0	56.7
Fat	24.2	18.4	15.8
Lysine	32.6	28.5	43.1
Methionine	11.3	6.4	15.9

Figure 3 shows a comparison for the average GWP, EU and LU with other protein rich feed ingredients. The production of larvae meal and fishmeal results in high EU affecting the GWP but are not land intensive like SBM.

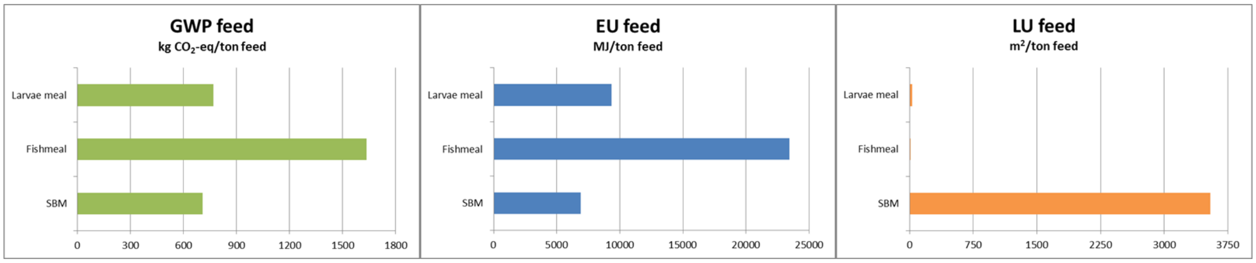

Figure 3. Comparison of global warming potential (GWP), energy use (EU) and land use (LU) of larvae meal, fishmeal and soybean meal (SBM) based on ton dry matter feed

4. Discussion

The results of this conference paper show the direct environmental impact of larvae meal production. Production of larvae meal, however, also resulted in indirect environmental consequences. The human food waste which was used to grow insects can be used for different application e.g. composting or production of biogas. The indirect environmental consequences of replacing another potential application of waste used for insects, therefore, should be considered as well. Just as the possible applications of the larvae manure. The larvae manure can, for example, be used as fertilizer or for biogas production. Further research on the indirect environmental impact is, therefore, required.

The range of GWP, EU and LU is based on a sensitivity analysis in which the values of GWP, EU and LU and quantitative input data were decreased and increased with 30%. Varying the values of emissions was required as some processes are uncertain. The most uncertain factor were the emissions related to the larvae substrate. Calculation of emissions were based on IPCC guidelines for manure and composting of food waste. We assumed that emissions of food waste were negligible as according to IPCC emissions of composting only occur after several months (IPCC 2006). Even though food waste is used for only 4 days, the circumstances for composting were favorable due to high temperatures and constant ploughing by the larvae. Un underestimation is, therefore, possible. Furthermore, IPCC calculations for manure were based on emissions related to the complete laying hen sector and not only for the storage of manure and, therefore, possibly resulting in an overestimation. To minimize the uncertainty experimental studies are required.

The nutrient content of larvae meal was determined on basis of only two samples. However, a literature review of Veldkamp et al. (2012) shows similar outcomes: larvae contain 43-68% protein and 4-32% fat on a dry matter basis. The protein content of insects is within the fishmeal and SBM range and its fat content is higher (Veldkamp et al. 2012).However, in vivo animal studies are required to determine the palatability, digestibility and other relevant characteristics of the larvae meal before a reliable comparison with fishmeal and SBM can be made.

In this study, we found that electricity use per kg DM of larvae meal was 4.46 MJ an gas use was 2.05 MJ. For mealworm production, a high electricity and gas use was also found. Oonincx and De Boer (2012) found an electricity use of 15.8 MJ and a gas use of 26.0 MJ per kg of DM mealworms. These values are thus higher than that of the production of housefly larvae, which is caused by a longer production cycle of mealworms (10 weeks instead of 5).

The production of larvae uses high amounts of energy due to the required ambient temperature. One should, however, take into account that the required energy use is an estimation and the bio-efficiency of the industrial process to acquire larvae meal is still advancing. However, the high cost price and institutional barriers (EU-legislation, health concerns etc.) are issues that should be overcome before an insect-based business model can be exploited (Veldkamp et al. 2012; Van Huis et al. 2013).

5. Conclusion

Energy use was the main contributor to the direct environmental impact of larvae meal production, however, the industrial process to acquire larvae meal is still advancing. Compared with fishmeal, larvae meal resulted in a lower GWP and EU and a similar LU. Compared with SBM larvae meal resulted in a higher GWP and EU but a lower LU. Two of the main production factors, land and fossil energy, are scarce. However, fossil energy can be replaced by more sustainable sources, i.e. solar- and wind energy, that reduces the GWP, while there is no practical solution for the scarcity of land. Therefore, we conclude that in the future larvae production has the potential to contribute as a more environmentally sustainable livestock feed.

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