# Increasing the Efficiency of Biowaste Digestion by Black Soldier Fly Larvae

Although biowaste conversion with black soldier fly larvae can effectively reduce waste, differences in waste content influence the output. A literature review identified that macronutrients and microbes are key for efficient and reliable biowaste conversion performance. Moritz Gold[1,2], Jeffery K. Tomberlin[3], Stefan Diener[4], Alexander Mathys[2], Christian Zurbrügg[1]

## Introduction

Black soldier fly larvae conversion is a new biowaste treatment technology. Larvae consume biowaste, convert it into larval biomass, and leave behind a compost-like residue, with characteristics similar to immature compost. Besides reducing waste dry mass by up to 70 %, the insect biomass that is produced has a high market value as animal feed. Revenues from this treatment product could provide an incentive for waste management and contribute to offsetting waste management costs, while providing more sustainable animal feeds.

Challenges to black soldier fly larva conversion are reliable and efficient operation. High quality waste sources often have competing uses and practice shows that it is not easy to obtain good quality waste for the processing. Poor waste management results in mixing of wastes with inorganics, incentivises landfilling of organic wastes, or involves complex logistics, thus, hindering access to black soldier fly larvae processing. Processing lower quality wastes typically result in a high variability of waste reduction, low larval biomass production and poor larval composition (e.g. lipids and proteins). This not only affects day-to-day operations (e.g. operation over or under the treatment capacity), but also compromises the sustainability and scalability of this treatment technology.

## Well-studied fly larvae

A literature review was done to identify the factors influencing performance parameters, concerning black soldier fly larvae and four other fly species whose larvae also feed on biowaste. The latter have been studied in more detail and are: pests for humans/animals (i.e. house and stable fly), used in maggot therapy (i.e. green bottle fly) or used as a model to understand biological processes (i.e. common fruit fly). The goal was to increase understanding of black soldier fly larvae digestion, and then use this knowledge to enhance performance and product quality. The complete review is available for free at http://bit.ly/2UVYSmB.

## System description

Figure 1 shows a conceptual description of the black soldier fly larvae conversion as two reactors. The fly larva is depicted as a single reactor in which all processes happen inside the larva, and the second reactor – the biowaste – includes all processes happening in the biowaste, outside the larva. Processes in both reactors are influenced by operational parameters, such as container dimensions, temperature, larval density, humidity, feeding rate, and feeding interval. The larval reactor and waste reactor are connected by processes, such as ingestion, secretions, and excretions.

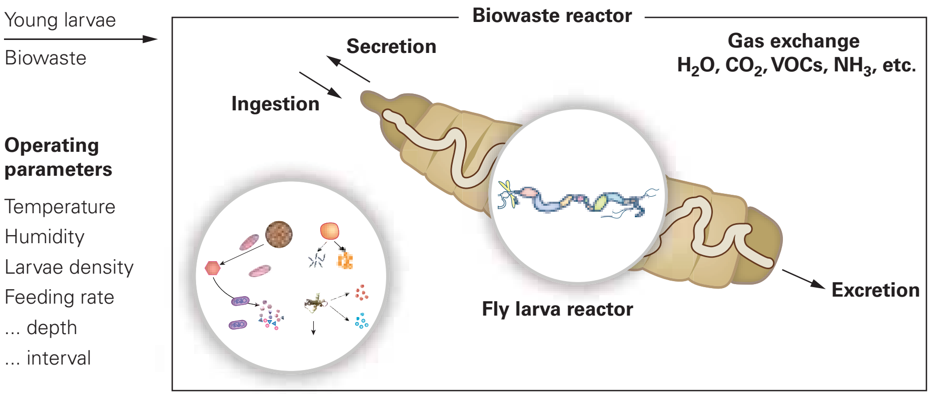


Figure 1: System description of black soldier fly biowaste conversion [1].

## Larval digestive tract

Whereas larval development has been studied using a variety of biowastes, little attention has yet been given to what happens inside the larva following biowaste ingestion. A schematic of a fly larva gut is shown in Figure 2. The digestive tract is a long tube (around 10 cm in length in developed larva) that doubles back and forth upon itself between the anterior and posterior end of the larva. The gut is divided into different regions with distinctive physical and chemical (e.g. pH and enzymes) characteristics. Our ongoing research aims at mimicking the digestive tract in vitro, both as a research tool and as a model to estimate the process performance of different biowastes.

## Biowaste macronutrient decomposition

Biowaste macronutrients include proteins, carbohydrates, fibres and lipids. Similar to humans, fly larvae eat to obtain these nutrients to gain buildings blocks and fuel for their metabolism and development. Biowaste macronutrient decomposition starts in the biowaste reactor triggered by microbes and associated environmental conditions, then followed by the ingestion and action of enzymes in the anterior midgut. Analogous to the human mouth, the anterior midgut appears to be mostly responsible for starting the decomposition of carbohydrates into glucose. Thereafter, the food passes into the mid-midgut. Similar to the human stomach, this section has a low pH and thereby plays a vital role in the inactivation of microbes. Analogous to the human small intestine, the posterior midgut is the longest part of the midgut and is important for the terminal decomposition of carbohydrates, proteins and lipids into its typical building blocks, i.e. glucose, and amino and fatty acids, and for their absorption into the haemolymph. The haemolymph is analogous to human blood and distributes the substances throughout the body. Non-digestible waste constituents are then excreted from the hindgut.

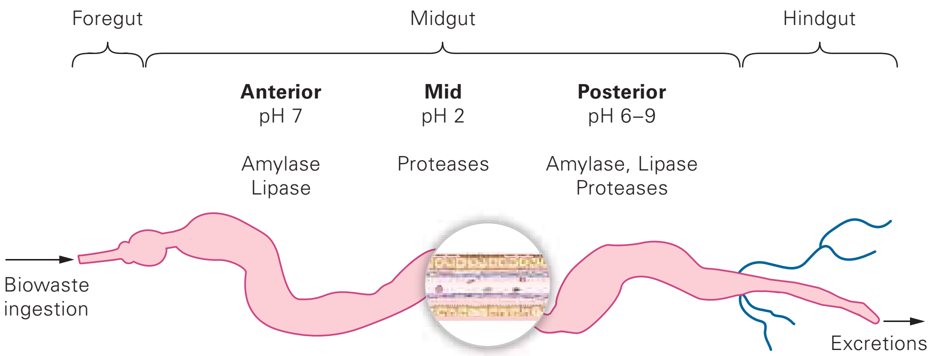


Figure 2: Schematic of a black soldier fly larva gut [1] adapted based on [2].

## Macronutrients and process performance

Amino acids, the building blocks of protein, and carbohydrates are considered to be the nutrients that have the largest influence on process performance. Larvae adjust their ingestion, decomposition (e.g. enzyme production) and absorption of these nutrients based on their current nutritional demands. Providing too much or too few nutrients can either bear a metabolic cost or lead to nutrient deficiencies, slowing development.

The results of our review suggest that amino acids are important for larval development time. Larvae feeding on biowaste with low protein content show slower development. Due to the deficiency of amino acids in the larval fat body, analogous to the human liver, the excretion of hormones needed for larval development are suppressed. In contrast, carbohydrates appear to be most influential for the accrual of larval lipid content. Larvae fed on biowaste with high carbohydrate content have higher lipid content. On low-protein and high-carbohydrate diets, larvae convert carbohydrates into lipids. Fibres are difficult to digest or not-digestible for larvae, thus, lowering waste reduction.

## Biowaste and larva microbial community

Fly larvae feed on diets containing a high number and diversity of microbes. These microbes have multiple functions that are important for black soldier fly larvae biowaste conversion. Microbes influence the decomposition of biowaste inside the biowaste and reactors. They are also a direct source of food, and produce essential nutrients and metabolites. Adding certain bacteria to the biowaste can increase process performance. For example, addition of *Lactobacillus buchneri* to soybean curd residue increased larval weight production by 39 % in comparison to a control without the bacteria [3]. It is as of yet unclear whether this performance increase is due to processes predominantly happening in the biowaste reactor or in the larva reactor (or a combination of the two). Our research suggests the biowaste microbial community is very important for the black soldier fly conversion system. Removing the microbial community from canteen waste by high-energy electron beam treatment shows decreased larval weight by 35 % compared to an untreated control [4].

| Parameter | Measurement methods | Influence |
|---|---|---|
| **Protein** | Determination of nitrogen and multiplication with a waste-specific k value, accounting for different amounts of non-protein nitrogen | + |
| **Digestible Carbohydrates** | e.g. starch and sugars, by enzymatic assays or following acid hydrolysis | + |
| **Lipids** | Extraction with a solvent (e.g. petroleum ether in a Soxhlet system) | ± |
| **Fibres** | Neutral and acid detergent fibre as an estimate for hemicellulose, and cellulose and lignin content | – |
| **Ash** | Residue following combustion, estimate for minerals and non-digestible constituents | – |

Table: Parameters to assess biowaste characteristics for black soldier fly larvae conversion. The plus and minus symbols indicate whether an increase in this parameter tends to increase or decrease process performance.

## Conclusion

Our research suggests that one reason for the variable process performance of black soldier fly larvae conversion is the varying amounts of protein, carbohydrates, lipids, fibres and inorganics in biowaste. These components influence waste reduction, larval development and larval composition. Formulating the biowastes to ensure similar nutrient contents would reduce this variability, but a comprehensive biowaste characterisation would have to be done to obtain this information. The Table summarises the relevant parameters to measure. Ongoing analyses of different biowastes identified that typical low-value biowastes do not usually lack protein (> 10 % dry mass), but rather lack digestible carbohydrates. Biowastes high in digestible carbohydrates, however, may already be used as animal feed and are, therefore, not accessible or come at a price. Another likely reason for process variability is the microbial composition of biowaste. Pre- and co-treatment of biowaste with beneficial microbes has a large potential to increase process performance.

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