Journal of Cleaner Production 171 (2018) 403–412

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Insect as feed: An emergy assessment of insect meal as a sustainable protein source for the Brazilian poultry industry

Gabriela Allegretti [a, *], Edson Talamini [a], Verônica Schmidt [a], Paulo Cesar Bogorni [b], Enrique Ortega [c]

[a] Federal University of Rio Grande do Sul (UFRGS), Av. Bento Gonçalves 7712, Bairro Agronomia, Porto Alegre, RS CEP: 91540-000, Brazil
[b] BUG Agentes Biológicos, Rodovia SP-308 km 176, Bairro Santa Terezinha, Piracicaba, SP CEP: 13.411-097, Brazil
[c] Campinas State University (UNICAMP), Rua Monteiro Lobato, 80 Cidade Universitária, Campinas, SP CEP: 13046-610, Brazil

ARTICLE INFO

Article history:
Received 27 June 2017
Received in revised form
21 September 2017
Accepted 27 September 2017
Available online 30 September 2017

Yutao Wang

Keywords:
Bioeconomics
Thermodynamic
Energy
Ecological engineering
Industrial ecology

ABSTRACT

Projections point to a global increase in meat consumption as a result of rising income and changes in food patterns, especially in developing countries. Poultry meat is an option for supplying this demand and Brazil is currently the main global exporter of this protein. Of the resources involved in this industrial process, soybean meal, which is a protein source for farmed animals, requires a large quantity of energy. In order to increase the sustainability of the poultry industry, it is necessary to find a more efficient alternative to this poultry feed. Through emergy assessment, this study proposes to evaluate the production and processing of Black Soldier Fly Larvae (BSFL) as an insect meal and to compare its use with soybean meal in a Brazilian poultry production system. The biological capacity of BSFL to convert the remaining energy from a previous process (grain residue) into a novel protein is demonstrated by emergetic indices, whose best values favor this new technology. Transformity (emergy per energy of the product) decreased 144.74% while renewability increased by 45.64%. The emergy yield ratio (EYR) reduced from 1.71 to 1.00 in insect meal production compared to soybean meal, the environmental loading ratio (ELR) improved from 1.99 to 1.04 and the emergy sustainable index (ESI) improved from 0.86 to 0.96. Gains were also observed in poultry production: the transformity of poultry meat decreased by 16.45% (156,104 sej/J), renewability increased by 25.03%, EYR increased from 1.33 to 1.41 and ELR reduced from 4.96 to 3.68, when insect meal was used in comparison to soybean meal. These results, based on an experimental model, imply that BSFL meal can improve sustainability in the Brazilian poultry production process. Challenges and possibilities regarding the use of insect meal by the Brazilian poultry industry are discussed.

1. Introduction

The increasing global population and changes in food consumption patterns mean that it is important to find out other protein sources. Regardless of whether they are animal or vegetable in origin, they must be capable of supplying food demand in a viable and sustainable way (Ruviaro et al., 2012; Gandhi and Zhou, 2014). Growing income, especially in developing countries, such as China, India and African countries, is envisaged to be responsible for an increase in meat consumption of 1.9% per year over the next decade. Poultry is one of the available meats that can help supply that demand (USDA, 2016). Currently, Brazil is a main global poultry meat exporter, contributing 13.14 million tons to this industry in 2015 (ABPA, 2015). The three main producer and exporter states are located in the South Region and represent 76.6% of the total exports from the country (ABPA, 2015). This region faces environmental problems related to pollution (organic residues) and natural resource availability, such as water (Drastig et al., 2016), which are concerning and limiting the expansion of the poultry industry.

The intensification of livestock production in recent decades has forced the use of grains in animal diets. Of the world's crop production, 35% is allocated to animal feed that produces human food (meat, eggs and dairy products) indirectly and much less efficiently (Foley et al., 2011). Shepon et al. (2016) demonstrated that the

* Corresponding author.
E-mail addresses: gabica14@hotmail.com (G. Allegretti), edson.talamini@ufrgs.br (E. Talamini), veronica.schmidt@ufrgs.br (V. Schmidt), paulo.bogorni@bugbrasil.com.br (P.C. Bogorni), ortegaunicamp@gmail.com (E. Ortega).

https://doi.org/10.1016/j.jclepro.2017.09.244
0959-6526/

production of poultry is more efficient than that of other meats (especially beef), and poultry can feed more people, while requiring less land than beef. However, poultry production is not totally efficient because of its usage of nutrients that are available in grains such as corn and soybean.

Meat production systems require a relatively high quantity of land, energy and water, and they contribute to the pollution of soil and groundwater and emit large amounts of greenhouse gases (GHG) in many countries (Bhat et al., 2015). Palhares (2012) calculated the water use by Brazilian broiler farms between 2000 and 2010 and found that indirect water consumption for the production of grain represented 99% of the total water use. The direct water consumption by chickens, to drink and to cool and refresh the barns, represented less than 0.32% of the total water demand in poultry production.

Finding technologies to extract all the energy from nutrient sources, such as grains, before discarding the remains as organic waste, is a huge challenge to mankind. Man, like all living organisms, uses available environmental resources (with low entropy) turning them into products with economic value (higher entropy) and residues. Thus, we can ask: are we using the full energy potential of grains before discarding them? Are we appropriating the energy available in grains before generating organic waste? How can we extract the maximum energetic value of this resource to reduce our environmental impact? One approach to answering these questions is to investigate the use of insects as feed to improve the sustainability of the poultry sector.

Allegretti et al. (2017) identify that, among the insect species with the capacity to convert organic waste in insect meal under Brazilian climatic conditions, BSFL has the ability to act as a bioreactor. They are capable of extracting energy from all kinds of organic waste (animal, vegetable and urban waste) to produce protein and lipids to be used as animal feed (Van Huis et al., 2013; Smetana et al., 2016; Salomone et al., 2017).

In addition to its nutrient-producing capacity, BSFL can promote environmental gains acting as an ecological engineering tool, as demonstrated by Sheppard et al. (1994) and Nguyen et al. (2015) in experiments with 50.0%, 67.9% and 74.2% reductions in waste volume, depending on the kind of substrate. Myers et al. (2008) showed a reduction in nitrogen and phosphorus compounds of 50% and 70%, respectively. Reductions in waste odors from bacterial growth restrictions were also described by Van Huis et al., (2013), as well as the ability to generate an organic compound that can be used as a biofertilizer (Newton et al., 2005; Van Huis et al., 2013).

As Georgescu-Roegen (1971) proposes, life and economy are entropic processes that are inevitable and irreversible over time. Even if zootechnical enhancements can improve feed conversion, converting feed to meat will always generate residues. The challenge is to slow down this entropic process by using all the available nutritive potential (energy) of feed before disposing of it in nature as residue.

As energy flows and conversions are the subject of thermodynamic analysis, thermodynamic metrics can be readily used to describe the environmental performance of any material or energy-based technology in industrial ecology (Liao et al., 2012). This study used emergy assessment as a tool to study thermodynamics and explore the potential of creating and processing BSFL, in order to replace soybean meal as the protein component of the diet of broilers in Brazil.

Following Odum's methodology, all inputs, whether from nature or the economy, were converted into a common unit – solar energy (seJ) (Odum, 1996). An experiment developed in Brazil, which creates BSFL from grain residues resulting from the creation of other insects destined for use in agricultural biological control, was used to calculate the emergetic values of inputs and outputs of the process and the respective emergy indicators. The use of this new protein source was compared with traditional soybean meal in a poultry farm using the same methodology. The composition indices and losses and gains associated with this technology are discussed, enriching the debate and developing new pathways to the sustainability of the poultry sector.

2. Methods

In order to facilitate an understanding of the different steps of the research presented here, and as it is common to both the first part, insect rearing, and the second part, poultry production, the methodology of emergy assessment will be explained. Subsequently the details of each step, including data collection, will be described.

2.1. Emergy assessment

The emergy approach is flexible enough to be easily applied to the study of many different systems, whether they are natural or synthetic (Jorgensen, 2000). By definition, emergy is the embodied energy necessary to generate a flow (Odum, 1996). Emergy assessment proposes to measure all contributions (money, mass, energy and information) in terms of work – emergy (with M) and expressed in solar equivalent Joules (seJ) (Odum, 1996; Brown and Ulgiati, 2004).

The particularly valuable contribution of Odum's methodology is the capacity to convert all inputs and outputs of a process to the same unit (seJ) through the conversion factor called transformity. Transformity is the solar emergy required to make one unit of a product or a service (i.e. kg, Joule or dollar) and it can be used as a measure of the inverse value of the system efficiency, allowing comparisons among other energy forms (Chen and Chen, 2011). Transformity for each input can be obtained from a direct search of the International Society for the Advancement of Emergy Research (ISAER) database, on which most research is based. When data is not available, transformity can be measured using different techniques, such as bromatology, which was used for insect meal in the present study.

The transformities used in this study originated from a database developed before 2000. The values were updated by multiplying the old value by 1.27, because in 2016 the budget of emergy received by the biosphere was recalculated: it changed from 9.44E+24 sej year^{-1} to 12E+24 sej year^{-1} (Odum et al., 2000; Brown and Ulgiati, 2016).

The methodology has evolved in the last few years with a detailed process of emergy accounting being given by some researchers all over the world (Chen et al., 2006; Shao and Chen, 2016; Giannetti et al., 2006) and periodic updates of the baseline (Brown and Ulgiati, 2010; Campbell, 2016).

Even with enhancements, the three steps must be followed according to the recommended methodology: a) construction of a systems energy flow diagram defining the main components and the system boundaries; b) organization of the data in an emergy evaluation table; c) calculation of emergy indices and discussion of the results for practical purposes (Odum, 1996). The first step considers symbols proposed by Odum in order to differentiate the types of sources – sources from nature are situated on the left side of the diagram and sources from the economy (material and services) are positioned at the top. Outputs are on the right side of the diagram and at the bottom is the energy sink or the entropy lost in all phases of the process.

The second step is the emergy table where all resources are classified and listed according to their origin: nature (I) or economy (F). Resources from the economy are divided into material (M),