

INSECTS AS TOOLS FOR MAKING CIRCULAR ECONOMY IN APPLIED RESEARCH PROJECTS

LARA MAISTRELLO ^a

^a *Dipartimento di Scienze della Vita, Centro Interdipartimentale BIOGEST-SITEIA, Università di Modena e Reggio Emilia, Via G. Amendola 2, 42122 Reggio-Emilia.*

Corresponding Author: lara.maistrello@unimore.it

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The world is currently experiencing a great contradiction between the need to feed a constantly growing human population, satisfying the need for proteins without negatively affecting the environment to obtain them, and on the other hand a shameful food waste along the different levels of the value chain. In this context, insects can play a fundamental role as bioconverters to upcycle the bio-waste into high value-added products (proteins, fats, chitin and frass fertilizer) useful for various industrial and agricultural sectors, starting from the food and feed industry.

In particular, the black soldier fly (BSF) *Hermetia illucens* is the most widely used mini-livestock due to its extraordinarily efficient bioconversion capacity, making it a perfect tool to implement circular economy. BSF has been chosen for the valorization of various types of organic side streams in applied research projects carried out between 2016 and 2023 in Emilia Romagna region, where the agri-food production is a key sector of the region’s economy. Project outcomes include: optimization of BSF larval rearing in various agri-food by-products; protocols for the fractionation of BSF biomass; pilot plants for the rearing, processing and stabilization of BSF; a patent for an egg-laying device; agronomic assessments of the frass; development of bird and fish feed formulations; LCA of the different rearing processes of the BSF; development of bioplastics from BSF proteins; GIS-based multi-criteria site suitability assessment for insect farms. Despite the great interest, insect farming is not yet a reality in Italy. Potential reasons for this situation are discussed.

KEY WORDS: Insects as bioconverters, black soldier fly, insect farming, bio-waste valorization

CONTRADICTORY ISSUES: GROWING POPULATION, PROTEIN HUNGER AND FOOD WASTE

On November 15, 2022, the human population in the world reached 8 billion units and is projected to reach 9.7 billion by 2050 (GU *et al.*, 2021). One of the major challenges is to feed the increasing global population with nutritious food with the aim of reducing as much as possible the environmental impact of food production. According to FAO estimates, the world demand for animal-derived protein is expected to rise by 70–80% (FAO, 2017) by 2050. However, the animal-based food supply chain is the one with the greatest environmental impact in terms of GHG (green house gas) emissions, land and water use, acidification and eutrophication potential (POORE & NEMECEK, 2018). Furthermore, the current farming systems, both for animal and plant based foods, are the least resilient to all types of hazards, including biotic, abiotic and international risk factors (TZACHOR *et al.*, 2021).

On the other side, about one third to one fourth of all food produced for human consumption is lost or wasted globally each year, with a consequent major squandering of water, land, energy, labour and capital (FAO, 2019). In

European countries, the total bio-waste (i.e. biodegradable waste, which does not include forestry or agricultural residues, manure, sewage sludge, and waste from the textile and paper industries) in municipal waste is on average 168 kg/person, accounting for 34% of the total waste production (EUROPEAN ENVIRONMENT AGENCY *et al.*, 2020). Food is lost or wasted throughout the entire supply chain, but mostly in households (53%), followed by processing (19%), food service (12%), food production (11%) and wholesale and retails (5%) (STENMARCK *et al.*, 2016). According to the EU food waste hierarchy, waste prevention has the highest priority, followed by re-use (redistribution to people and use as animal feed), recycling by anaerobic digestion and composting, and by incineration with energy recovery while disposal without energy recovery and in landfills are the least desirable options (EUROPEAN ENVIRONMENT AGENCY *et al.*, 2020).

INSECT FARMING AS A SUSTAINABLE SOLUTION FOR THE CONTRADICTORY ISSUES

In this context, the challenge is to find sustainable alternatives that upcycle food side streams while providing

valuable resources to be used for feed and food production. This is where insects come into play. Growing food waste represents a serious environmental, political and social issue and the use of insects as bioconverters of food side streams is a valuable solution to reduce this issue while offering high quality nutrients that can be exploited not only for feed and food production (FAO, 2021) but also for many other industrial and agricultural purposes.

Of the 1,024,000 described insect species (STORK, 2018), 2111 are currently eaten by humans and pets or farm animals (FAO, 2021). Edible insect species are a nutritious alternative due to the macro- and micronutrients they possess. In general, they have a protein content that varies from 40 to 65% (dry matter) depending on the species, they are rich in essential amino acids, mono- and polyunsaturated fatty acids, vitamins, minerals and fiber (chitin) (ORDOÑEZ-ARAQUE *et al.*, 2022). Most of the edible species are harvested from the wild and eaten in tropical-subtropical regions, and there are now only a few species with optimal characteristics for mass rearing in industrial conditions (VAN HUIS, 2020). Currently, the black soldier fly (BSF) *Hermetia illucens* (Diptera, Stratiomyidae) (Fig. 1) is the most widely used edible insect as mini-livestock globally (VAN HUIS 2020), as the larvae can thrive on a variety of wet organic side streams, including manure and catering waste.



Fig. 1 - The black soldier fly *Hermetia illucens*: mature larvae, adult and eggmasses (Foto Giulia Pinotti)

The bioconversion process carried out by BSF larvae is summarized in Fig. 2. Low-value heterogeneous bio-waste is converted into highly homogenous products with high added value: mature larvae and frass. Larval biomass is rich in proteins, lipids, chitin and antimicrobial bioactive compounds, substances which are used in the feed/food industry and in many other industrial contexts (biomedical uses, cosmetics, biodiesel, bioplastics, biodegradable/edible packaging, emulsifying and foaming agents, lubricants) (MÜLLER *et al.*, 2017, RAVI *et al.*, 2020, SURENDRA *et al.*, 2020). Larval frass, rich in nutrients and chitin, is an excellent fertilizer for agricultural purposes (KACZOR *et al.*, 2022, LOPES *et al.*, 2022).

The average larval development time is typically 15-20 days and the average reduction of the initial substrate is 60-80%, but these parameters vary greatly according

to the rearing substrate; besides, due to the larval activity there is a significant decline in the bacterial load and bad smells (BESKIN *et al.* 2018, GOLD *et al.* 2018).

APPLIED RESEARCH PROJECTS FOCUSED ON BLACK SOLDIER FLY IN EMILIA ROMAGNA

Due to the extraordinarily efficient bioconversion ability, BSF makes a perfect tool to implement circular economy. For this reason, BSF has been chosen for the valorization of various types of organic side streams in applied research projects (Fig. 3) carried out in Italy between 2016 and 2023 in Emilia Romagna region, where the agri-food production is a key sector of the region's economy. In Emilia Romagna there are many agri-food companies, especially in the food processing chain, with consequent high amounts and large availability of agro-industrial production waste and by-products. A small fraction of these side streams is used for animal feed, composting and energy production. However, most of this bio-waste is either incinerated or sent to landfill and alternatives that allow its upcycling are strongly needed. The projects, whose main features are summarized in Fig. 3, are the following: ValoriBio, Flies4Value, Bioeco-Flies, Flies4Feed and Scalibur. ValoriBio and Flies4Value were regional “research & innovation” pro-

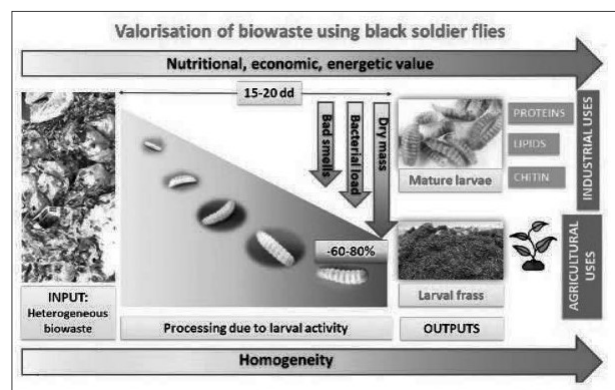


Fig. 2 - Schematization of the bioconversion process carried out by *Hermetia illucens* larvae.

jects whose financed partners were applied research centres located Emilia Romagna. Each project also had to include companies, which had to have an active role in the project (such as donors of materials, potential end users) with staff involvement, but were not financed. Scalibur was an “innovation action” in the Horizon 2020 Research and Innovation Programme, whose partners included research centres, companies and municipalities from several EU countries. The general objectives of this type of projects is to provide innovative research based solutions and technologies (i.e. pilot plants, patents), exploitable by companies and the community, useful for the development of new value chains.

Bioeco-Flies and Flies4Feed are rural development projects whose partners are research centres and farms and the objective is to provide farmers with “ready-to-use” research based solutions, i.e. the diversification of

agricultural activities, an alternative source of income.

All projects had specific dissemination plans dedicated to stakeholders and the scientific community, namely: research articles, informative articles for non-experts, press-releases, meetings for stakeholders, field and laboratory visits, training courses for farmers (only for rural development projects). All projects were carried out by teams with highly multidisciplinary skills. All the projects had entomology, food chemistry, LCA, and engineering (for the creation of prototypes) in common. Considering specific expertise, Bioeco-Flies and Flies4Feed had agronomy and animal feed, respectively; ValoriBio had chemometrics, geology, science and material technology, agronomy, food technology and legal studies; Flies4Value had food technology, microbiology, animal feed, agronomy, GIS expertise, sociology; Scalibur had food technology, science and material technology and legal studies.

The prototypes built in ValoriBio (<https://www.valoribio.eu/en/>) aimed at optimizing BSF larvae rearing on chicken manure, water and chabazite (BORTOLINI *et al.*, 2020), and the adult conditions to maximize egg laying (MACAVEI *et al.*, 2020), including the development of a specific device for BSF egg-laying, which has been patented (BENASSI *et al.*, 2018). Specific protocols have been developed for BSF larvae fractionation, performing also a life cycle analysis (LCA) (CALIGIANI *et al.*, 2018; 2019, ROSA *et al.*, 2020). BSF proteins have been used to develop a biodegradable bioplastic film (BARBI *et al.*, 2019; 2021) to be used as a mulch sheet (SETTI *et al.* 2020), while the frass has been evaluated as a soil conditioner in soilless production of potted baby leaf lettuce, basil and tomato plants (SETTI *et al.*, 2019).

The challenge of Bioeco-Flies (<https://progetti.crpv.it/Home/ProjectDetail/28>) was the valorization of seasonal agrifood by-products to rear BSF larvae year-round (Barbi *et al.*, 2020), assessing also the effect of the rearing substrate on total protein and amino acid composition of BSF larvae (FUSO *et al.*, 2021). The performance of BSF larvae was evaluated in a mass production prototype, the frass was tested on lettuce production and an LCA was performed (MAISTRELLO *et al.* 2020).

In Flies4Value (<https://flies4value.it/en>) an optimal mix of stabilized agri-food by-products was used to obtain carotenoid-rich BSF larvae (LENI *et al.*, 2022), which were used to formulate a specific feed for laying hens in order to obtain eggs with naturally red yolk. The project also evaluated the acceptability of eggs obtained from insect-fed laying hens by Italian consumers (LIPPI *et al.*, 2021) and developed a GIS-based Multi Criteria Decision Making analysis to evaluate the suitability of Emilia Romagna territory to the installation of insect farms (FIORILLO *et al.*, 2022).

In the European project Scalibur, the work package lead by UNIMORE was dedicated to obtaining proteins from municipal bio-waste using insects as bioconvert-

ers. The ValoriBio prototype for larvae was implemented for the mass rearing of BSF larvae on HO.RE.CA (hotel-restaurant-catering) waste (*i.e.* side streams from a canteen) and a new prototype for the insect fractionation was built. Other groups have evaluated the suitability of BSF larvae meal as an ingredient for dog food and the use of BSF chitin to develop innovative biomaterials for packaging (<https://scalibur.eu/resources/>).

In Flies4Feed (http://flies4feed.crpv.it/nqcontent.cf-m?a_id=22320), still in progress, thanks to the association between an insect farm prototype and a biogas production plant, the excess heat of the latter is exploited to breed BSF larvae on mill waste (SINISGALLI *et al.*, 2022). The BSF meal is then used to formulate specific feeds for trout and pigeons.

WHY IS INSECT FARMING NOT YET A REALITY IN ITALY?

In Europe, the use of insects as tools to upcycle organic side streams into valuable resources, thus putting the circular economy into practice, is severely limited by specific regulations (Reg. (EC) No 999/2001; Reg.

Project title and logo	Years; role	Funding program	Funding entity	Biowaste used as substrate	Main outputs
GO! Flies4Feed	2021-2023 PI	Rural Devel. Plan 2014-2020 Op. 16.1.01 - GO EIP- Agri - FA 3A	Emilia Romagna Region	By-products of vegetable origin from agri-food industries	Prototype for BSF farming associated to biogas plant; optimization of insect rearing; feed formulations for trout and pigeons
BIOECO-FLIES	2017-2019 PI	Rural Devel. Plan 2014-2020 Op. 16.1.01 - GO EIP- Agri - FA 5C	Emilia Romagna Region	By-products of vegetable origin from agri-food industries	Optimization of BSF rearing on seasonal substrates, also in a pilot plant; agronomic evaluations of frass on lettuce
FLIES 4 VALUE	2019-2021 Coordinator & PI	Eur. Reg. Dev. Fund (ERDF) Progr. 2014-2020, AXIS 1 Res. & Innovation PG/2018/631984	Emilia Romagna Region	Plant by-products from agri-food industries; by-products from dairy industry	Prototypes for BSF rearing & stabilization; optimization of BSF rearing; carotenoid-rich BSF-based feed for laying hens; eggs with red yolks; GIS-based multi-criteria site suitability assessment for insect farms
ValoriBio	2016-2018 Coordinator & PI	Eur. Reg. Dev. Fund (ERDF) Progr. 2014-2020, AXIS 1 Res. & Innovation PG/2015/737518	Emilia Romagna Region	Poultry manure	Prototypes for insect (A-L) farming; optimization of insect rearing (A-L); patent on an egg-laying device; BSF fractionation protocols; bioplastics from insect proteins; agronomic evaluations of frass
SCALIBUR	2018-2022 Participant	H2020 Research and Innovation Progr. CE-SFS-25-2018; IA	European Union	HO.RE.CA waste from a canteen	Implemented prototypes for a) insect farming (A-L); b) insect fractionation; optimization of insect rearing; evaluations of BSF as dog food; BSF chitin for innovative biomaterials and packaging

Fig. 3 - Applied research projects on the use of *Hermetia illucens* as bioconverter to valorise different types of biowaste. All project were carried out at the Applied Entomology Laboratory, Centro Interdipartimentale BIOGEST-SITEIA, UNIMORE (= Università di Modena e Reggio Emilia) (Role= role of L. Maistrello in the project, BSFL= black soldier fly larvae, A= adults, L= larvae)

(EC) No 767/2009) which prevent the use of manure and any substrate formally recognized as “waste”, including domestic and HO.RE.CA food waste, as feed for animals. These regulations apply to any type of farmed animals, and farmed insects are also subject to this rule. The primary concern is related to the safety of the insect meal and frass, in terms of heavy metals and other potentially dangerous contaminants. Although in the laboratory BSF larvae exhibited bioaccumulation of several elements, including metals, from optimal feed sources, a pilot-scale study showed that a former food-stuffs-based mixture resulted in a highly efficient and heavy metal-free production of BSF larvae and frass (GLIGORESCU *et al.*, 2022).

In any case, the insect farming sector for feed and food purposes is growing strongly in several European countries. According to the European interest organiza-

tion for insect producers (IPIFF), the annual production of insect protein in Europe is expected to be 3,000-5000 million kg/year in 2030 (<https://ipiff.org/>). Yet, in Italy, despite the great interest aroused by the aforementioned projects thanks to specific dissemination events and articles and during other initiatives organized by various bodies, the number of insect farms currently operating is limited to very few units.

The main reasons for this situation can essentially be traced back to a few issues. In the first place, an unclear legislation, mainly related to the subtle difference on what should be considered a by-product or waste (D. lgs. 152/2006 – TUA, art.184 bis; Regulation (EC) n. 1069/2009; Reg. (UE) n. 142/2011). Secondly, economic reasons, namely the need for large initial investments and the absence of a specific incentive system that favours this sector. Thirdly, the lack of specially trained personnel capable of deal with technical problems of insect farming. Finally, the difficulties in finding and connecting the right partners and stakeholders. In this regard, the creation of a specific network to connect all the elements of the new value chain would be highly desirable: from potential investors, to suppliers of suitable bio-waste, to the those who possess the necessary plant technology for insect farming and processing, to those who have the appropriate scientific knowledge and practical experience to carry out insect farming, to potential end users of insect proteins, fats, chitin, antimicrobial compounds and frass in various industrial and agricultural sectors.

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