A citizen science-based approach to promote circular economy in the context of a fast-growing insect industry

T. Klammsteiner[1], A. Walter[2], C.D. Heussler[1], M. Gassner[1], H. Insam[1]

[1]Department of Microbiology, University of Innsbruck, Innsbruck, Tyrol, 6020, Austria
[2]Department of Biotechnology and Food Engineering, MCI – The Entrepreneurial School, Innsbruck, Tyrol, 6020, Austria
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Presenting author email: thomas.klammsteiner@uibk.ac.at

Introduction

It has been evident for a long time that insects play a key role in sustaining our natural environment. They provide indispensable services as pollinators (Dangles and Casas, 2019), detritivores (Schoenly *et al.*, 1991) and human food source (Sogari *et al.*, 2019) – just to name a few. Their species diversity is a long way from being comprehensively mapped (Stork *et al.*, 2015), but the so far described taxonomy highlights their vast functional diversity with confidence (Chown and Terblanche, 2006). Over the past years, after having served as nutrient source to many, mainly Asian and South American, cultures for thousands of years (DeFoliart, 1999), insects are about to penetrate the industry and are attracting interest from the economy. Recent market surveys carried out by Meticulous Research (2019, 2020) estimate the edible insect market to reach a value of nearly USD 8 billion over the next ten years. The researchers emphasize the forerunner role of the Black Soldier Fly (BSF, *Hermetia illucens;* Figure 1**A**), whose products and industrial application could add up to a market value of around USD 2.5 billion in the near future. One of the fly's most valuable features lays in the ability of its larvae to efficiently convert organic wastes into high quality biomass, thereby providing natural means to contribute to a circular economy (Cickova *et al.*, 2015; Pastor *et al.*, 2015). The BSF's versatility offers a source for protein, fat, oil, chitin, fertilizer and biomolecules to produce feedstuff, fuel, cosmetics and potentially novel antibiotics.

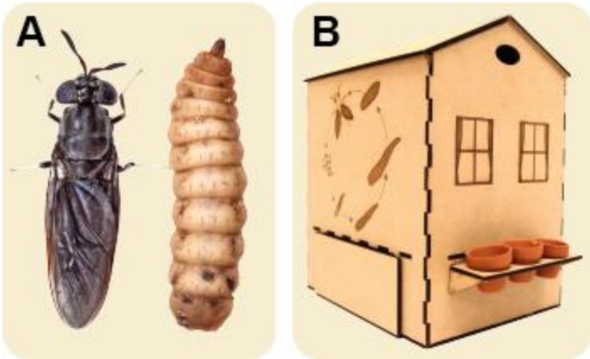

Figure. 1 - **A** Adult and larva of the Black Soldier Fly. **B** Do-it-yourself breeding container for larvae powered by kitchen waste.

Despite all apparent ecological advantages found in breeding insects, most Western countries lack a strong history of using - or even breeding - insects, making it a challenge to establish a consumer market and industrial growth. Therefore, we conceptualized a do-it-yourself breeding system (Figure 1**B**) and invited citizens of all age groups to partake in free workshops to build their own rearing unit for larvae. The goal behind this system was that, by taking care of their own three-week bio-waste-based feeding experiment, participants experience a familiarization with the use of insects and the promising future role thereof in the waste/feed value chain. Communicating fundamental principles of circular economy on an interdisciplinary level and giving an impetus to think about sustainable solutions for the re-valorisation of waste constituted essential goals of these workshops.

Material and methods

Workshops were carried out similarly for the two target groups, school kids and adult citizens, and consisted of a theoretical and practical part. Group work and implementation in the school's syllabus were prioritized in school workshops. In the theoretical part, surveys on the attitude towards insects in general, their value for ecology and their use as food and feed were conducted. This was followed by an introductory lecture covering the production and treatment of waste as well as recent developments in the emerging field of insect industry. During the practical part, rearing units were assembled and the experimental tasks of the upcoming weeks (e.g. weighing and feeding of larvae) were practiced. To maximize comparability, each participant was equipped with the same set of materials: a pocket precision scale (0.01 g resolution), a pre-printed lab journal to fill in observations, forceps and 200 even-aged larvae.

Each rearing unit was built from a wooden house-like body, laser-cut from medium density fibreboard and a leak-proof plastic container was fitted inside the hull. The plastic container was equipped with a max. 40 ° sloped ramp, which provided the larvae an option to leave the moist waste (i.e. the inner bucket) once they were transitioning to the (pre)pupal stage. An escape-proof collection cup meeting the end of the ramp caught the migrating larvae and offered a dry and safe space for pupation. Each participant supervised his/her own feeding experiment for three weeks, fed the larvae with daily occurring household bio-waste, and documented larval development.

Results and Discussion

The project was advertised at conferences, in local newspaper articles, our website (fromwastetofeed.wordpress.com), an Instagram channel (@fromwastetofeed) and various events for public relations. More than 100 pupils from five different types of schools and 30 citizens spanning an age range from 24 to 76 years were instructed to supervise their own three-week feeding experiment (Table 1).

Table 1. Overview on the project statistics.

Description	Values
Actively participated pupils (14-18 years) *With 1-4 rearing units per class*	110
Actively participated citizens (24-76 years) *With 1 rearing unit per citizen*	30
Workshops	11
Distributed larvae	10,000
Rearing units built	40
Material costs/unit [€]	33
Average home-trial runtime [days]	23 ± 1
Larval survival [%]	93 ± 12
Transitioned to pupation [%]	31 ± 29

By having to follow a standardized feeding, sampling, and documentation procedure to successfully carry out the experiment, participants were reliant on confronting their own organic waste. In doing so, critical reflection on waste production and overcoming the aversion of handling insects was motivated. The majority of the experiments was successful, showing a high larval survival rate and rapid development, specified by frequent transition to (pre)pupal stages already after three weeks. The average high biomass increases of approx. 1500% from 12 ± 1 mg larva^{-1} at the beginning to 190 ± 50 mg larva^{-1} at the end of the experiments was rated as proof of concept for the rearing system. Moreover, participants frequently stated that the easily observable growth progress provided additional motivation to carry on with the experiment. Since most participants followed distinct diets, also the composition of the biowaste fed to the larvae varied. The effect of different waste patterns on larval growth will further be used to pinpoint favourable substrates to increase larval biomass yield.

Conclusion

The collective effort of many studies from the last decade created a scientific foundation for insect-based applications and provided the fertilizer for the emergence of a new industry. It is now up to the citizens to shed their biased opinions and embrace the opportunity to support the development of ecologically sustainable means to close loops in feed and food production cycles. Based on the workshop participant's feedback and the gathered data, offering science-oriented hands-on workshops has been found to be a highly efficient way to encourage the public to get involved in this topic and at the same time generate data to develop and improve rearing systems.

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