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Actions needed before insects can contribute to a real closed-loop circular economy in the EU

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EDITORIAL

Abstract

Insects are the waste managers of nature and could play a vital role in closing the loop of nutrients from society back into the food industry and thereby reduce the environmental impact of our food production system, as is the aim of EU's Farm to Fork strategy. Insects can be used to convert biodegradable waste into their own biomass that can be used as food or in animal feed, thus linking waste management to food production. However, food safety regulations prevent the use of around 70% of available food waste in the EU as rearing substrate for insects. To tap into the true environmental benefits of insects as an alternative protein source, they have to be reared on mixed food waste. The main reason for the food safety regulation is the outbreak of Mad Cow disease (BSE) in the 1980s, caused by prions (misfolded proteins). The circular system that gave rise to Mad Cow disease is the most closed loop system possible. Using insects in waste management to convert bio-waste into animal feed does not entail such a closed loop system, but rather introduces an extra barrier to disease transmission. In order to fully tap into the benefits of insects as an alternative protein source, it is crucial that funds are allocated to determine whether prions are truly a risk in a circular insect food production system.

Keywords: animal feed, circular food production, European Green Deal, food safety, prions

1. Introduction

In December 2015, the European Commission launched its first action plan for transitioning to a circular economy within the European Union (EU) (European Commission, 2015a). The intention of this first action plan was to boost transition to a circular economy in which resources are re-used to a greater extent by closing loops. This would not only reduce the environmental impact of products, but also create new jobs and encourage a more sustainable economic growth model. In a circular economy, as defined by the Ellen MacArthur Foundation (2015), economic growth is decoupled from the extraction of virgin resources and instead focuses on 'growth within', using existing stocks of products and materials. The Ellen MacArthur Foundation (2015) highlights the major wastage in the food production sector, with around 30% of food produced being lost or wasted and up to 70% of the nutrients applied in fertiliser not being taken up by plants, resulting in less than 5% of fertiliser nutrients reaching human bodies. In addition to reducing food wastage, the report stresses the necessity for increased nutrient recycling to reduce resource inefficiency and create a more regenerative food production system (Ellen MacArthur Foundation, 2015).

2. Waste management in the EU

The waste management aspect is one of the cornerstones of the action plan. The framework directive outlines how waste should be managed in the EU on the basis of a waste hierarchy (Figure 1). Preventive measures are at the top of the hierarchy, while disposal (landfilling) is at the bottom and is the management method that should be given lowest priority. However, in 2020, 23% of municipal waste in the EU was still landfilled. Although this was a great improvement over 2018, when 38.5% of municipal waste in the EU was landfilled (Eurostat, 2021), it is still much too high to achieve a true circular economy.

Figure 1. The waste hierarchy dictating how waste should be treated in the European Union.

3. Planetary boundaries of biochemical nutrient flows

All 54 actions of the first EU action plan were completed by 2019 (European Commission, 2019b). In March 2020 (European Commission, 2020a), a new action plan economy was launched as one of the major building blocks of the new European Green Deal, with the overall aim of making the EU greenhouse gas emission-neutral and decoupling growth from resource use by 2050 (European Commission, 2019a). The new action plan is a strategy for making the European economy climate-neutral and resource-efficient. It emphasises the need to include more mainstream economic players in the circular economy, while maintaining resource use within the planetary boundaries (Rockström *et al.*, 2009). According to Steffen *et al.* (2015), biochemical flows of nitrogen and phosphorus have already exceeded the planetary boundaries. However, it is rather difficult to assess the planetary boundary for biochemical flows, because trade-offs between the benefits of fertiliser application (increased food production) and adverse impacts of its overuse have to be balanced. The negative aspects of overuse of nitrogen and phosphorus are eutrophication of terrestrial and marine ecosystems, leading to loss of biodiversity and hypoxic conditions, respectively; acidification of soils and freshwater; formation of the potent greenhouse gas nitrous oxide (N_2O); air pollution; nitrate groundwater contamination; and stratospheric ozone depletion (De Vries *et al.*, 2013). However, use of nitrogen and phosphorus fertilisers is very unevenly distributed across the globe and the negative impacts described above mostly occur regionally, in places of overuse. Another major source of anthropogenic nitrogen is inadequately managed wastewater systems. Van Puijenbroek *et al.* (2015), found that nutrient losses to surface waters can be expected to increase by 70% by 2050, due to inadequate sanitation following on from population growth and increased urbanisation. Increased nutrient recycling and re-utilisation, preventing additional inputs of reactive nitrogen to the already excessive pool of anthropogenic nitrogen in natural systems, can thus be justified more by the need to prevent pollution than by the need to conserve nutrient resources.

4. Sustainable nutrient management

One of the objectives of the European Green Deal is to decouple economic growth from resource use (European Commission, 2020a). The impact of EU food production systems must be reduced as outlined in the Farm to Fork strategy, where several aspects are targeted, such as reducing excessive fertilisation and increasing organic farming and animal welfare (European Commission, 2020b). The impact of nutrient surpluses in the environment will be tackled by reducing nutrient losses by 50% and fertiliser use by at least 20% by 2030 (European Commission, 2020c). One of the ways in which this will be achieved is by 'sustainable nutrient management', i.e. better management of nitrogen and phosphorus throughout their entire life cycle, by e.g. recycling organic waste and different sanitation products as renewable fertilisers. In the EU waste hierarchy (Figure 1), *recycling* is on step 3. We stipulate that converting mixed food waste into insect biomass should be placed on a higher level in the waste hierarchy than other common biological treatments such as digestion and composting. One way of visualising the difference between using food waste as a rearing substrate for insects and digesting or composting it could be to divide the *recycling* level in the waste hierarchy into recycling of complex molecules (e.g. amino and fatty acids) and recycling of plant nutrients. This division of the recycle level may be justified, since complex molecules, such as amino acids and fatty acids, are concentrated in the larval biomass (Ewald *et al.*, 2020; Rodrigues *et al.*, 2022). However, the higher placement in the waste hierarchy would only be the case when the generated insects are used as an alternative protein source.

5. Restrictions on the use of insects as animal feed in the EU

At present, most EU food waste cannot be fed directly to farmed animals or to insects, because insects are considered farmed animals according to current legislation (European Commission, 2009). Under this legislation, insects cannot be fed animal by-products or included in animal feed for other farmed animals. Exemptions to this legislation started in 2017, when processed insect protein was allowed as feed in aquaculture (European Commission, 2017). This exemption has been followed by additional ones as listed in Section 6 below. The regulation on animal by-products is intended to decrease the risk of transmitting diseases, since there are risks of recycling pathogenic microorganisms and other pollutants when closing the loop of food waste by recycling substances from the waste back to the feed and food chain (Boqvist *et al.*, 2018). A circular system presents several other challenges, one being that food waste is scattered throughout society. Retrieving these distributed fractions in a feed protein resource is more complex and expensive than using a concentrated protein fraction from agriculture, as it requires a collection network and quality assurance at each collection point (Cobo *et al.*, 2018). The EU regulations on recycling food waste were tightened considerably in response to the bovine spongiform encephalopathy (BSE) outbreak in the UK in the 1980-1990s, after which an uneaten piece of meat left on the plate is considered an animal by-product and therefore labelled as a biohazard (Vågsholm *et al.*, 2020). Closed loop circular systems of animal tissue have since been considered too complex and associated with too high a risk of contamination with unwanted substances and organisms. This has had a detrimental impact on the circularity in food production in the EU. Prior to the BSE outbreak, considerably more food waste was used as animal feed than is the case today, when only 3% of total food waste is re-directed to animal feed (Vågsholm *et al.*, 2020). Instead, linear flows in the food production chain, allowing only for larger loops of food waste recycling, such as fertilisation with bio-based fertilisers for plant nutrient recycling, have been created. Two major barriers currently prevent disease transmission when recycling plant nutrients in food waste in the EU: (1) sanitisation prior to use, currently heat treatment for one hour at 70 °C or another treatment with similar effect; and (2) biological treatment such as digestion or composting.

6. Incorporating insects in food production systems

With the European Green Deal, the EU is in the process of moving step by step towards more circular flows. One way to advance this is the use of insects to increase circularity.

The EU has demonstrated a will to incorporate insects in its food production systems in recent years by:

- Authorising processed animal proteins obtained from insects reared on plant-based diets for use in aquaculture feed (European Commission, 2017) in 2017.
- Authorising processed animal proteins obtained from insects reared on plant-based diets for use in poultry and pig feed (European Commission, 2021a).
- Authorising four novel foods into the novel food legislation (European Commission, 2015b): dried, ground and frozen yellow mealworm (*Tenebrio molitor*) and house cricket (*Acheta domesticus*), and dried and frozen migratory locus (*Locusta migratoria*).
- Introducing regulations governing production and use of insect frass on the EU market (European Commission, 2021b).

The problem is that insects in the EU are currently reared predominantly on vegetable substrates such as side-streams from the food industry, because food waste is still considered too risky in terms of disease transmission to be used as insect feed. Although it is beneficial to use food industry waste in a resource-efficient way, these side-streams are best used for insects intended for human consumption or for production animals that have the capacity to utilise them directly (e.g. pigs). Many insects, such as fly larvae, and other invertebrates have been described as the waste managers of the environment (Fowles and Nansen, 2020) and in order to tap into the major environmental benefits that can be provided by insects, this is exactly how we should use them. In fact, according to Smetana *et al.* (2016), producing animal feed protein from black solider fly (*Hermetia illucens*) larvae reared on dried distiller's grains (a food industry side-stream) would result in a feed with the same environmental impact as commercial chicken feed and fish meal, while rearing the larvae on municipal waste would result in an animal feed with a considerably lower environmental impact. Here it should be stressed that even if the insects were not to be used as food or feed but perhaps for another technical use (e.g. production of bio-plastic), they are not allowed to be reared in any substrates containing animal by-products, because the insects themselves are classified as farmed animals. Therefore, insects cannot currently be used for any municipal waste management purposes in the EU. Having said that, using the insects solely for assisting the degradation of organic material does not entail the same environmental benefits as rearing them for use in feed and food.

In total, around 931 million tonnes of food waste were generated in Europe in 2019 (United Nations Environment Programme, 2021). In high-income countries in Europe, total food waste generation is 118 kg per person and day, and of this almost 70% is mixed household waste and as such not available as insect feed (United Nations Environment Programme, 2021). Consequently, the majority of food waste in Europe today can only be recycled for plant nutrients using other biological treatments.

7. Obstacles to closed loop insect systems

Biological contaminants

Many pathogenic microorganisms, such as the zoonotic bacteria *Salmonella* spp. and animal viruses such as adeno-, reo- and enteroviruses, are de-activated in black soldier fly larvae composting (Lalander *et al.*, 2015; Lopes *et al.*, 2020). However, it has also been shown that the eggs of the parasitic worm *Ascaris suum* are not as strongly affected by fly-larvae composting and can be found in the larvae at the end of treatment, particularly if the larvae are harvested in their feeding instars (Lalander *et al.*, 2013). Most pathogenic risks can be managed by the current treatment of animal by-product fractions, i.e. heating at 70 °C for one hour or a treatment with similar effect (Vinnerås *et al.*, 2003). This sanitisation step needs to be retained when considering the conversion of food waste into animal feed using fly larvae, but can be conducted as a final step in the process when harvesting and killing the larvae.

Van Looveren *et al.* (2022) investigated the occurrence of the vegetative state and spores of the foodborne pathogen *Clostridium perfringens* (spores of which are not deactivated by heat treatment at 70 °C) in an industrial black soldier fly larvae-rearing facility. Although low concentrations were present in the substrate used for the larvae, the occurrence of *Cl. perfringens* reproductive units in the larvae themselves was below the detection limit. These are positive findings, but there are other biological risks associated with *Clostridium* spp. that must be investigated more closely. Future studies on spore-formers need to consider the toxin-producing *Clostridium botulinum*. Its toxin is a concern in poultry production, and if *Cl. botulinum* enters a herd there is a risk of it spreading via carcasses and the litter bed, as well as via insects in the dead animals (Wobeser, 1997).

Chemical contaminants

Another concern is the fate of metal and non-metal pollutants in the black soldier fly composting process. Many pharmaceuticals and pesticides, as well as mycotoxins, are degraded in black soldier fly larvae composting, with no bio-accumulation in the larvae (Lalander *et al.*, 2016; Purschke *et al.*, 2017). These are also promising findings, but the heavy metals cadmium and lead have been observed to bio-accumulate in black soldier fly larvae (Purschke *et al.*, 2017). Van der Fels-Klerx *et al.* (2020) found that a number of chemical contaminants, most notably cadmium and mineral oils, also can bio-accumulate in black soldier fly larvae, although not at levels exceeding the permissible threshold in the EU. Monitoring the levels of heavy metals and chemical contaminants in incoming and outgoing material in the black soldier fly larvae composting process is an important part of quality assurance. The only way to ensure that metal contaminants do not end up in the larvae is to ensure that they do not enter the treatment process.

Prions

The greatest obstacle to achieving a fully circular food production system in the EU is the risks associated with prions, misfolded proteins that build up in the brain and cause transmissible spongiform encephalopathies (TSE – prion diseases). Prions can infect cattle, sheep/goat, moose/deer and humans, causing BSE, scrapie, chronic wasting disease and Creutzfeldt-Jakob disease, respectively (Centers for Disease Control and Prevention, 2018). Prions are highly stable and thus not inactivated in the standard sanitisation treatment for food waste (70 °C for 1 h). For inactivation, a treatment at 133 °C and 3 bar of pressure for 20 minutes is required (Ducrot *et al.*, 2008). In a black soldier fly larvae composting process of food waste, where proteins are concentrated in the larval biomass and used in feed production, it is crucial to determine what happens to prions. The main question to answer is whether the fly larvae can get infected and/or carry the resistant prions with them into the food production cycle. Otherwise, there is a risk of repeating the mistake of the 1970s, when it took over a decade after introducing the new process for meat and bone meal production before BSE was considered a zoonotic disease and a further decade before adequate restrictions were placed on meat and bone meal management throughout the EU (Vågsholm *et al.*, 2020). However, the failed circular food production system leading to the BSE outbreak in Europe involved calves and dairy cows being fed ruminant meat and bone meal (the most closed loop system possible). In contrast, the food production system we propose involves rearing insects on food waste not likely to contain prions (as specified, bovine offal suspected of being able to transmit prions has been prohibited in food use since 1989 (Vågsholm *et al.*, 2020)) and then feeding the insects to fish, poultry or pigs, but not to ruminant animals known to be susceptible to TSE. Feeding food waste to insects, rather than directly to farmed animals, lowers the risks of disease transmission. However, to avoid the mistakes of the past with failed circular food production systems, it is crucial to determine if there are any risks associated with prions in a circular insect food production system.

8. Conclusion

Insects are likely to play a vital role in increasing the circularity of future food production systems in the EU. In order to exploit the full potential of insects as recycling agents, food waste has to be used as one of the major insect feed substrates. More research funding is needed to rapidly overcome current obstacles to an insect-assisted circular flow of nutrients, to enable true Farm-to-Fork-to-Farm food production systems in the EU.

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