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Journal of Insects as Food and Feed

Dicke, M.

https://doi.org/10.3920/JIFF2018.0003

Journal of Insects as Food and Feed, 2018; 4(3): 147-156
SPECIAL ISSUE: Insects in European feed and food chains

Wageningen Academic Publishers

Insects as feed and the Sustainable Development Goals

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Received: 7 January 2018 / Accepted: 12 June 2018

REVIEW ARTICLE

Abstract

One of the Sustainable Development Goals (SDGs) of the United Nations is to achieve food security and improved nutrition. To be successful in feeding the rapidly growing human population, we need innovative changes in food production. The challenge of safeguarding food security is considerable because many potential solutions are incompatible with solutions for other challenges that we face, including climate change mitigation and halting the biodiversity loss. To produce animal proteins, we currently rely to a large extent on feedstuff for livestock that is either suitable as food for humans (e.g. cereals and soymeal) or on a resource that is becoming scarce due to overfishing of the oceans (fishmeal). To set a first step towards a circular approach to feed production, insects provide interesting opportunities as various species can be reared on organic waste streams, including waste streams of food production and manure. This paper discusses the opportunities for using insects as a valuable feed source for the production of livestock. Insects do not only provide excellent opportunities to replace fishmeal and soymeal, but may also have important additional benefits. These include positive effects on livestock health and welfare with opportunities to reduce antibiotic use in livestock production. This is discussed in the integrated context of five of the sustainable development goals. Recent entrepreneurial and regulatory developments underline the opportunities for employing insects as feed. In this development an important indirect effect may be that consumers get acquainted with insects as a valuable and sustainable component of the food chain. This may result in the acceleration of adopting insects as food and thus of producing mini-livestock as a sustainable source of animal protein.

Keywords: food security, climate change, biodiversity, health, welfare

1. Introduction

In September 2015 the General Assembly of the United Nations adopted a resolution to 'shift the world on to a sustainable and resilient path'. A total of 17 Sustainable Development Goals (SDGs) were formulated, with the main ones being to end poverty (SDG 1) and hunger (SDG 2). This plan was entitled 'the 2030 Agenda for Sustainable Development' and focusses on issues of critical importance for humanity and the planet (United Nations, 2015). These 17 SDGs comprise a coherent set of integrated goals.

SDG 2 aims to achieve food security and improved nutrition and promote sustainable agriculture. This is a true challenge because of the rapid growth of the human population that is projected to reach 9-10 billion in 2050. This SDG is directly connected to several others (United Nations, 2015), of which I will highlight four (Figure 1A).

SDG 13 is to take urgent action to combat climate change and its impacts. This SDG is not only important in its own right, but also because climate change is likely to result in a yield decrease rather than increase in many areas (Figure 1B: 1), especially those that currently are food insecure (Wheeler and Von Braun, 2013). Therefore, reaching SDG 13 supports reaching SDG 2.

SDG 12 is to ensure sustainable consumption and production patterns and achieve sustainable management and efficient use of natural resources while substantially reducing waste generation through prevention, reduction, recycling and reuse. This connects to SDG 2 because it aims,

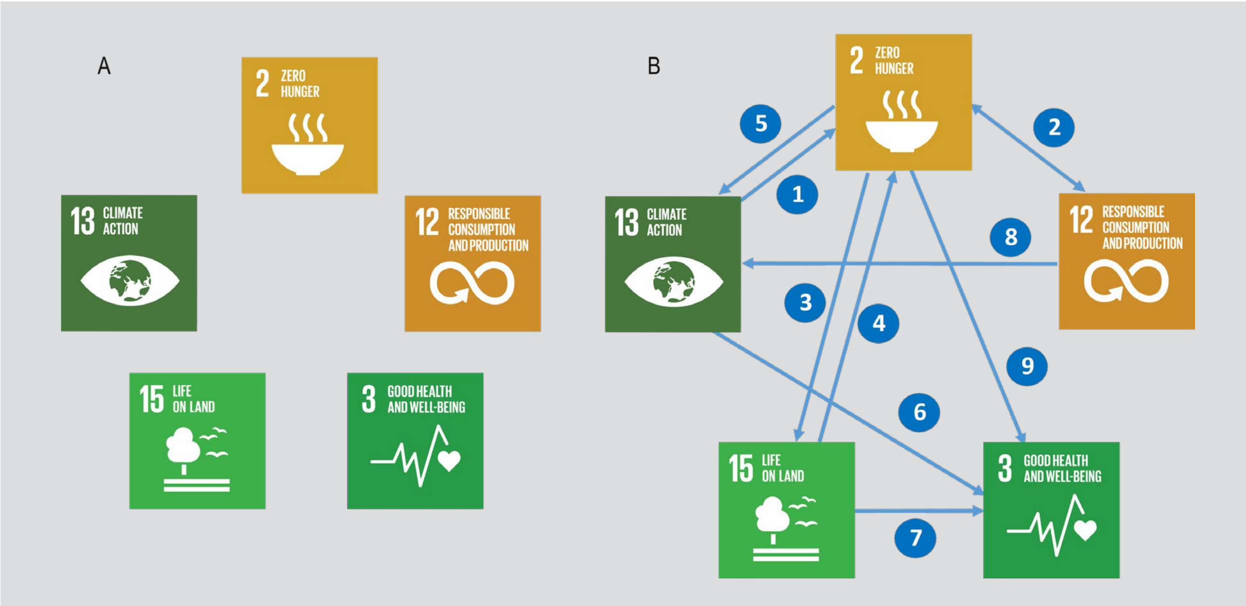

Figure 1. (A) Five of the 17 Sustainable Development Goals (SDGs) of the United Nations that have a relation to achieving food security and improved nutrition and promoting sustainable agriculture. (B) Interconnectedness of the five SDGs as discussed in this paper. Numbers next to arrows refer to numbers referred to in the main text.

among others, at substantially reducing waste generation and at reducing wasteful consumption. In other words, this SDG aims at a circular economy. Different food production systems differ in environmental impacts (Clark and Tilman, 2017), underlining the connection between SDGs 2 and 12. Moreover, the increased use of coarse grains such as maize for biofuel instead of food (threefold increase in the period 2004-2014; OECD/FAO, 2015), interferes with food security, a phenomenon termed the food-versus-fuel trade-off (Figure 1B: 2).

SDG 15 aims to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. This is relevant to SDG 2 because intensification of food production and an increase in agricultural area negative impact on biodiversity (Steinfeld *et al.*, 2006) (Figure 1B: 3). Yet, biodiversity provides vital ecosystem services that facilitate environmentally benign food production, including pollination, natural pest control and fertile soil conditions (Costanza *et al.*, 2014) (Figure 1B: 4).

SDG 3 focusses on ensuring healthy lives and promoting well-being for all at all ages. This is directly connected to food security because sufficient food of adequate quality is vital for good health (Black *et al.*, 2008; Müller and Krawinkel, 2005).

Because these challenges to reach the SDGs are closely connected, addressing them as a whole requires innovative solutions. One of the solutions for food insecurity consists of making fundamental changes in the production of food and feed as a result of constraints in the availability of resources, water, land, and energy (Foley *et al.*, 2011; Godfray *et al.*, 2010). For instance, the FAO estimated that we need to more than double food production towards 2050 compared to the level in 2005 (FAO, 2009). Effectively making such fundamental changes also requires economics based on circularity and consideration of resource limitations (Raworth, 2017).

2. Protein supply

A dominant issue in food security is the production of sufficient high-quality proteins, which currently relies mainly upon the production of livestock. However, livestock production presently requires as much as 70% of all agricultural land (Steinfeld *et al.*, 2006) and contributes tremendously to greenhouse gas emission (Hedenus *et al.*, 2014; Lesschen *et al.*, 2011), thus contributing to climate change (Figure 1B: 5). Most of this is the result of the use of human food as feed for livestock, and the inefficient conversion of feed to meat by especially cattle (Oonincx and De Boer, 2012). An interesting alternative source of proteins is provided by insects (Van Huis *et al.*, 2015): insect nutritional quality is comparable to that of conventional meat (Van Huis *et al.*, 2014), yet insect production has a much smaller ecological footprint, in terms of land and water use and greenhouse warming potential compared to the production of chicken, pigs and cattle (Halloran *et al.*, 2016; Oonincx and De Boer, 2012; Van Huis *et al.*, 2013). This is especially due to the much better feed to meat conversion ratio of insects: approximately 2.2 kg of feed is required per kg of edible weight production for crickets, whereas this is more than 10 times higher (25 kg per kg edible weight produced) for beef (Van Huis, 2013; Van Huis *et al.*, 2014). Moreover, important feed sources for livestock production currently include fishmeal and soymeal, both competing with availability as a food source to humans. For instance, these protein sources make up more than half of salmon feed, which contained 18% fishmeal and 37% soymeal in 2013 (Ytrestoyl *et al.*, 2015). Since 1990, the total contribution of soymeal and fishmeal in salmon feed has remained stable but fishmeal has been gradually replaced to a large extent by soymeal (Ytrestoyl *et al.*, 2015). The replacement of fishmeal by plant protein is a global trend in salmon and shrimp feed (FAO, 2016). This should be seen in the context of the fact that more than 85% of fish stocks are fully exploited or overexploited, whereas aquaculture continues to increase (Deutsch *et al.*, 2007; FAO, 2016) (Figure 1B: 3). This underlines that using fishmeal as feed has become highly unsustainable.

Current feedstocks include cereals that are suitable as food for humans. For instance, in 2012-2014 approximately 838 megatons, constituting 34% of the total global production of cereals, were used as feed instead of food (OECD/FAO, 2015). The amount of cereals used as feed is expected to rise to 1,100 megatons in 2050 (Alexandratos and Bruinsma, 2012). Thus, in 2050 up to 50% of global cereal production is expected to be used as feed instead of food (HPLE, 2016) and this is also visible in the rapid increase in the area of land used to produce maize and soybean, the two main crops used in animal feed: an increase of approximately 56 million hectares in the first decade of the 21st century (HPLE, 2016).

Finding alternative protein feed sources that do not compete with food will, therefore, provide an important contribution to food security. A promising option is to use insects as feed. In this context, it is interesting that various insect species can be reared on substrates that are not suitable for human consumption such as crop residues and waste streams derived from food production.

3. Insects for feed

Insects represent the most biodiverse group of animals on our planet. They occupy many niches, and provide a wide range of ecosystem services (Dicke, 2017). Insects are an important food source for a large range of animals. For instance, 89% of North American birds are primarily (61%) or partially (28%) insectivorous (Losey and Vaughan, 2006) and many other animal groups include insectivores such as bats, fish, frogs, lizards, moles, shrew, boar, and great apes (Deblauwe *et al.*, 2003; Henry *et al.*, 2015; McGrew, 2014; Schley and Roper, 2003). Among farmed animals, chicken, pigs and many fish species readily consume insects when given the chance (Van Huis and Tomberlin, 2017b; Veldkamp *et al.*, 2012). Among the insects that can be used as feedstuff are flies, crickets, mealworms and silkworms. The insects that seem to be best suitable as feed for livestock include larvae of the black soldier fly (*Hermetia illucens*; BSF), housefly (*Musca domestica*), and yellow mealworm (*Tenebrio molitor*). Many fly species are detritivores that feed on decomposing plant- and animal-derived substrates, such as dead plants, fungi or animals, as well as animal faeces (Barragan-Fonseca *et al.*, 2017; Cickova *et al.*, 2015; Tomberlin and Cammack, 2017). Many of these substrates are not themselves suitable as food or as feed ingredients for livestock and the fly larvae convert these waste streams into high-quality protein. For instance, BSF larvae contain protein levels representing 37 to 63% of dry matter, dependent on the substrate on which they were reared (Barragan-Fonseca *et al.*, 2017; Makkar *et al.*, 2014). The amino acid composition of BSF, as well as other insects, compares favourably to that of soybean meal (Barragan-Fonseca *et al.*, 2017; Finke and Oonincx, 2017; Makkar *et al.*, 2014). Flies and other insects also have a good fat composition, including high levels of polyunsaturated fatty acids (Makkar *et al.*, 2014). In some species, such as the BSF, the composition of the fatty acid components of the fat can be atypical: BSF contains high levels of lauric acid (Finke and Oonincx, 2017). Just like other animals, insects cannot biosynthesise the polyunsaturated fatty acids linoleic and linolenic acid. Yet, also here exceptions exist: the American cockroach *Periplaneta americana* is capable of synthesising these two polyunsaturated fatty acids (Finke and Oonincx, 2017).

Insects are rich in micronutrients important for animal health and development, such as iron, zinc and vitamins (Rumpold and Schluter, 2013) which further adds to the nutritional value of insects. These micronutrients are important nutritional elements, that many people have a deficiency of (Black *et al.*, 2008). Anaemia caused by iron deficiency affects one quarter of the world's population and is concentrated in preschool-aged children and women in especially Africa, Asia and Latin America, and to a lower extent in Europe, making it a global public health problem (McLean *et al.*, 2009). Zinc deficiency in Latin America, Africa and Asia results in a substantial disease burden among children less than 5 years of age resulting in approximately 453,000 deaths and 16 million disability-adjusted life years each year (Fischer Walker *et al.*, 2008). *In vitro* studies have shown that iron and zinc from insects may be bioavailable. If this is confirmed by *in vivo* studies this would mean that insects rich in iron and/or zinc can provide a valuable source of these micronutrients (Latunde-Dada *et al.*, 2016; Mwangi *et al.*, in press). In conclusion, insects are qualitatively interesting as feedstuff, not only in terms of protein.

4. Substrates to rear insects for feed

Among the insect species that are most promising as feedstuff, the two fly species (BSF and housefly) can be successfully reared on plant-derived and animal-derived substrates, including e.g. fruit remains such as mango peels, vegetable remains such as waste of pea production, biogas digestate, restaurant waste and livestock manure (Makkar *et al.*, 2014; Spranghers *et al.*, 2017; Wang and Shelomi, 2017). Whereas some of these substrates, such as fruit and vegetable remains, can also be used as feed for livestock, other substrates are unsuitable for this. For instance, livestock manure or even human faeces can be used to rear fly larvae (Barragan-Fonseca *et al.*, 2017; Makkar *et al.*, 2014). Thus, fly production can alleviate health problems associated with poor sanitation and inadequate human waste management (Banks *et al.*, 2014), which is currently practiced by sanitation companies such as Sanergy in Kenya and BioCycle in South Africa. Fly larvae commonly live in microbe-rich environments and the microbial composition of their feeding substrate may influence the performance of the fly larvae. The composition of the substrate may influence larval development time and yield but the protein content and quality is consistently high for BSF larvae fed on different diets (Barragan-Fonseca *et al.*, 2017; Makkar *et al.*, 2014; Spranghers *et al.*, 2017). Thus, various substrates can be used for the production of fly larvae and those not suitable for other uses in the food chain are most interesting from a food security standpoint as they avoid the food-versus-feed trade-off (Figure 1B: 2).

Yellow mealworms can also be reared on a variety of substrates including various plant-based waste streams such as bread remains, brewer's waste stream and potato peels (Van Broekhoven *et al.*, 2015), but are commonly reared on plant-based substrates based on flour supplemented with vegetables and fruits (Makkar *et al.*, 2014). These plant-based substrates can also be exploited as food and feed themselves, reducing their contribution to alleviating the food-versus-feed trade-off.

The choice of substrate will be influenced by the goal of the insect producer, as well as regulatory restrictions. When high production rates are dominant, high-quality substrates are likely to be favoured and these likely include components that can also be used as food for humans or can be used directly as feed for livestock (Lundy and Parrella, 2015). However, when waste reduction and circular economic motives are primary incentives, then lower quality substrates such as manure or low-quality plant-based substrates may be selected.

5. Waste stream of insect production

Even when insects can be fed with waste streams and are highly efficient in converting feed into biomass, insect production itself also yields a waste stream, consisting of moulting skins (exuviae), that consist for a large part of chitin, as well as insect faeces ('frass'). Although insect frass emits greenhouse gases, the rate of greenhouse gas emission per unit weight is much lower than for vertebrate manure (Oonincx *et al.*, 2010). Thus, while producing a high-quality protein source, the original waste stream has been reduced considerably and per unit its contribution to global warming is reduced as well. The waste stream from insect production may be used as fertiliser in agriculture (Kagata and Ohgushi, 2012) and various companies already sell insect frass as fertiliser: e.g. Flytilizer X (https://protix.eu/products_by_protix) or Magsoil (https://agriprotein.com/our-products). This further contributes to developing circular economy models of insects for feed (Figure 2).

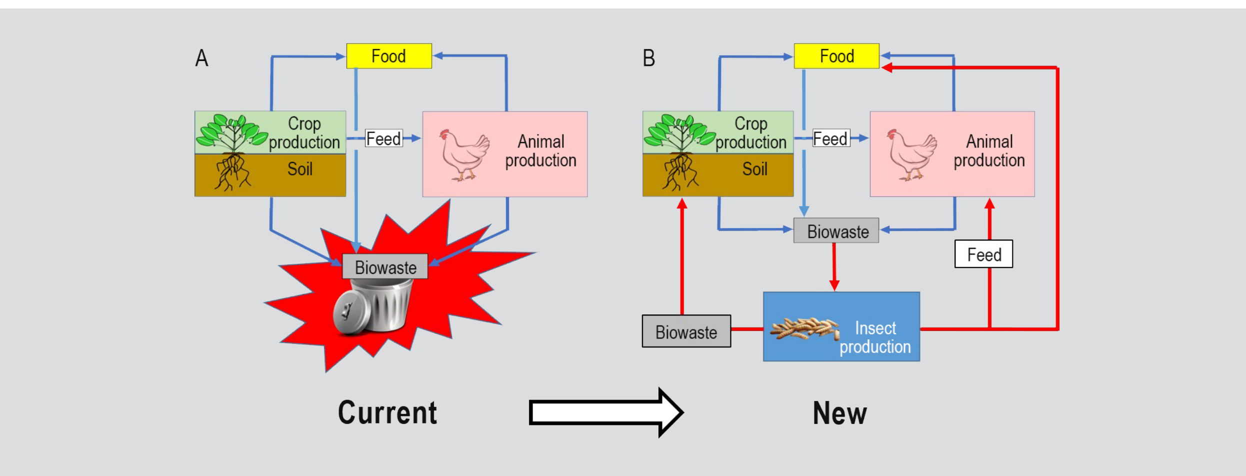

Figure 2. Insects can transform organic waste streams ('biowaste') into high-quality animal protein for food and feed. (A) current situation; (B) future situation, where red arrows indicate new biomass streams.

6. Suitability of insects as feed in terms of livestock or fish performance

The insect species that are potential sources of feed all have high levels of protein and the amino acid composition compares favourably to currently used feedstuffs such as soymeal or fishmeal (Makkar *et al.*, 2014; Van Huis *et al.*, 2013; Veldkamp *et al.*, 2012). Also, fat content and composition contribute to these insects being promising alternative feedstuffs for livestock (Makkar *et al.*, 2014). Yet, nutritional composition of the different insect species varies and so do the requirements of livestock and fish species that may be fed with the insects. Thus, the use of insects as feed requires system-specific investigations, as is common practice in all animal nutrition scientific research (e.g. Poppi and McLennan, 2010). A rapidly growing body of literature indicates that BSF, housefly and yellow mealworm are promising components of feedstuffs that can replace soymeal or fishmeal, either partially or completely (Makkar *et al.*, 2014; Van Huis and Tomberlin, 2017b; Veldkamp *et al.*, 2012). For instance, replacing soybean cake for 50 or 100% by defatted BSF larvae did not affect laying hen performance, as assessed by various parameters (Maurer *et al.*, 2016) and replacing soybean oil in the diet of broiler chicken by BSF larval fat resulted in similar broiler performance as for control broiler chicken (Schiavone *et al.*, 2017). BSF larvae can also effectively replace fishmeal or soymeal in whole or in part in pig feed (Newton *et al.*, 1977) or fish feed (Makkar *et al.*, 2014). For instance, when 85% of fishmeal and soymeal were replaced by insectmeal derived from BSF larvae, this did not affect salmon growth (Belghit *et al.*, 2018). In rainbow trout, inclusion of defatted BSF larvae up to 40% replacement of fishmeal did not impact growth and development (Renna *et al.*, 2017). Also, house fly and yellow mealworm larvae have proven to be good replacements of soymeal or fishmeal in feed for various production animals (Makkar *et al.*, 2014; Veldkamp and Bosch, 2015; Veldkamp *et al.*, 2012). The insects do not need to be fed as whole insects. For instance, production of BSF larvae can be used to produce protein meal as well as insect oil, both of which can be used separately in the production of feedstuff (Li *et al.*, 2016; Maurer *et al.*, 2016). In conclusion, different edible insect species can replace current components of animal feed in part or fully with no consequences, or sometimes even beneficial effects on farmed animals in terms of production or performance.

7. Insects in feed to promote livestock health

In some instances, the production or performance of livestock is improved as a result of the inclusion of insects (Makkar *et al.*, 2014). For instance, broiler chicken fed with mealworm larvae were better protected against oral challenge with *Salmonella* or *Escherichia coli* infection (Islam and Yang, 2017). Mealworm inclusion in the broiler's feed enhanced immunoglobulin levels and reduced mortality, potentially reducing the use of antibiotics (Islam and Yang, 2017). Several insect species, such as the mealworm *T. molitor,* the locust *Schistocerca gregaria* and the cricket *Gryllodes sigillatus* were found to be a rich source of bioactive peptides with antioxidant and anti-inflammatory activities (Zielinska *et al.*, 2017). At least 50% of the insect exoskeleton is composed of chitin, a high-molecular amino-sugar polysaccharide, and the second-most abundant polymer on Earth after cellulose. Chitin and its derivatives have antiviral, antibacterial and antitumor activities (Benhabiles *et al.*, 2012; Chirkov, 2002; Jeon and Kim, 2002; Lee, 2009; Tokura *et al.*, 1992) and immunological effects have been reported as well (Van Huis *et al.*, 2013). Chitin and its derivative chitosan are known to influence innate and adaptive immune responses in vertebrates (Figure 1B: 9). This is a topic that deserves to be studied intensively as it may imply that using insects as feed does not only replace other protein sources but may actually have additional benefits, not provided by soymeal or fishmeal.

Anecdotal observations indicate that livestock such as chicken preferentially consume live insects over cereals. Whether the supply of insects improves livestock welfare remains to be investigated and this is an important knowledge gap.

In conclusion, the use of insects as feed may result in improved health and welfare and potentially also in the reduction of antibiotic use in livestock production (Figure 1B: 9).

8. Insects as feed in the context of the SDGs

As indicated in the Introduction, an action agenda of 17 SDGs has been adopted by the United Nations and at least five of these are directly or indirectly connected to feeding the growing human population sustainably (Figure 1). The use of insects as feed has consequences for all five challenges.

SDG 2

In terms of food security, land use is a major issue when searching for opportunities to increase food production so as to ensure food security. To a large extent the enormous proportion of land required for livestock production (Steinfeld *et al.*, 2006) is caused by the use of a large part of crop production as feed instead of food (HPLE, 2016). To accommodate an increase in food production to enable food security by 2050, we will have to reconsider meat production as a whole in terms of (partial) alternatives for meat as well as alternatives for feedstuff. After all, at present cattle biomass on our planet is around 60% larger than human biomass (Smil, 2017). Insects are highly promising components of feed for chicken, pigs and fish.

Moreover, because insects provide a high-quality feedstuff that can be reared on waste streams, their use makes a large contribution to the reduction of land use for livestock production.

SDG 13

In addition to land use, livestock production also contributes considerably to greenhouse gas production and thus climate change (Figure 1B: 5) (De Vries and De Boer, 2010; Steinfeld *et al.*, 2006) and insects can provide important alternatives having much lower greenhouse gas emission rates (Oonincx and De Boer, 2012; Oonincx *et al.*, 2010).

SDG 12

Insects can replace the use of soymeal and fishmeal, at least partially. Especially when organic waste streams such as manure and crop residues can be used, this contributes to a sustainable production pattern and a circular economy. Whether these feeding substrates provide a contribution to mitigating climate change is dependent on current use of such organic waste streams. For instance, if such waste streams were previously used in bio-energy production, then exploiting them now for the production of insects as feed may result in a reduction of land use. However, if the bio-energy production that was based on the waste stream is replaced by the use of fossil fuels instead of solar energy, the effects on mitigating climate change may be lost (Van Zanten *et al.*, 2015). Therefore, changes in food production can influence climate change via consequences in the context of a circular economy (Figure 1B: 8). Studying these direct and indirect effects of changes in the production of food and feed can be done with life-cycle assessments (Halloran *et al.*, 2016; Oonincx and De Boer, 2012; Van Huis and Oonincx, 2017; Van Zanten *et al.*, 2015). The outcome of life-cycle assessments is dependent on the extensiveness of the perspective taken (Van Zanten *et al.*, 2015). Current life-cycle assessments underline the importance of taking the wider perspective that does not stop at considering the production of food but also includes indirect consequences that may result in a trade-off between effects on land use and climate change mitigation (Van Zanten *et al.*, 2015). Developing renewable energy sources such as solar energy will be important to avoid such trade-offs and will further allow changes in food production to fit in a circular economy that re-uses natural resources.

SDG 15

Human activities have an ever increasing effect on our planet and the biological diversity and its biomass on Earth is diminishing at unprecedented pace (Dirzo *et al.*, 2014; Hallmann *et al.*, 2017). Livestock production contributes substantially to the reduction of biodiversity and also here an important driver is land use (Figure 1B: 3) (Clark and Tilman, 2017; Steinfeld *et al.*, 2006). Therefore, any changes in livestock production that reduce land use are likely to mitigate biodiversity reduction. Replacing soymeal by insects raised on waste streams can make a considerable contribution to this (Van Zanten *et al.*, 2015).

SDG 3

Undernourishment is an important issue with 795 million people being undernourished in 2015 (FAO IFAD and WFP, 2015). Animal proteins are important for human development and human health (Black *et al.,* 2008). Yet, the high rate at which animal proteins are currently consumed in especially the developed world comes with increasing health issues (e.g. Pan *et al.*, 2011). Reduction of meat consumption in high-income countries, therefore, not only contributes to food security but also to public health (Figure 1B: 9). Moreover, food production also influences human health indirectly, e.g. via effects through climate change (Figure 1B: 6) or biodiversity (Figure 1B: 7) (Gasparrini *et al.*, 2017; Van den Bosch, 2017). Thus, searching for solutions to the five SDGs presented in Figure 1 is tightly linked with the challenge of producing healthy food for humankind that is independent of per capita income. Thus, innovations in sustainable food production have closely connected diet, environment, and health components (Tilman and Clark, 2014).

Other SDGs

Using insects as feed can improve sanitation when the insect can be reared on human faeces (SDG 6, Ensuring availability and sustainable management of water and sanitation for all). Collecting human faeces in slums promotes health (Mark *et al.*, 2015) and when the faeces can be used as substrate for insects such as fly larvae, they will yield a source of feed and fertiliser, thus contributing to SDGs 2 and 12. The world has seen a sharp increase in number of conflicts in the last decade and these conflicts may either be the cause of food insecurity or the consequence of food insecurity. Thus, striving for food security is closely connected to SDG 16: Promoting peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels. In conclusion, reaching several of the SDGs is closely connected to how we produce food for the growing human population, and especially what drastic changes we will make in food production.

9. Consumer acceptance

Insects are part of the regular diet of approximately 2 billion people, usually as a delicacy (Van Huis, 2013). Although this novel protein source also gains acceptance in countries where people were not used to this six-legged source of animal proteins, its acceptance requires time and convincing arguments (Van Huis *et al.*, 2014; Vantomme, 2017; Verneau *et al.*, 2016). Especially environmental aspects are convincing and important arguments to link the SDGs that were introduced in Figure 1 (Annan, 2015). Yet, the acceptance of insects as feed is usually higher than the acceptance as food to people that do not have a history of including insects in the food chain (Laureati *et al.*, 2016). The acceptance of insects as feed was reported to be high in European countries with different cultural and culinary backgrounds (Mancuso *et al.*, 2016; Verbeke *et al.*, 2015). For instance, whereas acceptance of insects as food is still low in Italy (Laureati *et al.*, 2016), acceptance as fish feed reaches 90% in a recent study (Mancuso *et al.*, 2016). For insects to be generally accepted, a stepwise approach seems to be the way to go. Introducing insects as feed may not only be a way to provide a feed source that contributes to solving some of the major challenges that humankind faces, but may also be a crucial step forward towards the acceptance of insects as mini-livestock, thus making an important contribution to food security.

In recent years, interesting developments have been made in the private sector regarding the production of insects as food and feed (Hanboonsong *et al.*, 2013; Van Huis *et al.*, 2013) ranging from smallholder farmers to capital-intensive companies. Recent analyses of the opportunities for private enterprises concluded that these are very promising indeed, with the latest estimation of the market size for insects as feed amounting to more than 1 billion US$ in 2022 (Van Huis and Tomberlin, 2017a). This is a clear sign that the acceptance of insects as feed has excellent prospects. Moreover, also legislation is being adapted to accommodate for food safety regarding insects as feed and food. For instance, since July 2017, regulations have been developed for insects as feed in aquaculture in the European Union (Byrne, 2016) and the use of insects as feed was legalised in Kenya in 2017 (KEBS, 2017). For an overview of the legal status of edible around the globe, see Reverberi (2018). The Thai Ministry of Agriculture has published the first Good Agricultural Practices for cricket farming (Scattergood, 2018). These are likely first regulatory steps on the path towards redesigning global food production in the context of accommodating up to 10 billion people (EFSA, 2016).

10. Conclusions

In addressing the challenge to feed the rapidly growing human population in a sustainable way, we need to account for consequences of potential solutions in the broader context of mitigating climate change, the food-versus-feed trade-off, the food-versus-fuel trade-off, mitigating biodiversity loss and promoting human health in addition to producing sufficient food. Moreover, we may have to reconsider what healthy food is in the context of a circular economy that takes planetary health in account. Insects likely provide an important component of future food systems not only by replacing other sources of protein or fat but also by providing additional benefits such as health-promoting constituents. Thus, insects may provide an important contribution to several of the SDGs and thus to shifting the world on to a sustainable and resilient path.

Acknowledgements

The insightful comments by an anonymous reviewer on a previous version of the manuscript have been very helpful and are gratefully acknowledged. The author's research on insects for food and feed is financially supported by the Netherlands Organisation for Scientific Research WOTRO Science for Global Development and the Wellcome Trust.

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