Protein transition in Colombia: Insects as feed in a circular agriculture

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Report of Seed Money Project SMP2016,
funded by Topsector Tuinbouw en Uitgangsmaterialen and Topsector Agri & Food

Wageningen, December 2020

WAGENINGEN UNIVERSITY & RESEARCH

UNIVERSIDAD NACIONAL DE COLOMBIA

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Foreword

In the context of the innovation agenda of the Topsector Agri & Food - Seed Money Project (TKI SMP20016) - a study was conducted on “Protein transition in Colombia: Insects as feed in a circular agriculture”.

Among the major challenges that society faces are providing sufficient food for the rapidly growing human population (SDG2), alleviating poverty (SDG1), producing food in a sustainable way by limiting the contribution to climate change (SDG13), conserving biodiversity (SDGs 14 and 15), through responsible consumption and production (SDG12). The development of a circular agriculture provides an important contribution to addressing these challenges.

With the expected growth of the human population towards 9-10 billion people by 2050, a projected increase in global food production of at least 60 percent above 2006 levels is required. However, the food system is a major driver of climate change, so that reductions in food loss and waste are required as well. Current feed production for livestock competes with food production for humans (e.g. cereals and soymeal) or relies on resources that threaten biodiversity (e.g. overfishing for fishmeal). Moreover, soymeal and fishmeal are imported, non-circular and expensive feed components.

For a novel, circular and sustainable approach to feed production, insects provide excellent opportunities because various species can be reared on organic left-over streams. In recent years, insect production for feed has been initiated and this industry is expected to grow exponentially in the near future. Moreover, the production of insects as feed also provides important opportunities for improving livelihood of smallholder farmers and developing inclusive business and reduction in production costs.

This report presents the findings of the Seed Money Project that aimed to identify the opportunities and first steps to be made towards implementing a protein transition by using insects as feed for poultry in Colombia. The project focussed on investigating the opportunities, challenges and need of knowledge for developing Black Soldier Flies as feed in Colombia, based upon initial experiences.

The project team consisted of the following project members:

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Abbreviations

BSF	Black Soldier Fly
EFSA	European Food Safety Authority
FENAVI	Federacion Nacional de Avicultores de Colombia
ICA	Instituto Colombiano Agropecuario, Colombian Agricultural Institute
INVIMA	Instituto Nacional de Vigilancia de Medicamentos y Alimentos, Colombia National Food and Drug Surveillance Institute
SDG	Sustainable Development Goals
SMP	Seed Money Project

Summary

To feed the forecasted nine or ten billion people in 2050, an increase in food production based on current production methods is not feasible. Novel methods need to be developed to generate sufficient food of high quality in a sustainable way. The Dutch Ministry of Agriculture, Nature and Food Quality aims to develop circular agriculture to develop such innovative ways of producing high quality food with a lower ecological footprint. One of the challenges of food security is to provide sufficient proteins. Currently, livestock is produced as protein source and they are fed with protein sources that can also be used as food for humans, such as cereals, soybeans and fishmeal. An emerging alternative for these protein sources is provided by insects. Insects are high in protein levels and various species can be reared on organic left-over streams that cannot serve as food for humans.
Colombia imports large volumes of cereals and soybeans as protein components of feed for livestock and two thirds of this is used by the poultry sector. This is not sustainable and alternatives are needed, preferably generated through circular approaches.
Internationally, many initiatives have been made to develop insects as feed, especially in Asia, Europe, Africa and North America. With partners from Colombia and the Netherlands, we have investigated the opportunities of developing insects for feed in Colombia, with a focus on the black soldier fly, a species that is used worldwide as feed and that originates from the tropical and subtropical American regions. The consortium consisted of small and large private industry, academia and the Dutch embassy in Bogotá. We have identified the opportunities, challenges as well as legislation and knowledge needs.

We conclude that there is great interest in developing black soldier flies for feed in Colombia by (a) insect farmers, (b) poultry farmers, (c) feed producers and (d) academia. Dutch private industry and academia are willing to help in developing this transition. There is a good basis for addressing the local knowledge gaps. The results of this SMP will be used for developing a plan for the next steps.

Introduction

Achieving food security continues to be a global challenge, which is under pressure due to the growth of the human population, increasing urbanization, and dietary changes (FAO, 2018). To meet with this challenge, an increase in food production is needed. Moreover, food security is linked to social stability, with armed conflicts threatening food production and causing food insecurity while food insecurity may lead to social destabilisation (Barragán-Fonseca et al., 2020). For these reasons, producing food is an important aspect of the Sustainable Development Goals (SDGs) which were formulated in a UN resolution in 2015 (Dicke, 2018; United Nations, 2015).

Our food production system has a large impact on global climate and biodiversity. Agriculture contributes considerably to global greenhouse gas emission, thus contributing to climate change (Hedenus et al., 2014; Poore & Nemecek, 2018). To feed the human population, habitable land has been converted from nature to cropland and as a result, the food production system utilizes approximately 50% of all habitable areas in the world (Ritchie & Roser, 2013). While food is being produced more efficiently and with a higher output per surface area than in the past, still more land would be needed in the future to upscale food production to feed the world when the food production systems does not change. This directly threatens the remaining natural areas in the world and, thus, biodiversity.

Of the land currently used for agriculture, 71% is used to produce feed for livestock rather than food that is consumed by humans directly (Ritchie & Roser, 2013). Some of the crops used as feed for livestock, such as cereals and soybeans, could be used for human consumption instead. Other sources of animal feed, such as fishmeal, rely on wild fish stocks and unsustainable use of these resources (overfishing) threatens biodiversity and depletes these resources for future use (Dicke, 2018). Feed is also often imported from other areas in the world, which involves energy for transport, creates a dependency on availability of this feed and competition with other countries for feed (Deppermann et al., 2018). As the demand for animal protein keeps rising, alternatives for these feed sources are urgently needed to ensure the sustainable use of resources.

The difficulties in upscaling food production using the current food system show that a different approach to food production is needed (Godfray et al., 2010). Recently, circular agriculture has gained attention. For example, in 2018 the Dutch Minister of Agriculture launched their vision on agriculture, which includes circular agriculture (Ministerie van Landbouw, 2018). Circularity aims to reduce waste that is produced in linear chains by linking this ‘waste’ to other supply chains, drawing from ecological principles, where one organism’s ‘waste’ is another organism’s resource. Eventually, resources from waste are reclaimed and feed back into the system, leading to more efficient use of resources. This ‘closing of the loop’ results in a circular system in which leftover streams are not considered waste, but resources for other elements of the food chain (Ministerie van Landbouw, 2018).

Insects can play an important role in circular agriculture because certain species grow well on organic waste streams such as agricultural by-products, side streams of food industry, kitchen waste or even manure and convert these resources into proteins, fats and micronutrients (Dicke, 2018). The insects produced are highly nutritious for livestock, such as poultry (Schiavone et al., 2017; Van Huis & Tomberlin, 2017; Veldkamp & Bosch, 2015).

The Black soldier fly (BSF, *Hermetia illucens*) is a detritivorous insects that is present in tropical and subtropical regions of the world. Larvae can develop on diverse waste streams including vegetable and fruit waste as well as animal manure resulting in significant waste reduction and high nutritional quality

insect biomass (Barragan-Fonseca et al., 2017; Bosch et al., 2019; Chia et al., 2018b; Gold et al., 2018). Larvae can be harvested after about two weeks under optimal diet and temperature conditions (Barragan-Fonseca et al., 2017; Chia et al., 2018b). Amino acid content is high (1.3-12.8%), which is comparable with fishmeal (2.1-13.1%) and soybean meal (1.3-20.7%)(Barragan-Fonseca et al., 2017). However, fat content of the larvae is significantly higher (approx. 30% based on wet weight), so only a partial replacement of above-mentioned ingredients is possible, or a defatting procedure is required for higher inclusion rates. BSF is not considered a pest and is not known as a vector of diseases. Adults are not attracted to human habitats and do not constitute a nuisance. These characteristics make BSF an attractive insect species for animal feed. Because BSF can be reared on various organic side streams and because it upgrades these low-value side streams into a high-value source of protein and fat, the production of BSF provides an interesting component to circular agriculture. Thus, BSF makes a sustainable contribution to a food production sector that currently depends largely on soybean meal (competition with food production) and fishmeal (biodiversity issue) as protein source.

The leftover streams from insect production, frass and residuals from the substrates, can be used as fertilizers in crop production (Schmitt & de Vries, 2020). This way, insects are able to close yet another loop and contribute even more to circularity (Figure 1, Dicke, 2018). Additionally, there are other benefits of insects in terms of sustainability. Insects use little land and water, which is an advantage in areas where land for growing feed is scarce and where water shortage limits crop growth.

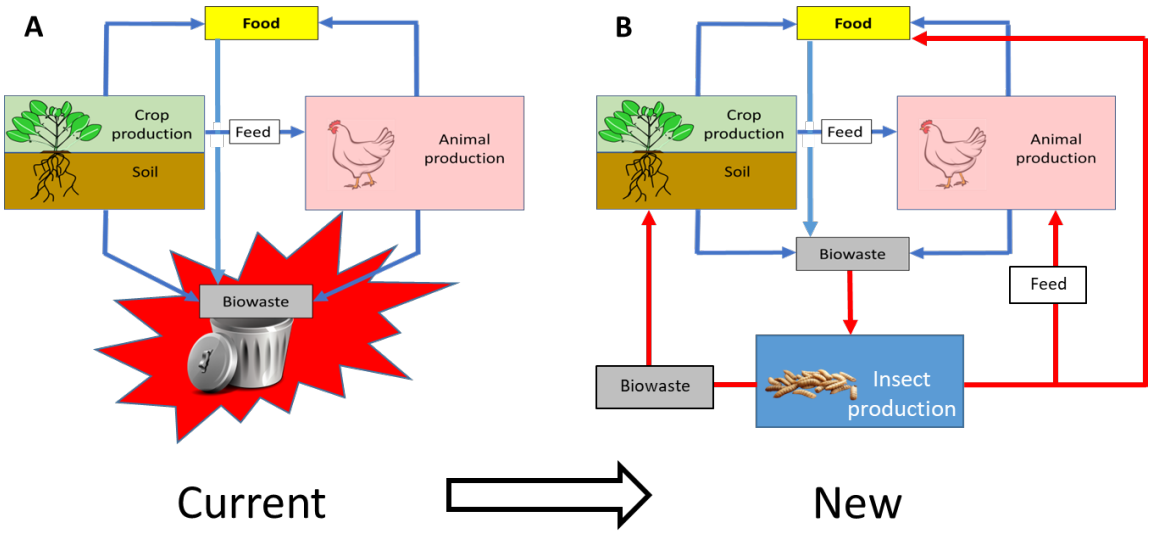

Figure 1. Potential of insects as feed in a circular agriculture. From Dicke (2018).

Developing a circular agriculture that is based upon insects as feed to replace unsustainable feed imports, does not only address SDG2 (zero hunger), but also SDG3 (health and wellbeing), SDG12 (responsible consumption and production), SDG14 (climate action), SDG15 (life on land), SDG14 (life below water) and SDG16 (peace and justice) (Figure 2, Barragán-Fonseca et al., 2020). Moreover, developing such a circular agriculture requires a multi-stakeholder approach.

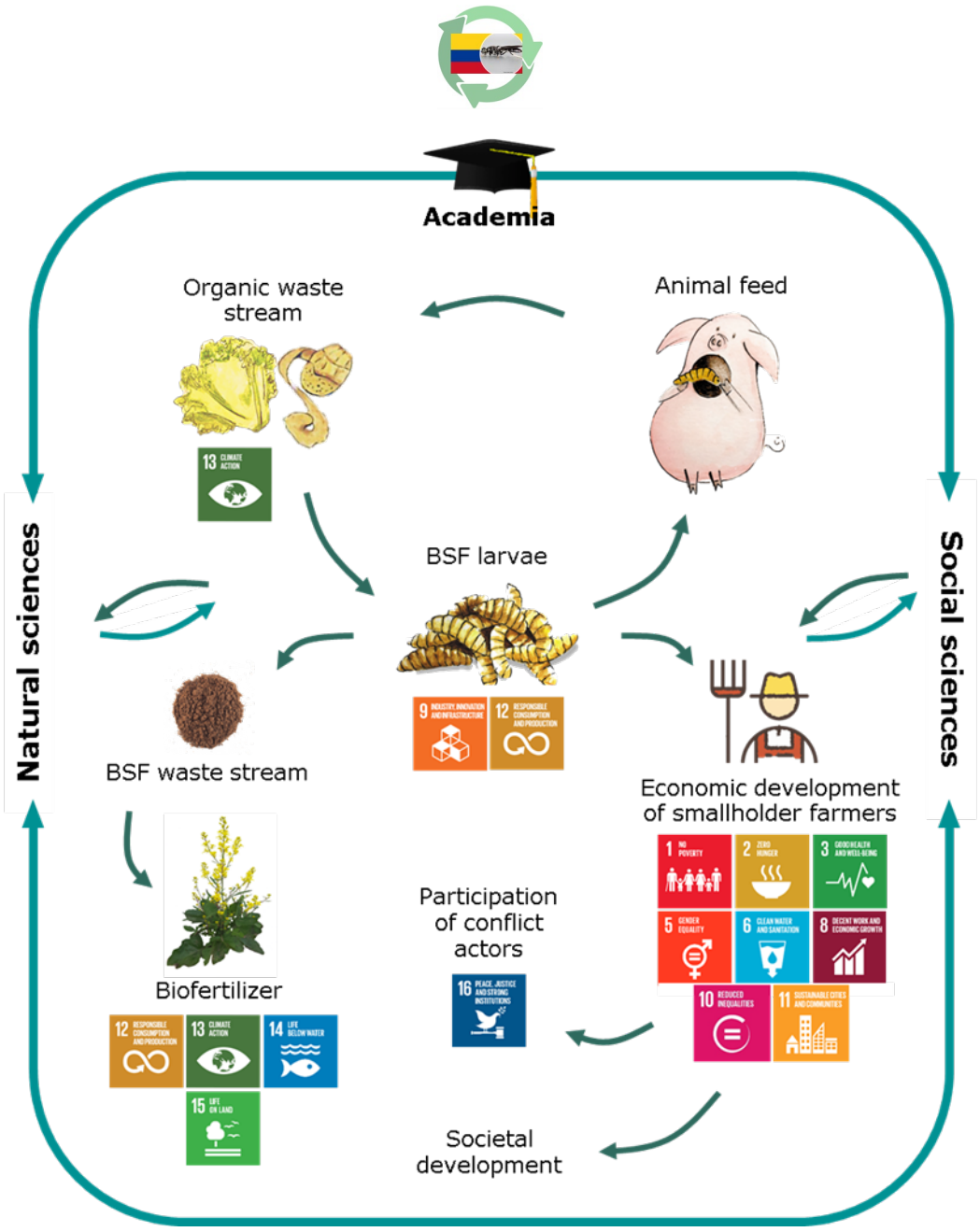

Figure 2. Developing a circular agriculture based on the production of black soldier flies (BSF) as feed and using the BSF waste stream as biofertilizer can support food security, poverty alleviation, economic integration, sustainable communities in rural areas, thus promoting participation and reintegration of former conflict actors to support peace and justice. From Barragán-Fonseca et al. (2020).

The Netherlands' Ministry of Agriculture, Nature and Food Quality promotes circular agriculture not only nationally but in other countries as well (du Pré, 2020). In Colombia the vision of circular agriculture has resonated and national initiatives to stimulate circular agriculture have been implemented. In the Netherlands, private industry is among the frontrunners for BSF production and contributes to knowledge that is pivotal in the protein transition based on insects. In Colombia, the interest in BSF as feed has been aroused, with a special interest in developing this as feed component for poultry. Colombian poultry industry has a need of locally produced affordable protein sources. Currently, the protein sources in poultry feed in Colombia are mainly imported, placing Colombia among the top importing countries regarding protein sources for feed. Annually, 1 billion US$ of corn

meal, 1.5 million MT of soymeal and 12000 tonnes of fishmeal are imported by Colombia (www.indexmundi.com). Production of BSF in Colombia, using local leftover streams, may contribute to lower dependence on imported feed, providing cheaper sources of protein, and aid in the development of a circular agriculture.

Approach of this seed money project

This project investigated the opportunities and challenges for the development of BSF production for poultry feed in Colombia, with a focus on collaboration between Colombian private industry and their Dutch counterparts. Involved parties were selected from the insect producers, feed producers and poultry producers, with counterparts from both Colombia and the Netherlands, including small- and large scale initiatives. In November 2019, a symposium was organized in Bogotá, Colombia, to introduce the opportunities of producing BSF as feed in Colombia. In December 2019 a proposal for a seed money project was developed which received funding from the Topsector AgriFood in the Netherlands. The stakeholders involved in the SMP from the Netherlands and Colombia were interviewed to obtain an overview of the prospective insect-fed poultry value chain. From these interviews, we gathered first information on the steps that are needed in the development of BSF as feed, such as required legislation, knowledge and investments.

Based on the results of these interviews an interactive workshop was organised in November 2020 with all project members, to assess the value chain and its stakeholders and to determine the opportunities and challenges of the new value chain. In this workshop the partners developed plans for the next steps. The findings of this SMP are presented in this report.

The current situation of (poultry) feed in Colombia

Poultry feed in Colombia depends on imports of protein sources from other countries, especially the USA. These imports are expensive and unsustainable in the long run, because production of soybean and corn competes with food production for humans (du Pré, 2020). Around 17% and 66% of feed produced and used in Colombia is used in the pork and poultry sector, respectively (Alltech Global Feed survey 2020). Imports of foreign corn are increasing due to the increasing demand from the animal feed industry, and the poultry industry was expected to grow by 5% in 2019 (Rau & Gomez, 2019). At the same time, there are ample leftover streams from the food production system in Colombia that could be used to produce insects/BSF as a protein source in feed. According to the Ministry of Environment and Sustainable Development of Colombia, about 12 million tonnes of organic side streams are generated per year, of which an average of 17% is recycled (Parra & Higuera, 2019). Colombia produces a high variety of fruits, vegetables and tubers, like coffee, Hass avocado, cacao, and potato which generate a lot of waste per year (Howland et al., 2019) that could be used as substrate to produce insects, which have become a vital piece in the puzzle of closing product life-cycle loops of multi-tiered circular food systems.

Views on insects as feed in Colombia

The opportunities of insects as feed are the focus of a research programme at the Universidad Nacional de Colombia and one of the results of this programme is the establishment of a spin-off company producing BSF eggs. Through this research programme, an important knowledge base is generated on the biology of BSF and its use in feed for livestock and fish. In the Colombian poultry sector the opportunities of using BSF as sustainable protein source in feed are known and this generates an interest in developing this novel approach to poultry feed (du Pré, 2020). In the interviews with the stakeholders the following observations have been made.

Perceived advantages of using BSF as feed component

The use of organic leftover streams provides ample opportunities to develop BSF production. Food industry produces large amounts of organic waste streams that now need to be discarded at a cost. These sources of organic waste streams are present throughout the country, thus providing opportunities for local production that do not rely on long-distance transport.

The scientific literature identifies benefits of the nutritional profile of BSF larvae for poultry (Dörper et al., 2020). BSF are high in protein as well as fat levels (Barragan-Fonseca et al., 2017; Veldkamp & Bosch, 2015). Moreover, the use of BSF in feed may provide benefits in terms of poultry welfare as well as poultry health. For instance, when providing live fly larvae, this stimulates poultry exploration behaviour, thus reducing pecking of other birds (Dörper et al., 2020; Veldkamp & van Niekerk, 2019). Adding BSF to feed may also improve gut microbiota and bird health, and thus may lead to reduced use of antibiotics to treat infections (Dörper et al., 2020).

The contribution to circular economy, sustainability and renewability of resources were seen as an important advantage. Enhancing circularity provides benefits to the environment in two ways, i.e. removing waste while replacing expensive feed imports.

The BSF originates from the tropical and subtropical Americas (Sheppard et al., 1994) and the climate of Colombia is suitable for producing BSF, with stable weather conditions and temperatures year round.

The stakeholders considered Colombia culturally ready for the production of poultry with insects as a feed component. They expect that consumers will accept this novel production method.

There are already good experiences with producing BSF as fish feed in Colombia through the project *Insects for Peace* (UNC, 2020) that can be used as a starting point to support expansion of this novel production method.

Perceived obstacles for using BSF as feed component

Legislation is currently lacking on using insects as feed component. Thus, there is no standard and no regulation of quality and safety aspects to be monitored. Colombia closely follows developments in legislation elsewhere, such as in the EU. In the EU, the use of insects in feed is currently allowed in acquaculture and the types of substrates that can be used for insect production are currently still legally limited (IPIFF, 2020).

Currently, there is a lack of knowledge among farmers. To initiate farming of insects for feed, farmers need training to learn how to grow BSF on leftover streams, which substrates are suitable and how these can be most effectively used. This is relevant for both smallholder farmers who wish to produce insects on farm for their own use or to supply feed mills (Chia et al., 2019) as well as insect farming at a bigger industrial scale (van Huis, 2020).

A reliable supply of suitable substrates is necessary to maintain a steady BSF production. The realisation of this stable supply of substrate of constant quality may be difficult to achieve depending on the scale of production and the logistics present in the area.
To facilitate the development of insects as feed, technological advances are needed for both insect production and insect processing. This comes with development costs that need to be included in market prices. This may be difficult when margins on the final products (meat/eggs) are low.
Consumer trust in the quality of the product is important. This depends on the safety of the substrates that are used (e.g. manure being of higher risk than vegetable remains).

The insect-based feed value chain

The generic insect-based feed value chain using BSF is presented in Figure 3. The basis of the value chain consists of BSF production and the provision of substrates. The substrates consist of organic leftover streams such as by-products from the food industry. These leftover streams serve as feed for the BSF larvae, which convert this to protein/fat/micronutrients. When BSF larvae have reached the desired size/life stage, they can be killed and processed for the use in chicken feed (or feeds for other farmed animals such as pigs or fish). Here, we focus on the use of BSF as component of poultry feed. BSF will be used as input by feed producers. Feed producers will use BSF to formulate feed for broilers and laying hens. Thus, the next element of the chain represents poultry producers who produce meat or eggs for consumption. The final actor group of the value chain is represented by consumers. The different steps in the value chain can involve different actors, or multiple steps can be executed by a single actor. For example, BSF could be reared on poultry farms using leftover streams from the farm itself, and locally processed into poultry feed (or fed to chicken without processing). It is also possible to produce BSF separately, formulate it into feed and sell the feed to poultry farmers, who use it to feed their animals.

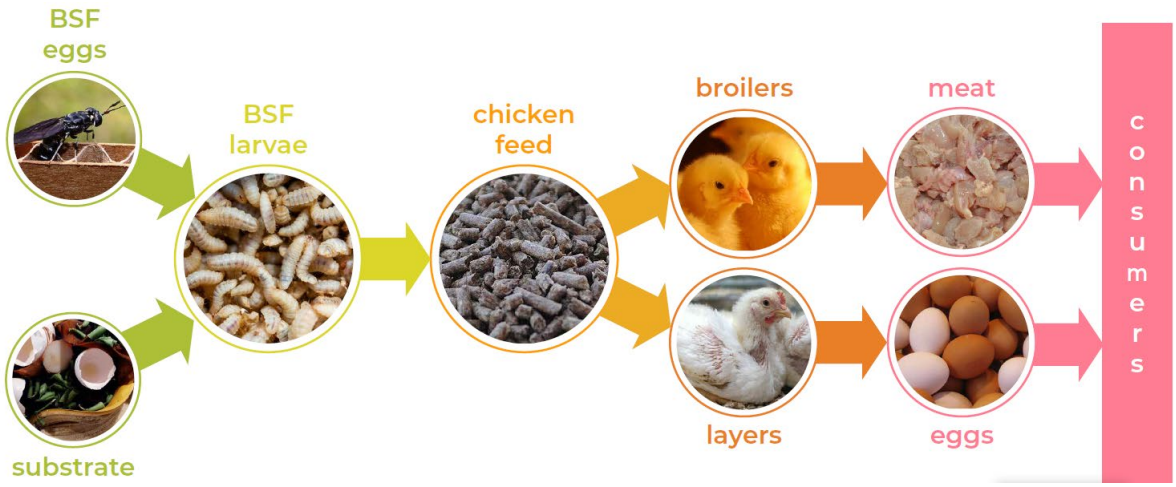

Figure 3.: The insect-based feed value chain using the black soldier fly (*Hermetia illucens*). Leftover streams are used as substrates to grow BSF larvae, which can be processed and added as a protein source to chicken feed. The feed is used to feed broilers for meat and laying hens for eggs. These products find their way to consumers via retail.

Basically, the insect-based value chain consists of two parts: the insect part on the left which involves the production of insect products that are a resource for the second part, i.e. the poultry part on the right which aims at producing poultry products such as meat and eggs for consumers. These two parts are connected by feed producers who use insect products as a resource and produce formulated feeds as an output. In essence, this value chain is not a chain but a loop because the substrate on which the insects are produced may be derived from waste streams from food industry, including poultry farmers, and consumers. Thus, by closing this loop insect-based poultry production has excellent potential to contribute to circular agriculture. Moreover, because the waste stream resulting from BSF production may be used as input for crop production (Schmitt & de Vries, 2020), insect production may also result in an additional contribution to circular agriculture (Figure 1B).

Needs in the development of insects as feed in Colombia

With the partners in this project, we had a workshop to identify the characteristics of the insects-for-poultry-feed value chain in Colombia with a focus on the stakeholders, opportunities, challenges and the knowledge needed for development of this value chain.

Stakeholders

The stakeholders of the insect-based poultry production value chain include those directly involved in the various parts of the value chain, such as BSF producers, feed producers, and poultry farmers, but also stakeholders at the beginning of the value chain, such as private and public organisations that produce organic waste and need to discard this at a cost (Table 1). Regarding waste producers, an important aspect is transportation in relation to infrastructure. Regional substrate supply as well BSF production has many advantages.

Table 1. Identified stakeholders for developing an insect-based poultry production value chain in Colombia

Substrate	BSF production	Feed	Poultry	Poultry products	Consumers
Private producers of substrate & municipal waste agency Waste stream collectors Farmers Feed manufacturers Legislators/ government Animal (insects and poultry) producers	BSF producers Equipment suppliers Poultry farmers Organic waste producers Feed producers	Feed producers BSF producers Poultry producers Retail Government agencies	Poultry farmers and their association FENAVI Feed producers Retail Consumers Chicken and egg producers	Poultry farmers Retail Direct food sellers Food processors Consumers	Retail Consumers Farmers Final costumers Food production companies Regulatory agencies

Opportunities of producing BSF on organic waste streams as component of poultry feed

The project has yielded an extensive overview of the opportunities for developing this value chain in Colombia (Table 2). Based on the list of opportunities, an inventory of the most important opportunities has been made. Managing waste sustainably is an important opportunity, because waste is a large problem that affects the population in various ways. Many waste streams are known to be suitable as substrate for BSF (Bosch et al., 2019).

Insects are known to have a good nutritional profile with a good digestibility (Barragan-Fonseca et al., 2017; Dörper et al., 2020; Van Huis & Tomberlin, 2017), so that is a great opportunity to replace traditional animal protein ingredients in feed (Dörper et al., 2020; Schiavone et al., 2017; Veldkamp & Bosch, 2015). There is an added value when the insects can be fed with side streams that have little value, such as manure. Using manure could really help close the loop. However, the latter is likely to meet with more regulation to be developed than when rearing BSF on vegetable and fruit-related side streams.

The number of scientists working on this subject worldwide is large and rapidly growing, generating a lot of knowledge (Barragan-Fonseca et al., 2017; Gasco et al., 2019; Schiavone et al., 2017; van Huis, 2020; Van Huis & Tomberlin, 2017; van Huis et al., 2013; Van Huis et al., 2015; Veldkamp & Eilenberg, 2018). This means that there is a solid knowledge base that can be exploited to develop this value chain for the specific situation in Colombia. Besides acting as a protein source, there are additional benefits from BSF such as the effect on animal welfare and the health benefits of chitin (van Huis et al., 2013; Veldkamp & van Niekerk, 2019).

Insects such as BSF provide an alternative source of protein for the livestock industry, which reduces their environmental footprint and costs. It enhances the circularity of livestock production (Veldkamp et al., 2012). Poultry naturally consume insects and when available they actively forage for this resource. The public's attitude related to consumption and sustainable production is changing. Therefore, companies need to strengthen their sustainability policies and activities and including insects as protein source in feed is a valuable opportunity. Moreover, setting up insect production creates jobs and contributes to the local communities and economy. Smallholder producers in Colombia are having difficulties to obtain sufficient protein for their feed, because logistics and transportation in rural Colombia are difficult. Local production of protein for feed could really help smallholder producers and also add jobs. BSF may be reared both by smallholder farmers to produce their own protein for animal feed (Barragán-Fonseca et al., 2020; Chia et al., 2019) as well as by private companies at a much larger scale (Van Huis & Tomberlin, 2017).

Most important opportunities appear to be related to the early part of the value chain, representing waste management, insect production and replacing expensive unsustainable components of poultry feed.

Table 2. Opportunities of producing BSF on organic leftover streams as poultry feed in Colombia, as identified by the project partners

Substrate	BSF production	Feed	Poultry	Poultry products	Consumers
Waste is considered a problem in terms of pollution, health, public image, legally Recycling / increasing value of waste Reduce costs of waste disposal Seasonal fluctuations Available almost anywhere / large quantities available	Market ready for a solution Limited competition and inadequate substitute solutions available Side business or main business Diverse geographical distribution Ecobranding Innovative and efficient option that solves two major problems of the traditional production methods	Sustainable feed Reduction of feed costs, independence of international expensive import Increasing diversity of the ingredients for an optimized formulation of feed A good quality protein Local and stable production Can be used for more than only poultry Animal welfare improvement	Stimulating the immune system, improving bird health Increased production Poultry producers need solution for both organic waste and animal feed ingredients The diversity of production sizes allows different degrees of technification More stable production Cost efficiency Circular economy Environmental progress Poultry farmer can be substrate producer	Marketing as sustainable, local etc Higher margins Welfare label Circular economy proof Augmentation of production Lower costs of feed Better characteristics of the product	Marketing as better quality chicken Marketing of sustainability New culture of circular economical / ecology based products New nutrition model Constant and increasing demand of traditional and new products

Challenges of producing BSF on organic waste streams as component of poultry feed

Just like opportunities, also challenges can be identified for every element of the value chain (Table 3). Many of these identified challenges relate to unknown aspects and they represent an important overview of where knowledge is needed to avoid them. Based on the list of challenges, an inventory of the most important challenges has been made.

An important challenge consists of legislation issues. Right now, there is not regulation of the use of BSF in Colombia, but this could change. If regulations would restrict the use of BSF, this would be a major limiting factor. Fortunately, academia is promoting the development of regulation for insects as feed with the relevant Colombian authorities (ICA and Ministry of Environment).

An important challenge is to produce BSF at a price that is competitive with other feed ingredients such as fishmeal and soybean meal. Insects may bring qualities such as improvement of chicken health and welfare (Dörper et al., 2020; Veldkamp & van Niekerk, 2019) and marketing can use arguments of sustainability and quality and this is important but the financial aspect is crucial. It is important to

assess the consequences of upscaling of BSF production in terms of negative effects on other food production sectors. For example, manure and compost are used by agriculture as a fertilizer. What happens when these are instead used as substrate to produce insects? Or can the waste stream of insect production ('frass') be a suitable substitute (Schmitt & de Vries, 2020)? This indicates that the value of the insect-based feed for the poultry value chain cannot be seen in isolation but should be considered in the context of other (agricultural) activities (Smetana et al., 2016; van Zanten et al., 2015).

Because the insect-for-feed value chain is not an isolated value chain, environmental and financial scenarios should be developed for profitable business models, but it is also important to realize that poultry is a political topic in Colombia. For many people, consuming chicken meat and eggs is the only option to include animal protein in their diet. Thus, there is a large pressure to keep it affordable for the population at large.

The poultry sector is very competitive. Its challenge is to be economically feasible, because consumers commonly consider the lowest price to be the most important and thus replacing current protein sources with BSF should be seen in the context of costs for poultry production. Moreover, storage of BSF should be possible to facilitate a continuous, stable supply of insects as feed. A stable supply is important to allow for year-round availability just as is the case for soymeal or fishmeal.

For the feed industry, it is important that BSF producers can effectively process the BSF larvae. This may involve the investment in dedicated machinery to process BSF which may be a relatively large investment for a smaller company. For scaling up to reduce the price of insects, knowledge is needed on how to scale up effectively and on the readiness of the market (feed producers and poultry producers). Readiness of the market may be promoted by demonstrating that BSF is a good alternative material for feed from a nutritional point of view (Veldkamp & Bosch, 2015). Although the price is very important, benefits in terms of growth rate of poultry or increased yield in terms of meat or eggs, or increased health of the birds would be a bonus.

Organic waste currently brings costs for the producer to discard of it. For example, companies pay for disposing of manure. If these costs can be eliminated for the substrate producer that would be beneficial but there is a risk that the waste stream, now becoming a resource, may be sold so that BSF producers would still incur costs for the substrate. Not all waste streams are readily available, some of them are already used as feed themselves, such as e.g. brewery waste that is used in swine feed. Finally, some waste streams are used for biogas production. In general though, waste from alcohol production (especially pure alcohol production) is plentiful in supply and of good quality for BSF growth.

In conclusion, although challenges were identified for all elements of the value chain (Table 3), the most important risks as perceived by the participants seem to relate to the first part of the value chain.

Table 3. Challenges of including BSF reared on organic waste streams as poultry feed in Colombia, as identified by the project partners

Substrate	BSF production	Feed	Poultry	Poultry products	Consumers
Food safety Seasonal fluctuations Contamination with chemicals or microbes Non-controlled substrate production Environmental issues (odours, outsiders, insects etc) Legal requirements for management	Production requirements Production problems Colony collapse Climate conditions Bad management Lack of quality Legal prohibition for production or use of BSF products Appearance of new diseases Low productivity of genetic lines in the country	Focused on small – medium producers, hard to scale up to large producers Guaranteeing constant supply Not competitive in price to replace traditional raw materials at the initial stage The size of the market is unknown for this alternative source Quality control / safety / contamination from substrate Steady increase in the costs of ingredients Low diversity and availability, local and international For BSF products, acceptance of in foreign markets depend on substrate	If BSF production is near, health of birds may be at risk Adjustment of the farms Competition among birds in the hen house Food safety Environmental issues Bad administration of nutrition Diseases affecting large scale productions Fear of the new and non-traditional	Change in taste Change in fatty acid profile of meat Different colour Change in consumer behaviour Importation of poultry products at lower prices than those of the local market	Consumer perception/acceptance Change in taste Low quality products High prices Perceived health threats

Development of legislation on insects for feed in Colombia

With the participants we have made an inventory of the needs for legislation on BSF production and its use as animal feed. At present, there is very little legislation on insects as food or feed, but the Universidad Nacional de Colombia and ICA have started working on this. Main issues for legislation

relate to food safety, in terms of chemistry and microorganisms. This is similar to the situation in the EU, where EFSA has analysed the risks of insects for food or feed to support regulation (EFSA, 2015). The participants do not consider food safety a risk because they think that with good regulation this is manageable, as indeed is the case in Europe based on the EFSA assessment (EFSA, 2015).

Food safety was not really discussed when addressing the challenges. Why does ICA have a different opinion on this? The discussion participants indicated that they consider the challenges manageable and that there are steps that can be made to mitigate risks. This is reflected in legislation in the EU where risks of food safety have been documented to serve as a basis of legislation (EFSA, 2015). A good first step would be to officially recognize that insects can be a valuable feed ingredient, based on the state of the art of scientific knowledge (van Huis, 2013, 2020; Van Huis & Tomberlin, 2017; van Huis et al., 2013). Besides, some insect species should also be considered as animals being traditionally produced like the honey bee *Apis mellifera*, which will support the development of legislation for insects in Colombia as animal feed for the Ministry of Agriculture and the Ministry of the Environment. There should be standards for quality and parameters for contaminant allowances. Also biosafety regulations for labourers who work in insect production should be included. Furthermore, regulation will need to include processing of insects and the inclusion of insects in poultry feed.

Legislation is important to facilitate and regulate the development of the value chain by providing clear rules which will support food safety as well as limit risks. The ministries to be involved are the Ministry of Agriculture and the Ministry of the Environment. For the development and implementation of legislation, it is important to involve stakeholders such as FENAVI. The embassy of the Netherlands may also play a role as advisor because the Netherlands is among the leaders in insects as feed and aims to promote this approach to circular agriculture internationally as well. However, the embassy cannot take a lead in this development because that is a topic for Colombian politics. A memorandum of understanding between the Netherlands and Colombia on circular economy is being developed, with a lot of reference to circular agriculture. In the Netherlands, insects cannot yet be included as component of poultry feed, their use is allowed for aquaculture since June 2017 and permission for their use in poultry feed is anticipated to happen soon.

Internationally, the byproduct of insect production (frass) is being developed as fertilizer for crops (Dicke, 2018; Schmitt & de Vries, 2020). This provides an important economic opportunity for the business case of producing insects but also requires regulation.

Table 4. Needs for legislation related to different elements of the insect-fed poultry production value chain in Colombia

Substrate	BSF production	Feed	Poultry	Poultry products	Consumers
Framework of rules so farmers know what to deal with ICA permission Legalization with DIAN Biosecurity law creation Adjustment to new options for organic waste treatment with organisms like BSF Permission of treatment on farm with BSf or for movement of the residue outside the farm before treatment to be treated with BSF Encourage separation and good practices, avoid contamination	Production permission Framework of rules so farmers know what to deal with investigate prohibitions Recognition of BSF products as ingredients for feed Recognition of BSF outside wildlife law Regulation and standardization of BSF products and producers Approval by Ministry of environment And Ministry of Agriculture	Can this protein be sold as raw material or is it needed to have a registration? legislation when BSF are legal to be used as feed Retail requirements on feed ICA approval Parameters of allowance of contaminants for BSF products as ingredient for feed	Feeding BSF to poultry needs to be legal ICA	INVIMA	INVIMA Information about the origin of ingredients and production process

Knowledge needs in this sector

Despite a rapidly growing international knowledge base, developing an insect-based poultry value chain requires the generation of knowledge to address local opportunities and threats. This especially relates to the production of BSF and of the use of BSF as component of poultry feed. The production of BSF in Colombia needs to be developed to be able to take advantage of local and national possibilities. This requires research on which substrates are available locally and how well do they support the production of BSF. This is dependent on the quality of the substrates (Barragan-Fonseca et al., 2019; Bosch et al., 2019; Chia et al., 2018b) and conditions of rearing BSF (Barragan-Fonseca et al., 2018; Chia et al., 2018a).

It is important to generate more knowledge on the safety of locally available substrates, including manure, in terms of contamination with toxins such as aflatoxins or pesticides and how the substrate

can be treated to prevent such contamination. There is a good knowledge base on this (Bosch et al., 2017; Bosch et al., 2019; Camenzuli et al., 2018; Charlton et al., 2015; Purschke et al., 2017), that can be used to guide research on these issues for substrates available in Colombia. Limited knowledge is available on processing of the larvae as this is often developed within private industry and not published. Processing methods that may be used include, for example, defatting and drying the BSF larvae. Protocols for the Colombian conditions will need to be developed. An important aspect here is the influence of scale, because processing is highly scale dependent and thus methods will be different for large versus small production units.

The type of substrate, rearing conditions, processing methodology etc. will determine the costs and benefits of insect production, and this requires the development of adequate business models. This not only relates to BSF producers but also to poultry producers, for whom BSF will be a new feed ingredient. Questions here relate to the nutritional benefits, rate of replacement of current protein sources by BSF, effects on poultry production and health as well as the environmental impact. The costs and benefits can differ a lot based on many factors, such as location, scale, substrates that are used and their price and market fluctuations. A company like EntoPro benefits from being close to the Universidad Nacional de Colombia in Bogotá, but this location comes with a lot of added costs from energy used to power climate chambers, because the climate at Bogotá is relatively cold. In a warmer location, the energy costs will be lower, but with distance from the university, support may be less intense. There can also be local variations in substrate availability and costs. Finally, the costs and benefits depend on the product you aim to deliver. The production of BSF eggs has different requirements than BSF larvae for feed. There is no general recipe for such companies.

In conclusion, knowledge gaps identified in the project especially relate to three aspects. 1) Knowledge on how to rear BSF on substrates that are available in Colombia and how to use the available resources best. 2) How can BSF be used as a feed component for poultry in Colombian conditions. What is the value of BSF in terms of nutrition, health and welfare to facilitate farmers to use BSF-containing feed. 3) Costs and benefits for BSF farmers, feed producers and poultry farmers. The cost-benefit analysis requires investigations of local resources for BSF production, and benefits that BSF has for feed producer and poultry farmers.

The available knowledge provides an excellent basis to start developing BSF for poultry feed in Colombia and at the same time invest in knowledge generation that is specific for the Colombian situation. This requires investing in research infrastructure and research projects focusing on BSF production, feed formulation and its use in poultry production. This implies a two-fold approach: (i) facilitating BSF for poultry feed through development of legislation, and (ii) initiating pilots to explore the opportunities and investing in research to address questions for the Colombia situation. This approach can benefit from similar approaches elsewhere, such as experiences gained in Colombia in the *Insects for Peace* project (UNC, 2020) and in Kenya where smallholder farmers were the focus (Chia et al., 2020; Chia et al., 2019; Onsongo et al., 2018) and in Europe where private industry is the focus (IPIFF, 2019a, b, 2020; van Huis, 2020). Through a learning-by-doing approach, pilot farms may actively explore what works and what does not work. These pilot farms may disseminate their knowledge to local farmers. This will require a transdisciplinary, collaborative approach involving academia, private industry, NGO's and national and local governmental agencies.

Conclusion and recommendations

Colombian livestock production is dependent on the import of large amounts of soymeal and fishmeal as protein component of feed. These feed components are expensive and non-sustainable while resulting in major transportation needs within the country. In the last decade the Black Soldier Fly (BSF) has internationally emerged as an interesting alternative for soymeal and fishmeal. BSF can be produced on organic side streams that originate from the food industry that are currently disposed of as waste at a cost to the producer. BSF can transform such waste streams into a high-quality protein source for feed. BSF has been developed as feed component in various parts of the world, for both smallholder farmers and for medium to largescale private industry. There is an internationally rapidly developing knowledge base that provides important information for the general inclusion on BSF in feed. This transition is taking place in low and middle income countries as well as developed countries and provides an excellent opportunity to close the loop and contribute to a circular agriculture.

For each country, the national conditions such as substrates available, climatic conditions, societal and regulatory conditions, infrastructure, economic situation and the attitude of farmers and the general public differ. Thus, by using the international knowledge basis and addressing questions for the local situation, the options for developing a BSF-based poultry feed value chain can be effectively developed. For this, a collaboration of governmental, public and private organisations is needed. The main elements to be addressed first are: (1) legislation in Colombia to provide a clear framework in which insects as feed can be developed, (2) research on BSF production in Colombia based on the available organic side streams, including an analysis of their composition, reliability of supply and stability of their quality, and (3) research on the formulation of poultry feed that includes BSF as well as the performance and health of broilers and laying hens fed with BSF-containing feed. These elements may be developed in parallel to generate opportunities to learn by doing. For an effective approach, a transdisciplinary approach, including academia (e.g. entomologists, ecologists, animal scientists, economists, feed scientists), private industry (waste producers, insect producers, feed producers, poultry producers), societal organisations (consumer organisations, NGOs) and governmental organisations (e.g. ICA, INVIMA) should be involved.

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