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Insects for peace

Katherine Y Barragán-Fonseca[1,4], Karol B Barragán-Fonseca[2,4], Gerard Verschoor[3], Joop JA van Loon[1] and Marcel Dicke[1]

Insects such as the black soldier fly (BSF) are a nutritious feed component for livestock with high protein levels. BSF can be reared on a wide range of organic residual streams. This allows for local production within a circular agriculture, decoupling livestock production from import of expensive feed components, such as fishmeal or soymeal. Rearing of BSF can be done by smallholder farmers, thus contributing to their livelihood, economic sustainability and social status. Smallholder farmers contribute importantly to food security, which is a prerequisite for a stable society. In armed conflicts, smallholder farmers are usually the first to suffer. In countries recovering from conflict, agricultural development should focus on restoring food production by smallholder farmers, improving their socio-economic position, thereby contributing to sustainable development goals 2 (zero hunger) and 16 (peace and justice). Here, we focus on these SDGs with an example of reintegration of ex-combatants as smallholder insect producers in post-conflict Colombia.

Addresses
[1] Laboratory of Entomology, Wageningen University, PO Box 16, 6700 AA Wageningen, The Netherlands

[2] Departamento de Producción Animal, Facultad de Medicina Veterinaria y de Zootecnia, Universidad Nacional de Colombia, 111321, Bogotá, Colombia
[3] Sociology of Development and Change Group, Wageningen University, PO Box 8130, 6700 EW Wageningen, The Netherlands

Corresponding author: Dicke, Marcel (marcel.dicke@wur.nl)
[4] These authors contributed equally to this work.

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Introduction

Insects are food to a wide variety of organisms including livestock and humans [1]. Employing insects as food and feed is gaining ample interest because the production of these animals may provide high-quality proteins, with low-value input, high-value output and low environmental impact compared to traditional sources of animal protein [2]. Insect production can, therefore, become an important component of a sustainable, circular agriculture by closing nutrient and energy cycles, fostering food security while minimising climate change and biodiversity loss. This meets various of the sustainable development goals of the United Nations [3] (Box 1; Figure 1). Here, we will especially focus on SDG 2 (zero hunger) and SDG 16 (peace and justice). Zero hunger and peace are interdependent; for instance, armed conflicts lead to reduced food production and, thus, hunger, that is, food insecurity [4,5••]. Conversely, rising food prices as a result of reduced food security may lead to social unrest, food riots and instability, as became clear in 2008 in many countries [6]. Because of the expected growth of the human population, nearing 9–10 billion people by 2050, food security will be at risk unless an increase in global food production of at least 60% above 2006 levels can be achieved [7]. Global food production depends to a large extent on smallholder farmers [8]; it is them who suffer most during conflict. Providing smallholder farmers with appropriate conditions to run their farms is an important element of both food security and a stable society [4]. As a consequence, developing sustainable protein production will make a valuable contribution to SDG 16. Here, we will focus on the potential of insects as feed to support reintegration of ex-combatants, with an example of developments in post-conflict Colombia.

Flies as feed: black soldier fly as an example

Fly larvae, such as the Black Soldier Fly (BSF) (*Hermetia illucens* L.; Diptera: Stratiomyidae) can be reared sustainably on a wide variety of organic waste streams and have an excellent nutritional quality [3,15]. BSF is currently mass-produced as feed on a large scale (tonnes of larval biomass/day) in China, USA, Canada, South Africa and several European countries. Yet, BSF is also highly suited to be reared by small-holder and medium-holder farmers [13•].

Black soldier fly biology and nutrition

BSF is widespread in the Americas, occurring from Argentina to central USA [16]. Larval development occurs between 12°C and 37°C, the optimum being 30°C [17]. The adult flies have a body length of 13−20 mm, their cuticle is black except the white halteres, tarsal leg parts and two opaque 'windows' in the anterior dorsal abdomen. Their wings are translucent, and the compound eyes are green with purple iridescent stripes. Adults feed on plant nectar and other liquids. Female flies produce 800–1200 eggs in large batches that they deposit in crevices close to decaying organic

Box 1 Insects for peace and the sustainable development goals (SDGs) of the United Nations

In September 2015, the General Assembly of the United Nations (UN) adopted a resolution to 'shift the world onto a sustainable and resilient path' [9]. A total of 17 sustainable development goals (SDGs) were formulated, with the main ones being to end poverty (SDG 1) and hunger (SDG 2). These 17 SDGs comprise a coherent set of integrated goals. Food security (SDG 2) is one of the major issues that humanity faces in the 21st century. An estimated increase in global food production of at least 60 percent above 2006 levels is required to feed 9–10 billion people by 2050 [7]. However, the food system is currently a major driver of climate change (SDG 13), so that the development of sustainable agriculture with lower greenhouse gas emission and reductions in food loss and waste is 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, SDG 14). Moreover, contemporary agriculture has a linear practise with external inputs and local deposition of residual streams. One of the challenges for food production in the 21st century is the transition from a linear to a circular agriculture. Insects provide interesting opportunities for developing a circular approach to feed production, because various species can be reared on organic residual streams that are part of their natural diets [2,3]. In the last decade, insect production for feed has been initiated [10,11] and this agricultural activity is expected to grow exponentially in the near future [12]. Increased use of insects as food and feed has been positioned within the context of the SDGs with a focus on at least 11 of the 17 SDGs, that is, 1 (no poverty), 2 (zero hunger), 3 (good health), 5 (gender equality), 6 (clean water and sanitation), 8 (good jobs and economic growth), 9 (industry, innovation and infrastructure), 12 (responsible consumption), 13 (climate action), 14 (life under water) and 15 (life on land) [3,13•,14] (Figure 1). In this paper we focus on insects for feed as a contribution to SDG 2 (zero hunger) and SDG 16 (peace and justice). We focus on opportunities to produce insects as feed to support the transition from conflict to peace in Colombia.

substrates. BSF larvae are polyphagous saprophages that can feed on many types of organic materials, including plant residues, animal manure and cadavers [18••]. A common value for larval density in such substrates is 1000 larvae per litre; the optimum water content of feed substrates is 65–70%. At 30°C BSF has a mean generation time of 42 days [17].

Diverse crop-derived residues, food waste and manures, and mixtures thereof, have been assessed for their suitability to serve as feed substrates for BSF larvae [18••]. In most waste-conversion studies, the larvae are reared on a starter diet such as chicken feed for 5–10 days and then transferred to the organic resource to be converted. Dry matter and nitrogen conversion efficiency vary substantially (from 1.3 to 32.8% and from 7.4 to 74.8%, respectively) [18••,19,20••]. The most likely explanations for the wide range of variability in conversion efficiency are differences in nutritional suitability of the wide diversity of substrates tested and differences in abiotic factors, in particular temperature and substrate water content [19,20••]. Optimising conversion efficiency can be achieved by adjusting crude protein and carbohydrate levels by mixing organic residues from different sources; for example, a mixture of abattoir waste and fruit/vegetables reduced feed protein concentration and improved protein conversion ratio to 47.7% as compared to 30.8% on abattoir waste alone [20••]. Alternatively, selection for enhanced conversion efficiency on particular diets may be an option for the future.

Nutritional value for livestock production

As feed for poultry, pigs and fish, the larvae are harvested from the feed substrate when fresh body mass has reached its maximum, in their 6th larval instar, before the prepupal cuticle has developed (Figure 2). Their protein level is 35% of dry body matter — independent of the substrate on which they are reared — with an amino acid profile of high nutritional quality for livestock species, containing all essential amino acids required in favourable proportions [21,22,23].

BSF larval dry matter also contains a substantial proportion of crude fat (7–58%), depending strongly on larval feed substrate: low on low-fat substrates (e.g. fruits and vegetables) and high on fish offal and bread [15,24]. A major fatty acid is lauric acid (C12 saturated fatty acid; 7.5–52% of total fatty acids) that has antimicrobial properties in poultry [25,26] and offers potential to reduce antibiotic use in poultry production.

Biofertilizer

After the larvae have been harvested, a waste stream remains. This consists of non-consumed substrate, frass and exuviae. This waste stream from insect production constitutes valuable biofertilizer to improve agricultural productivity, rich in N, P and K as well as microelements with the potential to replace mineral fertilizers [27,28••,29]. The use of the by-product of BSF production as soil amendment is not just an ecological option to enhance plant growth; the use of organic amendments is one of the most economic and practical options for improving soil and substrate quality and plant resilience [30,31] (Figure 2).

Flies to empower smallholder farmers

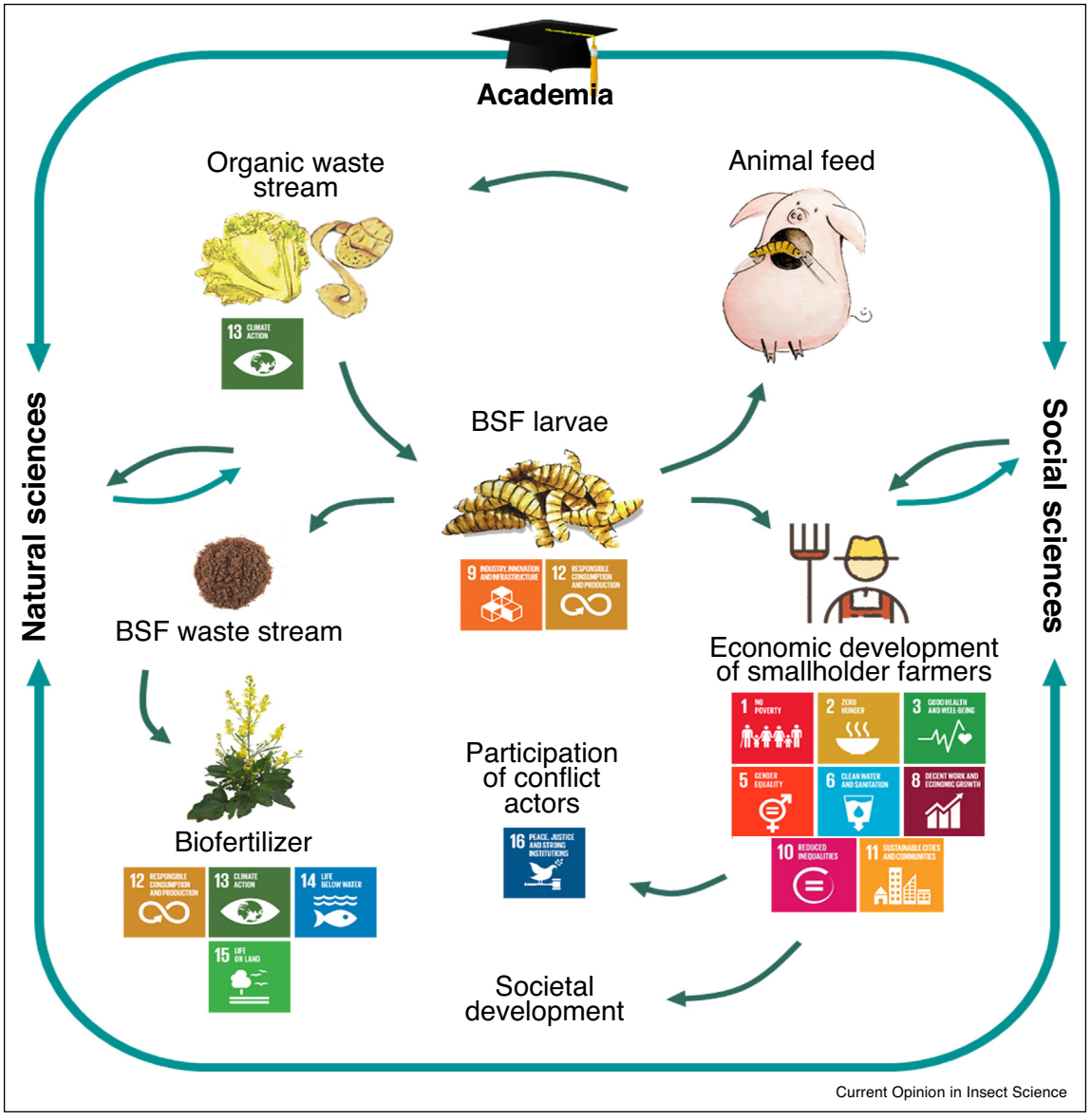
One of the main bottlenecks for market entry by small-scale livestock farmers is high feed prices as a result of imported industrial feed and middlemen. BSF may provide a solution to this bottleneck because BSF may be cultured on locally available waste streams and culturing can easily be learned by farmers (https://tinyurl.com/tzc6ln9) [13•]. Moreover, because the left-overs of insect production can be used as biofertilizer, farmers who adopt insect production may also become independent of expensive, externally derived fertilizer. Therefore, BSF may provide an important element for economic development of smallholder farmers (Figure 2). In a research project in collaboration with the International Centre for Insect Physiology and Ecology (icipe), we have assessed rearing methods based on local waste streams [32], the

Figure 1

SDG2 (zero hunger) is directly related to many other SDGs, ranging from SDG 1 (no poverty) to SDG 16 (peace and justice).

effects of abiotic conditions [17], and the effects of replacing fishmeal by BSF meal on pig and poultry production [23] in Kenya. Replacing fishmeal with BSF meal resulted in good livestock performance and, because of lower costs of BSF meal as compared to fishmeal, in a better return on investment [23,33]. Simultaneously, several projects have collectively developed a standard for insects as feed so that their use has been regulated by the Kenyan authorities [34]. Thus, everything is in place for changing livestock production and indeed smallholder farmers in Kenya have started to implement this by closing the loop on farm, for example, by producing BSF on chicken manure plus vegetable waste streams and feeding BSF to their chicken. Moreover, other farmers are engaging in the production of BSF exclusively. This may allow them to become suppliers of feed millers rather than buyers of products from feed millers. Among farmers in Kenya women were more aware of the opportunities of farming BSF than men [13•], thus providing chances for mitigating gender inequality (SDG 5). Challenges for introducing insects as replacement of traditional protein sources for feed include the development of the full value chain, including regulation, farmer acceptance, and feed miller involvement. For instance, to be able to supply BSF meal to feed millers, a stable supply of sufficient volume and stable quality is needed. This may require the

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 poverty alleviation, food security, economic integration, sustainable communities in rural areas, thus promoting participation and reintegration of former conflict actors to support peace and justice.

development of farmer cooperatives which would contribute to social integration. In Thailand, for example, more than 20 000 family farms rear insects for food and feed, thus providing them a clear position in Thailand's economy [35]. Therefore, producing insects as feed may provide important opportunities for smallholder and mediumholder farmers to improve their livelihood and social status and to be included in the economic value chain (Figure 2).

The case of post-conflict Colombia

In the last sixty years Colombia has been involved in an armed conflict that cost more than 930 000 lives, mostly in rural areas [36]. The origin of this conflict was the inequality in the distribution of land and the lack of access to basic rights such as health care and education; these factors combined led to the emergence of armed groups [37]. The Revolutionary Armed Forces of

Colombia (FARC-EP) [37] started in 1964 as a peasant self-defence group to represent the rural population [38].

The conflict officially ended in 2016 with the signing of the peace agreement after four years of negotiations between the Colombian government and FARC-EP. Reaching this peace agreement was a complicated process requiring efforts from all actors to build a new Colombian society [39]. Implementing the peace agreement to develop a peaceful and inclusive society is not a process exclusive to victims and offenders but a collective effort requiring the involvement of every sector of society. Academia has an important role to play, generating agricultural projects that benefit the reincorporated population and promoting integral rural development, a key element of the peace agreement (Figure 2). Supporting such developments in post-conflict situations contributes to long-term sustainable growth in the rural areas [4,40••].

Agricultural situation in Colombia

Agriculture is fundamental for the Colombian economy: 66% of the rural population is employed in agricultural businesses and approximately 10% of the national gross domestic product (GDP) comes from agriculture [41]. The great diversity of Colombian territories, along with climatic variation, allows for the production of a wide range of both tropical and temperate-zone crops. In addition, Colombia bolsters an extensive meat sector: 1.36, 0.84 and 0.24 million metric tonnes respectively for poultry, beef and pork in 2014 (https://ourworldindata.org/meat-production). Feed for animal production is mainly imported. For instance, 95% of Colombia's five million metric tonnes of corn import is used as feed [42]. In addition, 1.5 million metric tonnes of soybean meal are imported as feed component (https://tinyurl.com/uw8ltq4).

Moreover, the illegal cultivation of coca leaves, the basic ingredient of cocaine, is widely practiced by smallholders in Colombia [43]. The crop-substitution programme was one of the core elements of the peace agreement, to be supported by providing subsidies to those who uprooted their coca plants and replaced them with legal crops [44]. When BSF provides a good return on investment, just as in Kenya [23,33], culturing this fly may become a game changer in Colombia's war against illicit drug production.

Potential of BSF for smallholder agriculture – the Achilles heel of peace in Colombia

Agricultural support in countries emerging from conflict should focus on institution building and address vulnerability and social inequality through social protection and livelihood promotion [45]. SDG 16 calls for promoting just, peaceful and inclusive societies, and food security is an important element hereto. Integrating insect farming in the current subsistence model may promote integrated rural development that contributes to well-being, sustainability, as well as organizational, institutional and commercial strengthening of smallholder farmers. BSF production as an innovative and low-cost alternative to expensive imported feed can become an important driver of reintegration of ex-combatants by providing access to the local economy (Figure 2).

Future perspectives: producing flies to support the transition from conflict to peace

Providing smallholder farmers with a means to become independent of external inputs for feed and fertilizer may yield a local circular economy in which inhabitants of rural areas engage in an economic value chain with good return on investment. Such rural development is vital for the support of the true peace process, that is, its execution in local communities in post-war situations [5••]. Therefore, BSF can become an important contributor to peace in Colombia, just like it provides a valuable option for smallholder and medium-holder farmers in Kenya and Thailand to improve their livelihood and contribute to food security and a circular economy [13•]. To make this transition happen, the involvement of different stakeholders is important.

University social responsibility as a moral and ethical principle that guides the actions of universities should reflect their commitment to societal development, including the complex task of building peace and reconciliation [40••,46]. For instance, universities have been actively involved in reconstructing social cohesion in African countries [47]. Universities in Colombia have contributed to the dialogue between different actors in the conflict, as well as to the debate between diverse social groups and the government about the solutions [40••]. The Universidad Nacional de Colombia (UNC) has implemented different projects with FARC-EP ex-combatants, most of them related to support agricultural projects and to strengthen institution building and food security. To do so, UNC initiated the project *Use of the Black Soldier Fly as an alternative feed to reduce costs and improve the quality of life of ex-combatants in the process of reinstatement of the Icononzo-Tolima region*. During the seminar *Insects for Peace* on 20 November 2019 in Bogotá the first results of setting up BSF production in Icononzo, Colombia, have been presented by Ricardo Arciniegas Cárdenas, an ex-combatant who now focusses on the production of BSF as feed for tilapia production (Figure 3). Just as the project in Kenya, this project contributes to a circular agriculture that allows for the production of sustainable feed components without significant technology.

Smallholder farmers, including ex-combatants, may build a sustainable agribusiness that is less dependent on

Figure 3

Setting up a black soldier fly culture on farm by ex-combatants. **(a)** Rearing larvae on organic waste stream, **(b)** harvesting larvae, **(c)** rearing adult flies for oviposition, **(d)** interaction of academic partners and ex-combatants on production of black soldier flies as feed, **(e)** producing tilapia on farm, fed with black soldier fly larvae as feed ingredient. In the centre, seven full-grown sixth instar black soldier fly larvae are shown.

external inputs. By reintegrating ex-combatants in Colombian society, the production of insects for feed may contribute to SDG 16. Ex-combatants in Icononzo (Colombia) are enthusiastic and have engaged in rearing BSF as an economic option, and want to replicate it in other regions where they have settled. Next steps involve assessing farmer acceptance of integrating insect meal in animal feeds and willingness to pay for insect-based feed, like has been shown in Kenya [13•,50]. Moreover, linkages between farmers and the market need to be established to enhance utilization of insect meal as an innovative and locally available feed resource.

Upscaling the innovation of producing BSF by small-holder and medium-holder farmers requires an appealing approach and a participatory style is often most effective. Although the BSF occurs in Colombia [16], culturing it for feed is a novel opportunity and farmers need to be familiarised with it through hands-on training. Such an approach has been used for various agricultural innovations across the globe, including integrated pest management [48]. In Kenya, farmers as well as trainers of trainers have been educated in how to rear BSF (https://tinyurl.com/tzc6ln9); upon initiating this on their farm they spread the message in their community. Many agricultural innovations have been supported through so-called farmer field schools, which is a non-formal training method that provides farmers the opportunity to adapt their decisions to the local field situation [48,49]. Moreover, the public needs to be involved to benefit from the opportunities that rearing BSF as mini-livestock has for food production that is independent of imported goods like expensive feed and fertilizer. Finally,

academia has a role in providing basic knowledge to support decision making by farmers and the public.

Producing BSF on waste streams as protein component for feed can be done locally, generating a circular approach either to agriculture on-farm or in the local community [13•], thus generating an economy that is not dependent on external inputs. Producing BSF on farm with local waste streams will benefit the individual farmer and will contribute to his/her livelihood. Moreover, when farmers collaborate in cooperatives this provides opportunities for producing larger, stable volumes and this may in turn empower them as supplier to feed mills and thus also enhance their economic and thus societal involvement [13•]. This development of rural economic value chains will include wider (rural) society in the construction of the pre-conditions for peace. When such development of new agricultural value chains leads to inclusion in society of ex-combatants, engaging them in local and regional agribusiness, this will also support individual as well as community well-being. The technological component of the transition is generally available, yet needs to be adjusted to local conditions. As was made obvious during discussion at the seminar *Insects for Peace* in Bogotá, the transition must pay attention to ethical and food safety issues, and carefully dovetail these with wider political, economic, and cultural aspects [13•]. This will require a multi-stakeholder approach. As one of the stakeholders, academic institutes with a strong international embedding should take responsibility of engaging with farmers, politicians, private industry and NGO's to support the transition from conflict to peace. If this approach of including BSF into the development of peace is a successful contribution to the UN's SDG 16, these small but numerous soldiers will function like the UN's soldiers or Blue Helmets in various conflict zones in the world.

Conflict of interest statement

Nothing declared.

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This paper is a pledge for an active role of academia in post-conflict peacebuilding and reconciliation processes because these processes are complex and require multiple actors to participate to be successful. Among the activities in which academia can take initiatives are education on peace and human rights, training of ex-combatants, displaced people as well as victims and actors of the conflict.

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