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Socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya

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ABSTRACT

The growing scarcity of resources for feed production and environmental concerns highlight the unsustainability of conventional feed sources. Insect farming is considered as an alternative feed due to its low land and water requirements, its low ecological footprint, and circular economy contribution by converting biowaste into high-quality feed ingredients. While there is growing research on the technical feasibility and nutritional performance of insect-based feed, its potential beneifts are not quanitified. Using experimental and secondary data, we assess the potential socio-economic benefits of black soldier fly larvae meal (BSFLM) to the Kenyan poultry sector. We find that replacing 5−50% of the conventional feed sources (fishmeal, maize, and soya bean meal) by BSFLM can generate a potential economic benefit of 69−687 million USD (0.1−1% of the total GDP) and 16−159 million USD (0.02−0.24% of the GDP) if the entire poultry sector (the commercial poultry sector) adopts BSFLM. These could translate to reducing poverty by 0.32−3.19 million (0.07−0.74 million) people, increasing employment by 25,000−252,000 (3300−33,000) people, and recycling of 2−18 million (0.24−2 million) tonnes of biowaste. Further, our findings show that replacing the conventional feeds by 5−50% BSFLM in the commercial poultry sector would increase the availability of fish and maize that can feed 0.47−4.8 million people at the current per capita of fish and maize consumption in Kenya. Similarly, the foreign currency savings can increase by 1−10 million USD by reducing feed and inorganic fertilzer importation. These findings suggest that greater investment to promote BSFLM could boost economic, environmental and social sustainability.

1. Introduction

In the face of climate change, satisfying the demand for animal feed is increasingly becoming a global concern (Halloran et al., 2017; Mungkung et al., 2013; Smetana et al., 2016; van Huis, 2015; van Zanten et al., 2015). The conventional natural resources used to produce animal feed are not enough to fulfill the growing demand for animal products due to population growth, urbanization, and increasing income (Allegretti et al., 2018; Davis et al., 2016; Dobermann et al., 2017; FAO, 2019a; van Huis et al., 2013). Feed production is also constrained by food-feed competition and limited availability of land, fertilizers, energy and water.

The imbalance between demand and supply, in turn, increases the prices of inputs and poultry products (Makkar et al., 2014; van Huis et al., 2013). Over the last two decades, the global prices of fishmeal, maize, and soya bean meal increased by 70%, 65%, and 94%, respectively (World Bank, 2018a). During the same period, the rise in the global price of eggs and poultry meat was relatively small, amounting to 15% and 30%, respectively (FAO, 2019b; World Bank, 2018a). High feed prices impact the poultry industry by reducing producers' profit. Rises in the prices of eggs and poultry meat may also lead to social and political unrest. Collectively, these issues represent challenges on livestock production, human beings and the environment.

The use of insects as ingredients in animal feed is one potential solution to these constraints (Chia et al., 2019; Dobermann et al., 2017; Ewald et al., 2020; Lalander et al., 2015; Makkar et al., 2014; van Huis et al., 2013). Insect farming has several benefits along the feed−poultry value chain. Firstly, insects could be high-

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quality feed. For example, black soldier fly (BSF), which is the subject of this paper, constitutes 38.5–62.7% crude protein, 14.0–39.2% fat and 5282 kcal/kg of gross energy. The larvae are rich in micronutrients (iron, calcium, and zinc) and essential amino acids such as lysine, threonine, and methionine, which are major limiting in cereals- and legumes-based diets for poultry (Dobermann et al., 2017; Halloran et al., 2017; INRA-CIRAD-AFZ, 2020; Khusro et al., 2012; Mwangi, 2019; Nyingi, 2019; Onsongo et al., 2018; Onyoni, 2019; Sumbule, 2019; van Huis et al., 2013; Verkerk et al., 2007). Because of its high fat and energy content, BSF larvae could replace conventional energy sources such as maize, which has lower energy content (4450 kcal/kg of gross energy) than BSF larvae (Anand et al., 2008; INRA-CIRAD-AFZ, 2020). High-quality insect feeds may contribute not only to increased productivity but also reduce the cost of feed, which may reduce the price of eggs and poultry meat.

Secondly, as a new business venture, insect farming can create new jobs. It can also contribute to improved food security and income by providing a cheaper source of poultry feed and organic fertilizer, reducing food-feed competition, and diversifying income-generating opportunities of insect-producing farmers and other actors (Veldkamp and Bosch, 2015). Insect farming can also contribute to economic empowerment of vulnerable groups such as women and young farmers because of its low requirement of capital, land, and water (Hanboonsong et al., 2013).

Thirdly, a shift to an insect-based feed offers circular economy opportunities and thus enhances environmental cleanup services by recycling biowaste and greenhouse gas emissions (Ermolaev et al., 2019; Mertenat et al., 2019; Pang et al., 2020; PROteINSECT, 2016). Given that safe waste disposal remains a challenge in many low-income countries, insect farming not only reduces waste disposal costs but also contributes to better health (Dobermann et al., 2017; Halloran et al., 2017; van Zanten et al., 2015). The organic fertilizers produced from the insect farms may further enhance environmental sustainability and food security (Beesigamukama, 2019; Dobermann et al., 2017; Halloran et al., 2017; Onyoni, 2019; van Zanten et al., 2015).

Fourthly, domestically produced insect feed might help to save foreign currency by substituting it for imported conventional feeds and inorganic fertilizer. Such savings are especially important for many low-income countries that are not self-sufficient in animal feed and inorganic fertilizer as the savings can be used for other development activities.

While there is a growing body of research assessing the technical feasibility and nutritional performance of insect-based feeds, little is known about the potential economic benefits of insect feed (Roffeis et al., 2018). In this paper, we fill this knowledge gap by quantifying the potential socio-economic benefits of introducing black soldier fly larvae meal (BSFLM) in the Kenyan poultry feed. Specifically, we assess the potential socio-economic benefits of BSLFM as a partial replacement for conventional feed protein (i.e., fishmeal and soya bean) and energy (maize). We evaluate the effect of BSF farming on consumer and producer surplus, foreign currency savings, employment, food security, and poverty reduction. We contribute to the limited literature on the cost-saving effects of quality protein and biofortified maize (de Groote et al., 2010; Krishna et al., 2014). The findings of the study also inform policymakers to invest in research and development of the insect subsector in Kenya and beyond.

Although Kenya is one of the few African countries with a relatively well-developed animal feed industry, the country remains not self-sufficient (Bergevoet and Engelen, 2014; KMT, 2016a; Onono et al., 2018; USDA, 2014). Up to 40% of the feed demand is fulfilled through imports (USDA, 2014). The introduction of insect farming may contribute to fulfilling the unmet feed demand. Waste disposal is also one of the key challenges of Kenya (Kasozi and von Blottnitz, 2010; Soezer, 2017). Apart from providing quality protein feed and reducing the cost of feed, black soldier fly farming can offer a wide range of other benefits to Kenya's economy ranging from improving circular economy and environmental hygiene through recycling wastes (Chia et al., 2018; Kasozi and von Blottnitz, 2010), and production of organic fertilizers that can boost farm productivity and food security, especially in home gardens in both rural and urban areas (Beesigamukama, 2019; Onyoni, 2019). Kenya is one of the countries where the culture of rearing insects is emerging (Kelemu et al., 2015). The country is also supporting the insect farming sector by introducing standards for the use of dried insect products in compounded animal feed (KBS, 2016).

2. Estimation methods and data sources

This section describes the data and methods used to estimate the potential economic surplus, foreign currency saving, employment, food security, and poverty reduction benefits of introducing BSFLM to the Kenyan poultry sector. A Combination of experimental and secondary data sources are used. Before we move to the method sub-sections, it is important to bring to the attention of the readers that there is no actual data on adoption because BSFLM is recently introduced in Kenya. In our benefits estimation, we, therefore, assume three plausible adoption rates of BSFLM in the poultry sector: 5%, 15%, and 50%. The immediate sensitization of beneficiaries and commercialization of BSFLM could replace existing fishmeal, maize, and soya bean meal in the ranges of 5%–15%. These adoption rates are lower bounds because experimental studies show that insect-based feed could replace conventional feeds by anything from 10% to 100% without affecting the poultry's growth or production performance (Makkar et al., 2014; Onsongo et al., 2018; Schiavone et al., 2018; Veldkamp and Bosch, 2015). However, the full transition from conventional feed sources to feeds with insect meals inclusion may not happen in the short-run because convincing actors along the value chain may require some time. In the short-run, producers's fear of risk, limited information about the technology, lack of capacity and skills, producers and consumer preferences, and supply constraints may impede adoption, and the adoption might not go beyond a 5–15%. The adoption of BSFLM of 5–15% will reflect the benefits that could potentially accrue in the short-run. On the other hand, in the long run, adoption constraints will be relaxed through continuous awareness creation, capacity building, policy dialogue, learning by doing, providing more evidence on the cost and benefits of the technology to stakeholders, including policymakers. These will enable to change the behavior of stakeholders, which may enhance the adoption of the technology. The 50% adoption rate may thus indicate the long-run benefits of the BSFLM once actors along the value chain have enough information about it, and enough BSFLM are available in the market.

2.1. Estimation of economic surplus

We use the economic surplus model to quantify the potential producer and economic surplus of using BSFLM (Alston et al., 1995). In the economic surplus model, the benefit of the technology to producers and consumers depends on the type of markets assumed. In the absence of external trade (a closed economy), the benefit of the technology is shared between producers and consumers. A closed economy assumption is plausible in the context of Kenya because the import and export of eggs and poultry meat is less than 1% (FAO, 2019b). In a closed economy, a technology-induced supply increase in the volume of eggs and poultry meat would reduce the equilibrium price. This paper estimates the ex-ante effect of BSFLM, which shows the potential benefit of the technology before its wide-scale introduction in Kenya.

The introduction of a new livestock technology such as the BSFLM directly influences producers through increasing productivity and reducing production costs and indirectly influences consumers due to a reduction in the prices of animal products. The direct effects of the technology are represented by the *K*-shift parameter, which represents the proportionate shift in the supply curve or the per-unit production cost reduction due to the technology (Alston et al., 1995). The *K* -shift parameter is defined as:

$$K_m = \left(\frac{ATT_{ym}}{\varepsilon} - \frac{ATT_{cm}}{1 + ATT_{ym}}\right) \times r \quad (1)$$

where the index m stands for eggs and meat products. ATT_{ym} represents the proportionate change in the productivity of eggs and poultry meat, and ATT_{cm} is the proportionate change in the cost of production of eggs and poultry meat due to the introduction of BSFLM. The estimates of ATT_{ym} for eggs and poultry meat are obtained from an experiment involving broilers and laying hens conducted in Kenya (Mwangi, 2019; Nyingi, 2019; Onsongo et al., 2018; Sumbule, 2019). Black soldier fly larval based feeds increases egg productivity and production costs by 22% and 1%, respectively (Mwangi, 2019; Nyingi, 2019; Sumbule, 2019). The changes in poultry meat productivity and production costs are 11% and −7%, respectively (Onsongo et al., 2018). The price elasticity of supply (ε) for poultry products is 0.40 (Schiff and Montenegro, 1995). The *K*-shift parameter is calculated for eggs and poultry meat separately. The *K*-shift parameter in Equation (1) is weighted by the adoption or replacement rate (r) of conventional feeds by black soldier fly larval based feeds in the poultry sector.

Once the *K*-shift parameter is estimated, we calculate the total change in economic surplus accrues to consumers and producers of eggs and poultry meat. The changes in producer surplus (ΔPS_m) and consumer surplus (ΔCS_m) is computed as follows (Alston et al., 1995):

$$\Delta PS_m = P_m Q_m (K_m - Z_m)(1 + 0.5 Z_m \eta_m) \quad (2)$$

$$\Delta CS_m = P_m Q_m Z_m (1 + 0.5 Z_m \eta_m) \quad (3)$$

where $P_m$is an average producer price of eggs (2213 USD per t) and poultry meat (4279 USD per t) over the period 2012–2016 (FAO, 2019b), and Q_m is represented by the 2012–2016 average quantity of production of eggs (79,583 t) and poultry meat (26,634 t) (FAO, 2019b). Z_m is the relative change in price of eggs and poultry meat ($Z_m = K_m \times \varepsilon/(\varepsilon + \eta_m)$) (Alston et al., 1995), while η_m is the absolute price elasticity of demand, which is 0.74 for eggs (Cornelsen et al., 2016) and 0.64 for poultry meat (Shibia et al., 2017). The sum of ΔPS_m and ΔCS_m provides the change in total economic surplus due to BSFLM.

2.2. Estimation of foreign currency savings due to black soldier fly farming

Replacing imported feed with domestically produced insect feed would save foreign currency. The foreign currency saving is estimated via Equation (4), namely:

$$F = \sum_j r \times M_{jq} \times P_{jq} \quad (4)$$

where F is foreign currency saved by substituting proteins (fishmeal and soya bean meal) and energy (maize) with BSFLM; j is the index referring to fishmeal, maize, and soya bean meal; r is the adoption or replacement rate of conventional feeds by BSFLM (%); M_q is Kenya's estimated average imported fishmeal (4968 t) and soya bean meal (18,430 t) for poultry feed for the period 2009–2013 (FAO, 2019b; KMT, 2016b), as well as the estimated annual average imported maize (10,500 t) for poultry feed (personal communication, Association of Kenya Feed Manufacturers (Akefema)). P_q represents the average price of fishmeal (1552 USD per t) and soya bean meal (451 USD per t) for the period 2009–2013 in the international market (World Bank, 2018b), while the average price of imported maize for feed is taken as 337 USD per t (personal communication, Akefema Chairperson).

As mentioned in the introduction section, organic fertilizers are key by-products of insect farming. This means that the organic fertilizer has the potential to substitute imported inorganic fertilizers, which save foreign currency and improve environmental services. Given that most farmers in Africa struggle to access inorganic fertilizers, the mass production of organic fertilizers could help smallholder farmers. The potential economic gains from BSF- composted organic fertilizers are estimated using Equations (5)–(7), namely:

$$QS = q_f \times (r \times i_q) \quad (5)$$

$$QNPK = \pi \times QS \quad (6)$$

$$VNPK = P_{NPK} \times QNPK \quad (7)$$

where QS, is the quantity of organic fertilizer generated from the BSF farms, q_f represents 6 t of composted BSF fertilizer per t of dry BSFLM production (Beesigamukama, 2019), r is the adoption or replacement rate of conventional feeds by BSFLM (%), andi_q is the optimal poultry feed demand (t) (Table 1).[1] $QNPK$ is the quantity of nitrogen (N), phosphorus (P), and potassium (K) fertilizers produced. π represents the N, P, and K content of the composted BSF frass, 2.14% N, 0.85% P, and 0.58% K (Beesigamukama, 2019). $VNPK$ is the value of organic fertilizers, and P_{NPK} is the average price of N, P, and K in Kenya. We use the price for N, P, and K 585, 732, and 519 USD per t, respectively (Africa Fertilizer, 2019).

In equations (5)–(7), QS, $QNPK$, and $VNPK$ depend on the optimal poultry feed demand (i_q) replaced by BSFLM, which in turn depends on whether the commercial poultry sector or the smallholder poultry farmers will adopt BSFLM.[2] In the short-run, smallholder poultry farmers are unlikely to take BSFLM because of risk considerations and lack of information about the technology. The existing insect feed processors in Kenya also targets the commercial poultry sector. We estimate the benefits potentially accrued from organic fertilizers in two scenarios. In scenario 1, we assume that the commercial poultry sector (CPS) will only adopt BLSFM in the short-run. In Scenario 2, the CPS and traditional indigenous poultry sector (the entire poutry sector) will adopt BSFLM. The adoption of BSFLM by the entire poultry sector is likely to take more extended period, and it may show benefits of large-scale adoption of BSFLM in the long-run.

[b] The parameters for layers and broilers are based on information provided by the National Farmers Information Service of Kenya (NAFIS, 2019). For the indigenous poultry, we used the average of

[1] Optimal feed demand is the total feed required to feed chicken if the daily recommended amount of feed is given to the chicken.

[2] The Kenyan poultry industry comprises both smallholder and large-scale commercial producers. The majority of the birds (83%) are indigenous managed by smallholder farmers while the remaining 17% are managed by commercial poultry industry (Vernooij et al., 2018).

Table 1
Poultry optimal feed demand.

Breed type	Number of chickens (millions) [a]	Optimal recommended feed (g/fowl/day) [b]	Life expectancy	Feed demand (t)	
				Commercial poultry sector	Entire poultry sector
	A	C	D	E = A × C × D	F = A × C × D
Layers	5.49	82	365	163,531	163,531
Broilers	1.83	92	49	8229	8229
Indigenous	35.82	87	365	Not applicable	1,134,244
Total	43			171,760	1,306,004

[a] The number of chickens by breed type estimated based on Vernooij et al. (2018).

layers and broilers.

2.3. Employment effects

As a new economic activity, BSF farming will create job opportunities. This is particularly crucial in developing countries where the youth unemployment rate is significant. In Kenya, the youth unemployment rate is 12% of the 10.7 million Kenyans aged 15 to 34 who are part of the labor force (KNBS, 2018a). The unemployment rate is higher for females than males. Equations (8) and (9) estimate the employment effects of insect farming:

$$N = \frac{l \times r \times i_q}{H} \tag{8}$$

$$E = w \times N \tag{9}$$

where N represents the number of people who could directly be employed in the production of BSFLM, and l represents labor hours required to produce one t of BSFLM (815 h).[3] We obtain the values of l from BSFLM producing companies in Kenya: SANERGY Ltd and Ecodudu Ltd. r is the adoption or replacement rate of conventional feeds by BSFLM (%). i_q is the optimal poultry feed demand (t) (see Table 1), while H represents the total labor hours per year ($26 \times 8 \times 12\ months = 2496$), assuming a worker spends 26 days per month on an insect farm working 8 h a day for 12 months. E represents the earnings of labor, and w is the wage rate (2075 USD per year) currently paid by SANERGY Ltd and Ecodudu Ltd.

In equations (8) and (9), it is important to note that the estimated values depend on the optimal poultry feed demand (i_q) replaced by BSFLM. The employment effects of adopting BSFLM is therefore estimated using the two scenarios (CPS and entire poultry sector) discussed in the previous sub-section. It is also important to note that BSF farming and its introduction into the poultry sector may affect the performance and employment of other actors along the value chain. However, the computation of the employment effect here focuses only on BSF farming because we do not have employment data for other actors along the insect-farming value chain.

2.4. Food security effects

If BSFLM replaces fishmeal (*omena*),[4] maize, and soya bean used for poultry feed, food availability in the country will improve—contributing to food security. Poor Kenyans prefer *Omena* because it is cheaper than red meat and other fish types (KMT, 2019). In addition to the villages where it is harvested, *omena* is available throughout supermarkets in Kenya. Increasing the volume of *omena* for human consumption is likely to benefit Kenyans, especially the poor. The benefits that could be obtained if the *omena*-based feed were replaced by BSFLM can be computed using Equations (10) and (11):

$$Q_{omena} = r \times omena_{feed} \tag{10}$$

$$N_f = \frac{Q_{omena}}{C_f} \tag{11}$$

where $omena_{feed}$ represents domestically harvested *omena* used as poultry feed (t); r is the adoption or replacement rate of conventional feeds by BSFLM (%); Q_{omena} represents the volume of *omena* available for human consumption obtained by replacing *omena* feed with BSFLM; and N_f is the number of people that could be fed with the replaced *omena* at the current per-capita fish consumption (C_f) in Kenya (see Table 2).

To estimate the food security benefit when BSFLM replaces the soya bean meal, we reallocate land used for soya bean production to staple-food maize production. Because direct human consumption of soya bean production is less common in Kenya, the conversion of land to maize production may not affect the nutritional benefits (e.g., protein) of soya bean. Nearly 90% of total soya bean production is used for animal feed,of which 63% is a poultry feed (Chianu et al., 2008). Equations (12)–(14) estimates the food security benefit of reallocating soya bean land to maize production for food:

$$A_s = \frac{r \times S_f}{Y_s} \tag{12}$$

$$Q_m = (A_s \times Y_m) + \left(r \times M_{feed}\right) \tag{13}$$

$$N_m = \frac{Q_m}{C_m} \tag{14}$$

In Equation (12), $A_s$is the amount of area that could be reallocated from the production of soya beans to maize; r is the adoption or replacement rate of conventional feeds by BSFLM (%); $S_f$is quantity of soya bean used for poultry feed (t); and $Y_s$represents the average productivity of soya bean. In Equation (13), Q_m represents maize production resulted from reallocation of land for soya bean to maize production (t), Y_m is the productivity of maize, and M_{feed} is maize production used as poultry feed (t).

About 3% of domestically-produced maize is used as animal feed, and, of this, 64% goes to poultry (USDA, 2014). In Equation (14), N_m represents the number of people that could be fed by the additional maize produced at the current per-capita maize consumption (C_m) (see Table 2).

[3] This is without considering the amount of time spent on collecting organic waste for BSF farming because there is no data on this.

[4] A small cyprinid fish species commonly used for food and feed in the Lake Victoria region of East Africa (Legros and Luomba, 2011).

Table 2
Data used to estimate the food security effects of adopting BSLFM.

Variables	Average value	Source
Domestic *omena* used for poultry feed (2011–2015) (t) (Q_{omena})	33,015	Authors' estimate [a]
Price of *omena* (2011–2015) (USD/t) (P_{omena})	931	Farmgate prices
Fish consumption (2009–2013) (kg/person/year) (C_f)	3.82	FAO (2019b)
Domestic production of soya bean used for poultry feed (2013–2017) (t)[a] (S_f)	1460	Authors' estimate [a]
Productivity of soya beans (2013–2017) (t/ha) (Y_s)	1	FAO (2019b)
Productivity of maize (t/ha) (2013–2017) (Y_m)	1.82	FAO (2019b)
Domestic production of maize used for poultry feed (2013–2017) (t) (M_{feed})	67,030	Authors' estimate [a]
Maize consumption (2009–2013) (kg/person/year)	77	FAO (2019b)
Producer price of maize (2011–2015) (USD/t)	320	FAO (2019b)

[a] Domestic production of *omena*, soya bean, and maize used for poultry feed is as follows. The average *omena* harvest between 2011 and 2015 was 67,378 t. Of these, 47,165 t goes to animal feed and 70% of it is poultry feed (Kariuki, 2011). Between 2013 and 2017, the average soya bean production was 2317 t and 63% of it goes to poultry feed (Chianu et al., 2008; LC, 2016). Finally, the average maize production for the stated period was 3,491,172 t (KNBS, 2018b) and 3% of this was used as poultry feed (USAID, 2010).

2.5. Total economic benefits of black soldier fly farming and its effect on poverty reduction

The total economic benefits (*TEB*) to the Kenyan economy due to adoption of BSF farming is computed as follows:

$$\mathrm{TEB} = \Delta PS + \Delta CS + F + VNPK + E \tag{15}$$

We used the total economic benefits to compute the poverty reduction effect of adopting BSFLM. Most Kenyans live in rural areas where poverty is widespread. Black soldier fly larval meal induced poultry productivity gain can benefit the poor along the value chain, thereby contributing to poverty reduction. The number of people who could potentially escape poverty is estimated as follows (Kassie et al., 2018).

$$Pov = \left(\frac{\mathrm{TEB}}{LGDP} \times \delta\right) \times NP \tag{16}$$

In Equation (16), *Pov* is the number of people that can be lifted out of poverty, *TEB* represents the total economic benefits associated with the adoption of BSFLM, and *LGDP* represents Kenya's livestock gross domestic product. The five-year average LGDP for 2013–2017 is 3 billion USD (KNBS, 2018b; World Bank, 2018b). Poverty elasticity to *LGDP*, which is −0.88, is represented by δ (Thurlow et al., 2007) ,[5] while *NP* denotes the number of people who live below the poverty line in Kenya, namely 16.4 million, 71% of whom live in rural areas (KNBS, 2018c).

3. Results and discussions

3.1. Estimated economic surplus

We estimate the *K*-shift parameter for eggs and poultry meat separately (Fig. 1). At a 5% BSFLM adoption level, the Kenyan economy enjoys per-unit cost reduction of 2.7% in egg and 1.7% in poultry meat production. Similarly, a 15% adoption could reduce the unit cost of production by 8% for eggs and 5% for poultry meat. The long-term effect of BSFLM, at a 50% adoption rate, can reduce the cost of production by 27% in egg and 17% in poultry meat production.

The per-unit production cost reduction would result in a 7–69 million USD in economic surplus (see Table 3). This represents 3%–31% of Kenya's average poultry GDP of 225 million USD between 2013 and 2017. This estimate is also 0.01%–0.11% of Kenya's GDP (KNBS, 2018b, 2016).

[5] The poverty–growth elasticity is the average of elasticities of rural (−1.58) and urban (−0.58) areas (Thurlow et al., 2007).

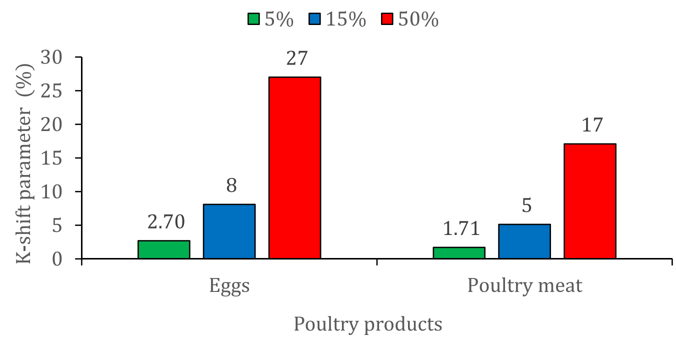

Fig. 1. The K-shift parameter (%) at 5–50% adoption rates.

3.2. Foreign currency savings

Fig. 2 shows the estimated foreign currency that could be saved by replacing fishmeal, maize, and soya bean meal by BSFLM. The estimated foreign currency savings are between 1 million USD per year in the short-run to 10 million USD per year in the long-run at a 50% adoption rate.

Table 4 shows the estimated foreign currency savings due to the production of organic fertilizers as a by-product of BSF farming. The total quantity of organic fertilizers (N, P and K) estimated to be 13,987 (1840)–139,873 (18,395) t, assuming BSFLM is adopted in the entire poultry sector (commercial poultry sector). This estimated quantity of organic fertilizers in the entire poultry sector (commercial poultry sector) represents 2.13% (0.28%) to 21.34% (2.81%) of the inorganic fertilizer import between 2013 and 2017, namely 655,597 t (KNBS, 2018b). In monetary value, this is equivalent to 9–85 million USD (1–11 million USD). In the future, it is crucial to understand the value of organic fertilizer on crop production. The on-station experiment in Kenya shows that combining organic fertilizer from BSF farming with conventional fertilizers increases yields of french beans, kale, tomato and maize by 41%, 34%, and 26% and 32%, respectively, compared with applying inorganic fertilizers alone (Onyoni, 2019).

Table 4 also presents the contribution of BSFLM production to a

Table 3
Economic surplus due to adoption of black soldier fly larval meal.

Benefits	Adoption rates (%)		
	5	15	50
Producer surplus (ΔPS) (millions of USD)	4.29	12.96	44.15
Consumer surplus (ΔCS) (millions of USD)	2.43	7.33	24.96
Total surplus (millions of USD)	6.72	20.30	69.10

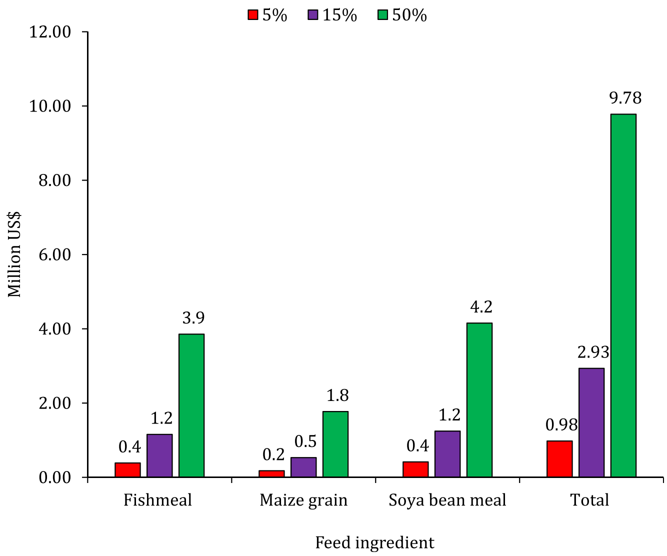

Fig. 2. Foreign currency savings (million USD) of replacing fishmeal, maize, and soya bean meal by black soldier fly larval meal per annum in Kenya.

circular economy through recycling waste. Using BSFLM in the CPS at a 5% adoption rate alone, the recycled biowaste is equivalent to 57% of the 422, 290 t of biowaste Nairobi releases annually (World Bank, 2019). A 15% adoption of BSFLM by the CPS would completely consume Nairobi's total biowaste each year and may demand additional biowaste from other sources (e.g., other towns).

3.3. Employment benefits of black soldier fly farming

Black soldier fly farming has the potential to provide 25,000–76,000 additional jobs if BSFLM replaces conventional feeds by 5–15% across the entire poultry sector. Similarly, if the CPS uses BSFLM at a 5–15% adoption rate, the increase in employment would potentially be between 3300 and 10,000 jobs (see Table 5). This is equivalent to reducing the country's youth unemployment by 0.03–0.09%, which was 10.7 million in 2015/16 (KNBS, 2018a). At a 50% adoption rate, the employment effect could increase the number of jobs by 33,000 for the CPS, and by 251,000 for the entire poultry sector. These are respectively 0.31% and 2.36% of the unemployed youth in Kenya. Given the high youth unemployment rate in Kenya (12%), these figures show that insect farming offers immense opportunities for new job creation. This is at least at par with–if not more than–the urban employment target (4200 jobs per year) set by the Ministry of Environment and Natural Resources of Kenya for solid waste recycling using a circular economy approach (Soezer, 2017). The employment benefits would become even more significant if other actors, such as sellers of substrates for

Table 5
Employment benefits of black soldier fly farming.

Benefits	Commercial poultry sector (CPS)			Entire poultry sector		
	Adoption rates (%)					
	5	15	50	5	15	50
Number of jobs	3314	9942	33,140	25,199	75,596	251,987
Earnings (Million US$)	6.88	20.63	68.76	52.28	156.85	522.85

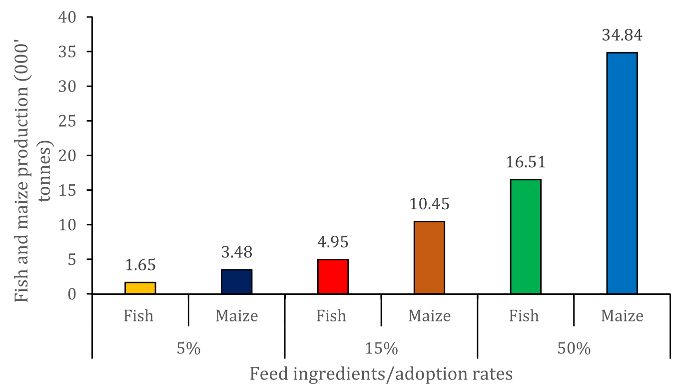

Fig. 3. Increase in fish and maize production for human consumption (000′ t) if black soldier fly larval meal partially replaces key conventional feed sources.

BSF rearing, processors of organic fertilizers, and sellers of organic fertilizers (including shopkeepers and transporters), were included in the employment benefit computation.

At a 5–15% adoption rate in the CPS scenario alone, workers' combined earnings could be between 7 and 21 million USD per year. If the entire poultry sector adopts BSFLM, the workers' combined earnings could reach 52–157 million USD at the lowest levels of adoption, namely 5–15%. The employment benefits would more than double as the BSFLM adoption rate increased to 50% in the long-run (Table 5).

3.4. Food security effects

Fig. 3 represents the additional amount of maize produced and *omena* harvested that would be available for human consumption if BSFLM replaced *omena*-based fishmeal, maize, and soya bean meal. At a 5 and 15% BSFLM adoption rate, Kenya could produce an additional 3480 and 10,450 t of maize, respectively. This represents 0.69–2% of Kenya's average imported maize between 2013 and 2017, which was about 501,813 t (KNBS, 2018b). Similarly, if BSFLM replaces fishmeal by 5 and 15%, it could respectively increase the availability of *omena* fish for human consumption by 1650 and 4950 t annually. The estimated amount of fish (*omena*) that can

Table 4
Organic fertilizers and the environmental benefits of BSF farming.

Benefits	Commercial poultry producers (CPS)			The entire poultry sector		
	Adoption rates (%)					
	5	15	50	5	15	50
N production (t)	1103	3308	11,027	8385	25,154	83,845
P production (t)	438	1314	4380	3330	9991	33,303
K production (t)	299	897	2989	2272	6817	22,724
Total organic fertlizers (N-P-K) (t)	1840	5519	18,395	13,987	41,962	139,873
N-P-K values (Millions of USD)	1	3	11	9	26	85
Total biowaste recycled (t)	240,464	721,391	2,404,638	1,828,406	5,485,217	18,284,056

Table 6
Number of additional people that can consume fish and maize production if black soldier fly larval meal partially replaces key conventional feed sources (fish meal, maize and soya bean meal).

Adoption rates (%)	Number of people fed by the extra production		
	Fish	Maize	Total
5	431,913	45,435	477,348
15	1,295,738	136,306	1,432,044
50	4,319,125	454,354	4,773,480

instead be used for human consumption constitutes 8–23% of the average fish imported between 2013 and 2017, namely 21,574 t (KNBS, 2018b). In the long run, at the 50% adoption rate of BSFLM, availability of omena–the fish of poor– and maize–the food security crop– for food consumption can increase by 17,000 t (77% of fish import) and 35,000 t (7% of the maize import), respectively. Furthermore, a 5–50% adoption of BSFLM can increase the number of people consuming fish and maize by 0.48–4.8 million at the current level of fish and maize consumption per capita (see Table 6).

3.5. Poverty reduction implication of the estimated total economic benefits

The analysis reveals that replacing 5–15% of conventional feeds by BSFLM in the entire poultry sector has the pontential to increase Kenya's total income by 69–206 million USD per year (Fig. 4), which represents 7–21% of Kenya's poultry GDP and 0.02–0.07% of the total GDP. This could reduce the number of poor people by 0.32–0.96 million, which represents 2–6% of the number of people who were living below the poverty line in 2015/2016. Similarly, adopting BSFLM by 5–15% in the entire poultry sector alone has the potential to boost the country's income by 16–47 million USD per year (Fig. 4) and move 0.07–0.22 million people above the poverty line. Using the economic gains at 50% adoption rate of BSFLM, Kenya could reduce the number of poor people below the poverty line by 3.19 (0.74) million if the entire poultry sector (the entire poultry sector) uses BSFLM. This indicates the potential long-term benefit of large-scale adoption of BSFLM.

4. Conclusions and policy implications

Our findings demonstrate that insect farming has the potential to contribute to the achievement of the economic, environmental, and social sustainable development goals of the United Nations. In the short to the long-run, a 5–50% adoption rate of BSFLM by the commercial poultry sector can generate a potential economic benefit in the order of 16–159 million USD annually, which is equivalent to 0.02–0.24% of Kenya's GDP. In order to generate these benefits, Kenya would need to recycle 0.24 to 2.4 million t of biowaste. Transalting this to economic value, each tonne of the biowaste generates USD 66 to the Kenyan economy, which is nearly 3 fold higher than the cost of waste disposal in Nairobi. [6] With the same ranges of adoption (5–50%), insect farming could generate a huge employment opportunities at least at par with–if not more than–the employment target of urban Kenyan waste recycling program set by the Ministry of Environment and Natural Resources of Kenya. Furthermore, we find that replacing fishmeal, maize, and soybean meal by BSFLM can increase the number of people who can have access to maize and *omena* by 0.47–4.8 million at the current per-capita fish and maize consumption in Kenya. Overall, the economic gains of rearing black soldier fly could reduce the number of people below the poverty line by 0.07–0.74 million. If the entire Kenyan poultry sector adopts BSFLM as feed, the economic gains could further translate to reducing poverty by 3.19 million people.

Although our findings show interesting positive impact stories of the potential adoption of BSFLM, the study has some limitations that could be tackled in future research. Firstly, even though Kenya imports amino acids, vitamins, and mineral supplements, the benefits of BSFLM in replacing these nutrients are not considered in the analysis because of data scarcity. Secondly, our estimates do not take into account the new capital generated through BSFLM production since data are not available. Thirdly, our estimates do not fully cover the forward and backward linkages of BSF farming along the value chain, i.e., our estimates use a partial equilibrium model, which assumes that the insect-feed innovation affects only the poultry sector. If we had calculated the general equilibrium effects, our estimate of the benefits of the insect-feed innovation would likely have been higher than results presented here. For example, the employment estimation excludes potential jobs in packaging, transporting, and selling BSFLM and organic fertilizer packaging, as well as employment that could be generated in the feed industry and poultry processing sector. Fourthly, the study does not capture directly the economic benefits of organic fertilizers' contribution to crop production and productivity gains.

Despite these caveats, the results of this study have the following impications. First, policy and programs that integrate insect farming in the agricultural sector can diversify and enhance the resilience of African economies in the face of climate change, while enhancing social gains and environmental services. Second, the transition from conventional feed sources to insect meals requires strong extension services and investment to create awareness along the value chian, enhance capacity and skills of actors, and shape consumer and producer preferences. Third, significant economic-social-enviroment benefits can be achieved if insect production can be carried at large scale, which further need channeling investment towards the insect production and processing sub-sector.

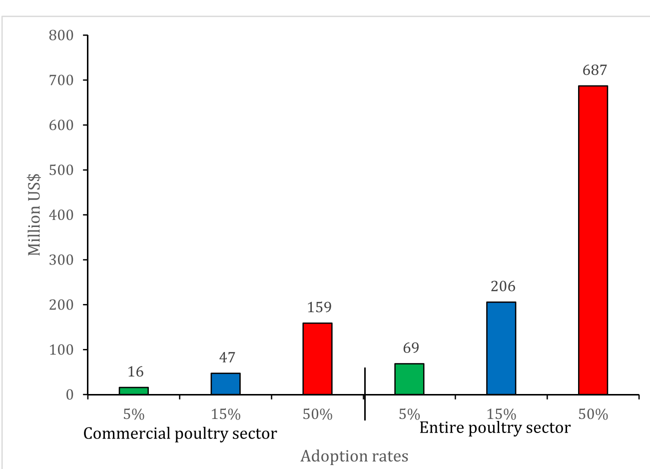

Fig. 4. Estimated total economic benefits by adoption rates.

Declaration of competing interest

The authors declare no conflict of interest.

[6] This is computed as the average value of (USD16 million/0.24 million t biowaste) and (USD 159 million/2.4 million t biowaste).

CRediT authorship contribution statement

Zewdu Abro: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing - original draft. **Menale Kassie:** Conceptualization, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing - review & editing. **Chrysantus Tanga:** Validation, Visualization, Writing - review & editing. **Dennis Beesigamukama:** Validation, Visualization, Writing - review & editing. **Gracious Diiro:** Visualization, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.121871.

References

Africa Fertilizer, 2019. National Fertilizer Prices. https://africafertilizer.org/national/#tab-id-3. Accessed 19 April 2019.
Allegretti, G., Talamini, E., Schmidt, V., Bogorni, P.C., Ortega, E., 2018. Insect as feed: an emergy assessment of insect meal as a sustainable protein source for the Brazilian poultry industry. J. Clean. Prod. 171, 403–412.
Alston, J.M., Norton, G.W., Pardey, P.G., 1995. Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press, New York.
Anand, H., Ganguly, A., Haldar, P., 2008. Potential value of Acridids as high protein supplement for poultry food. Int. J. Poultry Sci. 7, 722–725.
Beesigamukama, D., 2019. Development of Insect-Based Compost for Sustainable Soil Health Management Using By-Products from Insect Mass Rearing for Food and Feed.
Bergevoet, R., Engelen, A. van, 2014. The Kenyan Meat Sector Opportunities for Dutch Agribusiness. LEI Wageningen UR (University & Research Centre), Wageningen. LEI Report 2014-032.
Chia, S.Y., Mbi, C., Id, T., Khamis, F.M., Mohamed, A., Salifu, D., Id, S.S., Fiaboe, K.K.M., Niassy, S., Loon, J.J.A., Ekesi, S., 2018. Threshold temperatures and thermal requirements of black soldier fly Hermetia illucens : implications for mass production. PloS One 1–26.
Chia, S.Y., Tanga, C.M., van Loon, J.J., Dicke, M., 2019. Insects for sustainable animal feed: inclusive business models involving smallholder farmers. Curr. Opin. Environ. Sustain. 41, 23–30.
Chianu, J.N., Vanlauwe, B., Mahasi, J., Katungi, E., Akech, C., Mairura, F., Chianu, J.N., Sanginga, N., 2008. Soybean Situation and Outlook Analysis: the Case of Kenya. International Crops Research Institute for the Semi-arid Tropics (ICRISAT).
Cornelsen, L., Alarcon, P., Häsler, B., Amendah, D.D., Ferguson, E., Fèvre, E.M., Grace, D., Dominguez-Salas, P., Rushton, J., 2016. Cross-sectional study of drivers of animal-source food consumption in low-income urban areas of Nairobi, Kenya. BMC Nutr 2, 1–13.
Davis, K.F., Gephart, J.A., Emery, K.A., Leach, A.M., Galloway, J.N., D'Odorico, P., 2016. Meeting future food demand with current agricultural resources. Global Environ. Change 39, 125–132.
de Groote, H., Nyanamba, T., Wahome, R., 2010. Quality protein maize for the feed industry in Kenya. Outlook Agric. 39, 291–298.
Dobermann, D., Swift, J.A., Field, L.M., 2017. Opportunities and hurdles of edible insects for food and feed. Nutr. Bull. 42, 293–308.
Ermolaev, E., Lalander, C., Vinnerås, B., 2019. Greenhouse gas emissions from small-scale fly larvae composting with Hermetia illucens. Waste Manag. 96, 65–74.
Ewald, N., Vidakovic, A., Langeland, M., Kiessling, A., Sampels, S., Lalander, C., 2020. Fatty acid composition of black soldier fly larvae (Hermetia illucens) – possibilities and limitations for modification through diet. Waste Manag. 102, 40–47.
FAO, 2019a. Meat and Meat Products. FAO's Animal Production and Health Division. http://www.fao.org/ag/againfo/themes/en/meat/home.html. Accessed 8 March 2019.
FAO, 2019b. FAOSTAT. Data. Food Agric. Organ. http://www.fao.org/faostat/en/#data. Accessed 10 July 2019.
Halloran, A., Hanboonsong, Y., Roos, N., Bruun, S., 2017. Life cycle assessment of cricket farming in north-eastern Thailand. J. Clean. Prod. 156, 83–94.
Hanboonsong, Y., Jamjanya, T., Durst, P.B., 2013. Six-legged livestock : edible insect farming, collection and marketing in Thailand. Food and Agricultural Organization (FAO), Bankok.
INRA-CIRAD-AFZ, 2020. Feed Composition Table. Maize grain (Zea mays L.). Institut national de la recherche agronomique (NRA), Agriculutral Research For Development (CIRAD) and French association for animal production (AFZ). https://www.feedtables.com/content/maize. Accessed 12 March 2019.
Kariuki, M.B.J., 2011. Analysis of Market Performance: a Case of 'omena' Fish in Selected Outlets in Kenya. A Thesis Submitted to the Graduate School in Partial Fulfilment for the Requirements of the Master of Science Degree in Agricultural and Applied Economics. Egerton University.
Kasozi, A., von Blottnitz, H., 2010. Solid Waste Management in Nairobi: A Situation Analysis. Technical Document Accompanying the Integrated Solid Waste Management Plan. Environmental & Process Systems Engineering Group University of Cape, Town.
KBS, 2016. Dried Insect Products for Compounding Animal Feeds – Specification. Kenya Bureau of Standards (KBS), Naiorbi, Kenya.
Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N.K., Ekesi, S., 2015. African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J. Insects as Food Feed 1, 103–119.
Khusro, M., Andrew, N.R., Nicholas, A., 2012. Insects as poultry feed: a scoping study for poultry production systems in Australia. World. Poult. Sci. J. 68, 435–446.
KMT, 2016a. Animal Feed Study: Mapping Animal Feed Manufacturers and Ingradient Suppliers in Kenya. Markets Trust (KMT).
KMT, 2016b. Mapping Animal Feed Manufacturers and Ingredient Suppliers in Kenya. Kenya Markets Trust (KMT).
KMT, 2019. A Study on Meat End Market Trends in Kenya. Kenya Markets Trust (KMT).
KNBS, 2016. Statistical Abstract 2016. Kenya National Bureau of of Statistics (KNBS).
KNBS, 2018a. THE 2015/16 Kenya integrated household budget survey (KIHBS). In: Labour Force Basic Report. Kenya National Bureau of Statistics. (KNBS).
KNBS, 2018b. Statistical Abstract 2018. Kenya National Bureau of of Statistics (KNBS).
KNBS, 2018c. Basic Report on Well-Being in Kenya: Based on the Kenya Integrated Household Budget Survey (KIHBS). Kenya National Bureau of Statistics (KNBS).
Krishna, V.V., Erenstein, O., Sadashivappa, P., Vivek, B.S., 2014. Potential economic impact of biofortified maize in the Indian poultry sector. Int. Food Agribus. Manag. Rev. 17, 109–138.
Lalander, C.H., Fidjeland, J., Diener, S., Eriksson, S., Vinnerås, B., 2015. High Waste-To-Biomass Conversion and Efficient Salmonella Spp . Reduction Using Black Soldier Fly for Waste Recycling, pp. 261–271.
Lattice Consulting, 2016. Market study of the aquaculture market in Kenya. Kenya market-led aquaculture programme (KMAP). A report produced for Farm Africa, pp. 1–75.
Legros, D., Luomba, J., 2011. Dagaa Value Chain Analysis and Proposal for Trade Development. Report SF/2011/19.
Makkar, H.P.S., Tran, G., Heuzé, V., Ankers, P., 2014. State-of-the-art on use of insects as animal feed. Anim. Feed Sci. Technol. 197, 1–33.
Mertenat, A., Diener, S., Zurbrügg, C., 2019. Black Soldier Fly biowaste treatment – assessment of global warming potential. Waste Manag. 84, 173–181.
Mungkung, R., Aubin, J., Prihadi, T.H., Slembrouck, J., Van Der Werf, H.M.G., Legendre, M., 2013. Life cycle assessment for environmentally sustainable aquaculture management: a case study of combined aquaculture systems for carp and tilapia. J. Clean. Prod. 57, 249–256.
Mwangi, K.W., 2019. Growth Performance of Indigenous Chicken Fed on Diets Containing Black Soldier Fly Larvae Meal. A Thesis Submitted in Partial Fulfillment of the Requirements for Award of the Degree of Master of Science in Animal Science. Kenyatta University.
NAFIS, 2019. Feeds and Feeding. National Farmers Information Service of Kenya (NAFIS). http://www.nafis.go.ke/livestock/poultry-chicken/general-information/feeds-and-feeding/. Accessed 8 July 2019.
Nyingi, D.W., 2019. Insect Feed Utilization in Layer Diets: Effects on Performance

and Egg Quality in Improved Indigenous Chicken. A Thesis Submitted in Partial Fulfillment of the Requirements for Award of the Degree of Master of Science in Animal Science. Kenyatta University.
Onono, J.O., Alarcon, P., Karani, M., Muinde, P., Akoko, J.M., Maud, C., Fevre, E.M., Häsler, B., Rushton, J., 2018. Identification of production challenges and benefits using value chain mapping of egg food systems in Nairobi, Kenya. Agric. Syst. 159, 1–8.
Onsongo, V.O., Osuga, I.M., Gachuiri, C.K., Wachira, A.M., Miano, D.M., Tanga, C.M., Ekesi, S., Nakimbugwe, D., Fiaboe, K.K.M., 2018. Insects for income generation through animal feed: effect of dietary replacement of soybean and fish meal with black soldier fly meal on broiler growth and economic performance. J. Econ. Entomol. 1–8.
Onyoni, A., 2019. Effect Thesisof Black Soldier Fly-Composted Organic Fertilizer on the Growth and Yields of Phaseolus vulgaris, Solanum lycopersicum and Brassica oleracea Var. Acephala in Kenya. A Research Thesis Submitted to the Graduate School in Partial Fulfillment for Master of Science in Agronomy. Kenyata University.
Pang, W., Hou, D., Chen, J., Nowar, E.E., Li, Z., Hu, R., Tomberlin, J.K., Yu, Z., Li, Q., Wang, S., 2020. Reducing greenhouse gas emissions and enhancing carbon and nitrogen conversion in food wastes by the black soldier fly. J. Environ. Manag. 260, 110066.
PROteINSECT, 2016. Insect Protein – Feed for the Future: Addressing the Need for Feeds of the Future Today. White Paper 2016.
Roffeis, M., Wakefield, M.E., Almeida, J., Alves Valada, T.R., Devic, E., Koné, N., Kenis, M., Nacambo, S., Fitches, E.C., Koko, G.K.D., Mathijs, E., Achten, W.M.J., Muys, B., 2018. Life cycle cost assessment of insect based feed production in West Africa. J. Clean. Prod. 199, 792–806.
Schiavone, A., Dabbou, S., Marco, M. De, Cullere, M., Biasato, I., Biasibetti, E., Capucchio, M.T., Bergagna, S., Dezzutto, D., Meneguz, M., Gai, F., Zotte, A.D., Gasco, L., 2018. Black soldier fl y larva fat inclusion in fi nisher broiler chicken diet as an alternative fat source. Animal 1–8.
Schiff, M., Montenegro, C.E., 1995. Aggregate agricultural supply response in developing countries : a survey of selected issues. In: Policy Research Working Paper No. WPS 1485. World Bank, Washington, DC.
Shibia, M., Rahman, S.M., Chdmi, B., 2017. Consumer demand for meat in Kenya: an examination of the linear approximate almost ideal demand system. In: Selected Paper Prepared for Presentation at the 2017 Southern Agricultural Economics Association (SAEA) Annual Meetings.
Smetana, S., Palanisamy, M., Mathys, A., Heinz, V., 2016. Sustainability of insect use for feed and food: life Cycle Assessment perspective. J. Clean. Prod. 137, 741–751.
Soezer, A., 2017. A Circular Economy Solid Waste Management Approach for Urban Areas in kenya. Ministry of Environment and Natural Resources, Nairobi, Kenya.
Sumbule, E.K., 2019. Effect of Inclusion of Black Soldier Fly Larval Meals on Chicks, Growers and Layers Diet on Performance and Nutritional Benefits of Commercial Chicken. A Research Thesis Submitted to the Graduate School in Partial Fulfillment for the Requirements of the Master of Science. Egerton University.
Thurlow, J., Kiringai, J., Gautam, M., 2007. Rural investments to accelerate growth and poverty reduction in Kenya. In: International Food Policy Research Institute(IFPRI). IFPRI Discussion Paper 00723.
USAID, 2010. Staple Foods Chain Analyisis. Country Report Kenya. United States Agency for International Development (USAID).
USDA, 2014. Animal feed situation. In: USDA Foreign Agricultural Service. Global Agricultural Information Network (GAIN). US Department of Agriculture (USDA).
van Huis, A., 2015. Edible insects contributing to food security? Agric. Food Secur 4, 1–9.
van Huis, A., Itterbeeck, J. Van, Klunder, H., Mertens, E., Halloran, A., Muir, G., Vantomme, P., 2013. Edible Insects: Future Prospects for Food and Feed Security. Food and Agriculture Organization of the United Nations. Forestry paper 171.
van Zanten, H.H.E., Mollenhorst, H., Oonincx, D.G.A.B., Bikker, P., Meerburg, B.G., de Boer, I.J.M., 2015. From environmental nuisance to environmental opportunity: housefly larvae convert waste to livestock feed. J. Clean. Prod. 102, 362–369.
Veldkamp, T., Bosch, G., 2015. Insects - a protein rich feed ingredient in pig and poultry diets. Anim. Front. 5, 45–50.
Verkerk, M.C., Tramper, J., van Trijp, J.C.M., Martens, D.E., 2007. Insect cells for human food. Biotechnol. Adv. 25, 198–202.
Vernooij, A., Masaki, M.N., Meijer-Willems, D., 2018. Regionalisation in Poultry Development in Eastern Africa.
World Bank, 2018a. World Bank Commodity Price Data (The Pink Sheet). http://www.worldbank.org/en/research/commodity-markets. Accessed 27 November 2018.
World Bank, 2018b. World Development Indicators. The World Bank.
World Bank, 2019. What a Waste Global Database. https://datacatalog.worldbank.org/dataset/what-waste-global-database. accessed 5.16.19.