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Full-length article

# Adoption potential of black soldier fly (*Hermetia illucens* (L.), Diptera: Stratiomyidae) larvae composting technology among smallholder farmers in Greater Ahafo-Ano, Ashanti region of Ghana

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ABSTRACT

As the world's population increases, the growing demand for food intensifies the generation of agricultural waste, leading to several environmental issues. Intensive research indicates black soldier fly (BSF) larvae *Hermetia illucens* (Linnaeus, 1758) as efficient converters of organic waste into nutrient-rich biomass suitable for animal feed. Using a structured questionnaire and volunteer farmers (N = 595), we investigated the potential for adoption of BSF larvae composting technology for sustainable agricultural waste management in Greater Ahafo-Ano. Almost all surveyed farmers declared they generated a significant amount of biowaste on their farms and were willing to learn how to use the BSF-based technology to transform it into value-added products. The waste generated was mainly disposed of in pits at Ahafo-Ano South-East (56.2%), by composting at Ahafo-Ano South-West (34.9%) and by sale at Ahafo-Ano North (34.4%). Across the three districts, awareness of the BSF was very low – 14.5% in Ahafo-Ano South-East, 14.1% in Ahafo-Ano South-West and 0.5% in Ahafo-Ano North. However, high acceptance of the technology was recorded. It was found that about 8% of farmers surveyed in Ahafo-Ano South-East had already tried BSF farming on a small scale. Indicating this district as a good entry point to introduce the technology into Greater Ahafo-Ano.

## 1. Introduction

Agricultural production has increased more than threefold over the last 50 years because of the expansion of land area for agricultural use, the technological contribution of the green revolution which influenced productivity, and the accelerated growth of population [1]. Agriculture produces an average of 23.7 million tons of food per day worldwide [2]. This production is not without negative impacts on the environment. Agriculture is responsible for about 21% of greenhouse gas emissions and creates great pressure on the environment and the sustainability of ecosystems [3]. When harvesting any crop, only the leaves, grains, fruits, pods, or tubers are generally harvested. This represents 30 to 40% of the total biomass produced, with the remaining 60%–70% being waste. This waste biomass is usually dumped on the farm or burned openly on the field, thus contributing to the increasing ecosystem degradation.

Besides, increasing food demands would always intensify the existing challenges associated with agricultural waste management [4]. An innovative approach to recover resources lost along the production chain and convert them into value-added products would thus be beneficial. The black soldier fly (BSF) *Hermetia illucens*, offers a promising solution for recycling agricultural waste and by-products into value-added products [5,6]. BSF larvae feed voraciously on organic matter and convert it into protein-rich biomass that can effectively replace current protein sources in livestock diets [7–9]. The feeding process of this insect also generates a compost-like residue (BSF frass) which is highly valued for its fertilizing potential [10,11]. In addition, recycling agricultural waste using BSF larvae helps reduce greenhouse gas emissions compared to composting, and produce sustainable feed ingredients with low environmental impacts [8,12,13].

In line with recent global trends, Ghana is working on promoting waste recovery for reuse and recycling [14]. The informal sector is actively involved. Waste pickers often collect valuable waste from the municipal waste streams and sell them to recycling companies or for reuse purposes [15]. In Ghana, there is the potential for rearing BSF

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**Fig. 1.** BSF larvae composting technology as operated at IITA-Benin.
*Pre-treatment* – Agricultural waste mainly consisting of fruits and vegetables are collected and crushed using a motorized shredder. *Treatment* – The crushed biowaste is fed to BSF larvae from a pre-established BSF rearing colony. This process takes two to three weeks depending on the environmental conditions of the processing unit. *Harvesting* – Following the treatment process, the mature BSF larvae are separated from the residue and are ready to be processed into a feed ingredient. *BSF larvae as feed ingredient* – The harvested larvae are washed and can be fed fresh to chicken, fish, or other animals, or dried and ground to make a protein-rich meal to incorporate into the diet. *BSF frass* – After separation, the residue commonly known as frass is composted for a few more weeks to undergo maturation, after which it can be applied as organic fertilizer.

at large scale. BSF larvae are easily found in the natural environment in Ghana [16], and its application in agriculture can divert and reduce agricultural waste from landfill. The production of BSF larvae in Ghana can create employment and revenue opportunities for the unemployed population, especially the youths, farmers and waste pickers who may take part in the recovery, processing, and utilization.

Agriculture is one of the largest biological sectors with the highest biomass production, which represents an essential input for BSF farming [17–19]. Ghana has a long agricultural tradition, and it has been expanding and improving gradually over time [17]. In Greater Ahafo-Ano for example, agriculture is the primary occupation for over 75% of the population [20]. The environmental conditions favor the extensive farming of various livestock animals, and the cultivation of cash crops like cocoa and oil palm as well as food crops like plantain, maize, cocoyam, rice, cassava, and vegetable [21]. These extensive agricultural activities certainly generate substantial quantities of biowaste which need to be treated. This justifies the objective of this study which aims to assess the potential as well as the prospects of smallholder farmers in Greater Ahafo-Ano towards BSF larvae composting technology. This study builds on knowledge gained from the BSF larvae mass rearing unit at the International Institute of Tropical Agriculture (IITA) in Benin, operated as described in Fig. 1.

## 2. Materials and methods

### 2.1. Study sites

The study was conducted in Greater Ahafo-Ano in the Ashanti Region of Ghana (Fig. 2). Located between longitude 1°26′ and 2°20′W and latitude 6°4′ and 7° 06′N, Greater Ahafo-Ano has three districts namely, Ahafo-Ano North, Ahafo-Ano South-East, and Ahafo-Ano South-West, and covers an area of 1792.5 km$^2$ out of which 33% belongs to the Ahafo-Ano North District, 31% to the Ahafo-Ano South-East District and 36% to the Ahafo-Ano South-West District. The area falls within the wet semi-equatorial climatic region of Ghana, which is characterized by the occurrence of two rainy seasons. The major season occurs between March and June while the minor season spans September to November. The average annual precipitation is about 1700 mm–1850 mm per year while the mean annual temperature is around 30 °C with the lowest temperature being about 26.1 °C. Relative humidity range is 70%–75% making the area suitable for agriculture. Being in the transition belt, the main economic activity in the three districts has historically been agriculture. About 80% of the land is suitable for crop cultivation, and maize, rice, cassava, yam, cocoyam, and plantain are the main food crops cultivated. However, the soils and the rainfall regime can also support different types of agricultural products such as citrus, cocoa, oil palm, cassava, tomatoes, and vegetables. Animal husbandry is increasingly becoming an important economic activity in the district economy. In most settlements, sheep, goats, and poultry birds are reared in the backyards to provide additional income and as a protein supplement. The districts have been identified by the Ministry of Food and Agriculture among 21 districts with great potential for fish farming in Ghana.

### 2.2. Study design and data collection

This is a cross-sectional and descriptive study carried out in August 2022 in three selected Districts in the Ahanti Region of Ghana as previously describe above. Using structured questionnaire (Supplement file 1), the study was designed to elicit responses from respondents basically farmers in the poultry, fish, and vegetables sectors. The questionnaire consisted of a set of 30 questions grouped into six levels: (i) socio-demographic characteristics of respondents; (ii) general background of farming practices in Ahafo Ano; (iii) background and knowledge on the BSF-based technology in the study areas; (iv) attitudes towards BSF and its applications; (v) practices of BSF technology; and (vi) information on the generation of agri-livestock wastes in the locality. Questions were elaborated to help elucidate information on: (a) agri-livestock producers in the study area and their knowledge, acceptance, and practices towards BSF larvae composting technology and applications; (b) the availability of biowaste streams to serve as feedstock for BSF larvae rearing in the districts; and (c) the BSF value chains in the districts.

To ensure the full participation of a significant number of farmers, the agriculture extension officers (AEOs) from selected operational

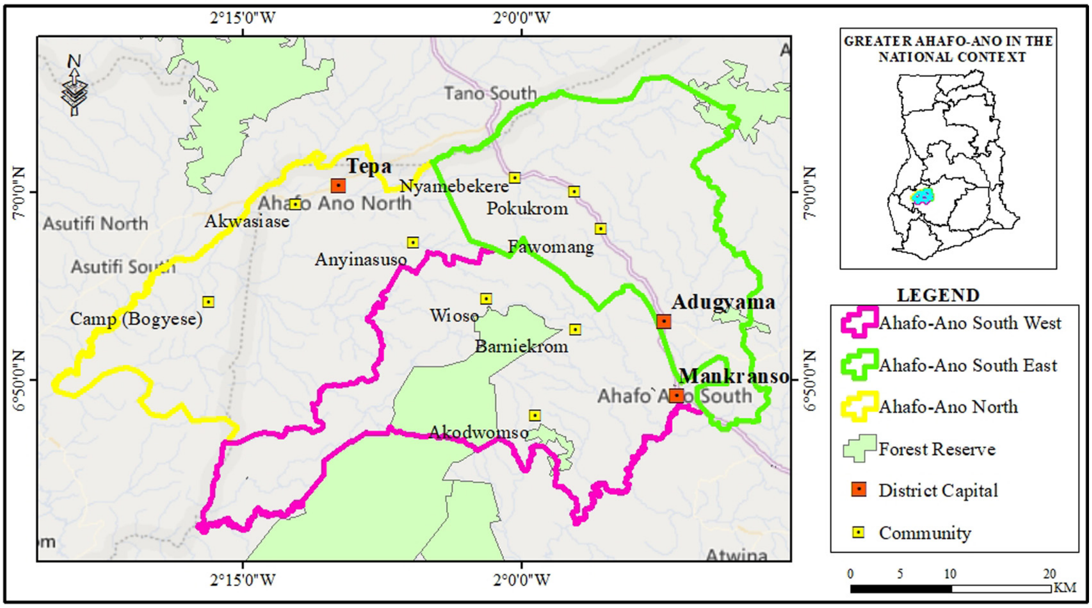


**Fig. 2.** Map of Greater Ahafo-Ano in the Ashanti egion of Ghana, showing the three study districts.

zones in the districts served as enumerators. After obtaining administrative authorizations from the District Agric-Directors, the AEOs received training on BSF larvae composting technology and the designed questionnaire. The questionnaire was validated through a pre-testing process to ensure its suitability for the study and the achievement of the expected results prior to submission to the volunteers' farmers after obtaining their free and informed consents. The study was approved by the Ethics Committee of the Internal Review Board (IRB) of IITA, and information collected from participants in the three Districts was treated confidentially. In the field, 30 enumerators and 3 supervisors were deployed to the districts to raise awareness and carry out the enumeration for three weeks. On the fourth week, the entire team met for collation of the questionnaires and debriefing. Each enumerator administered averagely 20 questionnaires, making a total number of 600 farmers interviewed. All methods were carried out in accordance with relevant guidelines and regulations.

### *2.3. Data analysis*

Data collected was processed in Microsoft Office Excel 2019 (Supplement file 2) and analyzed using IBM SPSS Statistics software version 28.0.1.0 and MedCalc Version 22.009. Descriptive statistics and variables computation were used to illustrate the socio-demographic characteristics, the issue of land degradation, the scale of food production, the generation of agri-livestock waste and the knowledge of BSF technology of the surveyed farmers. Logistic regression was used to assess the influence of predictive variables such as gender, age group, education, and farming type on knowledge, acceptance, and practice towards BSF larvae composting technology. The influence was considered significant when $p < 0.05$. To evaluate the level of knowledge of the surveyed farmers, a set of six simple questions were asked about the BSF and its applications. Farmers who answered the six questions correctly were considered to have good knowledge while those who did not answer correctly were considered to have bad knowledge. Farmers with good attitudes were those who accepted that the two main BSF products (BSF larvae protein and BSF frass fertilizer) could be used for food production, while those who had already raised BSF or attended a workshop on BSF-related activities were considered to have practical knowledge on the technology.

## 3. Results

### *3.1. Socio-demographic characteristics of participants*

The sociodemographic characteristics of farmers surveyed in Greater Ahafo-Ano are presented in Table 1. Overall, 29.41% of the respondents were females, while 70.59% were males. Majority were between 46 and 55 years old (45.54%), and few of them had completed primary school (13.94%) or secondary school levels (12.77%). Nevertheless, young people aged 35 to 45 form a good portion of farmers in Greater Ahafo-Ano. They were represented at 31.1% in Ahafo-Ano North, 27.1% in Ahafo Ano South-West and 22.0% in Ahafo-Ano South-East. 45.37% of participants were in crop farming, while 4.20% were in livestock farming, and 0.84% in fish farming. 48.90% of farmers combined crop and livestock farming, while 0.67% combined crop, livestock, and fish farming. In Ahafo-Ano North (56.6%), agricultural activity was predominated by crop farmers while in Ahafo-Ano South-East (62.0%) and Ahafo-Ano South-West (46.7%), the majority farmers combine crop and livestock.

### *3.2. Farmers knowledge*

The general knowledge of farmers in Greater Ahafo-Ano towards BSF larvae composting technology is presented in Table 2. In Ahafo-Ano South-East and South-West, 14.5% and 14.1% of respondents claimed they had ever heard of BSF and 12.5% and 13.1% declared they had seen BSF, respectively. In Ahafo-Ano North on the other hand, no farmer had ever seen BSF. Majority of respondents agreed that BSF-based technology can be sustainably used to produce animal feed (88.40%) and organic fertilizer (94.28%).

### *3.3. Factors associated with knowledge, acceptance and application of technology*

Knowledge of BSF and its applications (organic waste recycling, protein-rich larvae for feed formulation, organic frass fertilizer for crop production) were used to assign the surveyed farmers the qualifications of bad or good knowledge. The analysis showed that 12.10% of farmers in Ahafo-Ano South-East had relatively high level of knowledge on BSF. In Ahafo-Ano South-West and Ahafo-Ano North, on the other hand,

**Table 1**
Socio-demographic characteristics of smallholder farmers surveyed in Greater Ahafo-Ano.

| Characteristics | Ahafo-Ano North [N (%)] | Ahafo-Ano South-East [N (%)] | Ahafo Ano South-West [N (%)] | Overall [N (%)] |
|---|---|---|---|---|
| ***Gender*** | | | | |
| Female | 50 (25.5) | 65 (32.5) | 60 (30.2) | 175 (29.41) |
| Male | 146 (74.5) | 135 (67.5) | 139 (69.8) | 420 (70.58) |
| ***Age (Year)*** | | | | |
| 15–25 | 3 (1.5) | 5 (2.5) | 3 (1.5) | 11 (1.84) |
| 26–35 | 39 (19.9) | 31 (15.5) | 33 (16.6) | 103 (17.31) |
| 36–45 | 59 (30.1) | 44 (22.0) | 54 (27.1) | 157 (26.38) |
| 46–55 | 78 (39.8) | 107 (53.5) | 86 (43.2) | 271 (45.54) |
| 56–65 | 17 (8.7) | 13 (6.5) | 23 (11.6) | 53 (8.90) |
| ***Education*** | | | | |
| Middle school | 75 (38.3) | 92 (46.0) | 83 (41.7) | 250 (42.01) |
| No education | 42 (21.4) | 42 (21.0) | 39 (19.6) | 123 (20.67) |
| Non formal | 3 (1.5) | 4 (2.0) | 1 (0.5) | 8 (1.34) |
| Primary school | 25 (12.8) | 26 (13.0) | 32 (16.1) | 83 (13.94) |
| Secondary school | 27 (13.8) | 26 (13.0) | 23 (11.6) | 76 (12.77) |
| Technical | 10 (5.1) | 3 (1.5) | 7 (3.5) | 20 (3.36) |
| Tertiary school | 14 (7.1) | 7 (3.5) | 14 (7.0) | 35 (5.88) |
| ***Farming Type*** | | | | |
| Crop | 111 (56.6) | 67 (33.5) | 92 (46.3) | 270 (45.37) |
| Livestock | 8 (4.1) | 8 (4.0) | 9 (4.5) | 25 (4.20) |
| Fish | 1 (0.5) | 0 (0.0) | 4 (2.0) | 5 (0.84) |
| Crop & Livestock | 74 (37.8) | 124 (62.0) | 93 (46.7) | 291 (48.90) |
| Crop, Livestock & Fish | 2 (1.0) | 1 (0.5) | 1 (0.5) | 4 (0.67) |

N, number of responses.

**Table 2**
Farmers knowledge towards BSF larvae composting technology in Greater Ahafo-Ano.

| Categories | Answers | Ahafo-Ano North [N (%)] | Ahafo-Ano South-East [N (%)] | Ahafo-Ano South-West [N (%)] | Overall [N (%)] |
|---|---|---|---|---|---|
| Heard of BSF | Yes | 1 (0.5) | 29 (14.5) | 28 (14.1) | 58 (9.76) |
| | No | 195 (99.5) | 171 (85.5) | 170 (85.4) | 536 (90.23) |
| Seen the BSF | Yes | 0 (0.0) | 25 (12.5) | 26 (13.1) | 51 (8.58) |
| | No | 196 (100) | 175 (87.5) | 172 (86.4) | 543 (91.41) |
| Familiar with BSF | Yes | 0 (0.0) | 39 (19.5) | 21 (10.7) | 60 (10.13) |
| | No | 196 (100) | 161 (80.5) | 175 (89.3) | 532 (89.86) |
| BSF for Biofertilizer | Yes | 193 (98.5) | 194 (97.0) | 174 (87.4) | 561 (94.28) |
| | No | 3 (1.5) | 6 (3.0) | 25 (12.6) | 34 (5.71) |
| BSF for Human Food | Yes | 20 (10.2) | 195 (97.5) | 131 (65.8) | 346 (58.15) |
| | No | 176 (89.8) | 5 (2.5) | 68 (34.2) | 249 (41.84) |
| BSF for Animal Feed | Yes | 173 (88.3) | 196 (98.0) | 157 (78.9) | 526 (88.40) |
| | No | 23 (11.7) | 4 (2.0) | 42 (21.1) | 69 (11.59) |

BSF, black soldier fly; N, number of responses.

only 08.07% and 0.0% of the surveyed farmers had good knowledge on BSF technology and applications, respectively. The univariate analysis was conducted to determine potential associations between farmer knowledge and socio-demographic characteristics (Table 3). The results showed that farmers' knowledge of BSF technology in all districts was not significantly related ($p > 0.05$) to gender, age group, education level or farming type. However, in Ahafo-Ano South-West, farming type was a significant influencing factor. The results indicated that farmers in crop and livestock had significantly higher level of knowledge on BSF compared to farmers in livestock (OR: 2.05; 95% CI: 0.24 – 17.44; $p = 0.049$).

At a point during the administering of the questionnaire, respondents were sensitized on BSF technology and its applications. After this exercise, 88.77%, 85.50% and 79.39% of farmers in Ahafo-Ano North, Ahafo-Ano South-East and Ahafo-Ano South-West respectively agreed that BSF is a good innovation that could improve their production and incomes. Univariate analysis was also performed to assess potential factors related to the change in perspective among surveyed farmers after the sensitization (possible influencing factors of technology acceptance). As shown in Table 4, no factor was found to be significantly associated with the acceptance of the technology in Ahafo-Ano North ($p > 0.05$). In Ahafo-Ano South-East, on the other hand, the type of farming seems to influence attitudes towards BSF technology. Crop farmers had a significantly lower acceptance (OR: 0.12; 95% CI: 0.00–2.31; $p = 0.016$) compared to livestock farmers. In Ahafo-Ano South-West, the technology acceptance was also influenced by level of education. Farmers with a secondary education (OR: 0.12; 95% CI: 0.01 – 1.08; $p = 0.048$) and farmers with a technical education (OR: 0.10; 95% CI: 0.00 – 1.28; $p = 0.037$) had significantly less acceptance relative to farmers with a tertiary level of education.

Analyses were also conducted to assess the factors associated with the practice of BSF technology in the study area. In Ahafo-Ano North, all the farmers surveyed had never practiced BSF technology, while in Ahafo-Ano South-West 1.03% of the farmers surveyed claimed they had ever practiced. In Ahafo-Ano South-East, on the other hand, 07.67% of the farmers surveyed had already practiced the BSF technology. The univariate analysis showed that the application of the BSF technology is significantly associated with level of education and the farming type (Table 5). Crop farmers practiced BSF technology significantly less than livestock farmers (OR: 0.25; 95% CI: 0.05 – 1.27; $p = 0.045$). Farmers with a tertiary level of education practiced BSF technology more compared to farmers with secondary (OR: 0.02; 95% CI: 0.00 – 0.21; $p = 0.001$), primary (OR: 0.07; 95% CI: 0.01 – 0.51; $p = 0.008$), Middle school (OR: 0.15; 95% CI: 0.03 – 0.86; $p = 0.033$) and no education (OR: 0.14; 95% CI: 0.02 – 084; $p = 0.031$).

### 3.4. Waste streams and disposal methods

Fruit/vegetable wastes and chicken manure forms the highest fraction of biowaste generated by the farmers surveyed in Ahafo-Ano North. Out of the total farmers surveyed in this district, 38% of the farmers generated fruit/vegetable wastes while 30% generated chicken

**Table 3**
Factors influencing knowledge of BSF larvae composting technology in Greater Ahafo-Ano.

| Categories | Ahafo-Ano North | | | Ahafo-Ano South-East | | | Ahafo-Ano South-West | | |
|---|---|---|---|---|---|---|---|---|---|
| | High knowledge [N (%)] | Low knowledge [N (%)] | Univariate analysis OR (95% CI) | High knowledge [N (%)] | Low knowledge [N (%)] | Univariate analysis OR (95% CI) | High knowledge [N (%)] | Low knowledge [N (%)] | Univariate analysis OR (95% CI) |
| ***Gender*** (Female) | 2 (18.2) | 48 (25.9) | 0.63 (0.13–3.04) | 64 (33.0) | 1 (16.7) | 2.46 (0.28–21.51) | 7 (25.0) | 53 (31.0) | 0.74 (0.30–1.85) |
| Male | 9 (81.8) | 137 (74.1) | 1 | 130 (67.0) | 5 (83.3) | 1 | 21 (75.0) | 118 (69.0) | 1 |
| ***Age*** (15–25) | 0 (0.0) | 3 (1.6) | 1.17 (0.05–25.41) | 4 (2.1) | 1 (16.7) | 0.10 (0.00–1.79) | 1 (3.5) | 2 (1.1) | 2.87 (0.23–35.56) |
| 26–35 | 2 (18.2) | 37 (20.0) | 0.47 (0.09–2.50) | 29 (14.9) | 2 (33.3) | 0.34 (0.03–3.89) | 8 (28.6) | 25 (14.6) | 1.84 (0.62–5.49) |
| 36–45 | 6 (54.5) | 53 (28.7) | 1 | 43 (22.2) | 1 (16.7) | 1 | 8 (28.6) | 46 (26.9) | 1 |
| 46–55 | 3 (27.3) | 75 (40.5) | 0.35 (0.08–1.48) | 105 (54.1) | 2 (33.3) | 1.22 (0.11–13.82) | 7 (25.0) | 79 (46.2) | 0.5 (0.17–1.50) |
| 56–65 | 0 (0.0) | 17 (9.2) | 0.23 (0.01–4.39) | 13 (6.7) | 0 (0.0) | 0.93 (0.03–24.21) | 4 (14.3) | 19 (11.1) | 1.21 (0.35–4.50) |
| ***Education*** (Middle school) | 7 (63.6) | 68 (36.8) | 3.17 (0.17–58.77) | 90 (46.5) | 2 (33.3) | 2.41 (0.11–55.00) | 14 (50.0) | 69 (40.3) | 1.23 (0.24–6.05) |
| No education | 0 (0.0) | 42 (22.7) | 0.34 (0.01–17.98) | 40 (20.6) | 2 (33.3) | 1.08 (0.05–24.82) | 4 (14.3) | 35 (20.5) | 0.63 (0.11–4.23) |
| Non formal | 0 (0.0) | 3 (1.6) | – | 3 (1.5) | 1 (16.7) | 0.15 (0.00–4.86) | 0 (0.0) | 1 (0.6) | – |
| Primary school | 2 (18.2) | 23 (12.4) | 3.08 (0.14–68.91) | 26 (13.4) | 0 (0.0) | 3.53 (0.06–193.48) | 4 (14.3) | 28 (16.4) | 0.86 (0.14–5.33) |
| Secondary school | 2 (18.2) | 25 (13.5) | 2.84 (0.13–63.37) | 25 (12.9) | 1 (16.7) | 1.13 (0.04–30.81) | 3 (10.7) | 20 (11.7) | 0.90 (0.13–6.18) |
| Technical | 0 (0.0) | 10 (5.4) | 1.38 (0.02–75.37) | 3 (1.5) | 0 (0.0) | 0.47 (0.01–28.73) | 1 (3.6) | 6 (3.5) | 1.0(0.07–13.38) |
| Tertiary school | 0 (0.0) | 14 (7.6) | 1 | 7 (3.6) | 0 (0.0) | 1 | 2 (7.1) | 12 (7.0) | 1 |
| ***Farming Type*** (Crop) | 8 (72.7) | 103 (55.7) | 1.39 (0.07–26.32) | 65 (33.5) | 2 (33.3) | 1.54 (0.07–34.88) | 7 (25.0) | 85 (49.7) | 0.66 (0.07–6.05) |
| Crop & Livestock | 3 (27.3) | 71 (38.4) | 0.83 (0.04–17.52) | 120 (61.9) | 4 (66.7) | 1.57 (0.08–31.75) | 19 (67.8) | 74 (43.2) | 2.05 (0.24–17.44)* |
| Crop, Livestock & Fish | 0 (0.0) | 2 (1.1) | – | 1 (0.5) | 0 (0.0) | – | 0 (0.0) | 1 (0.6) | - |
| Fish | 0 (0.0) | 1 (0.5) | – | 0 (0.0) | 0 (0.0) | – | 1 (3.6) | 3 (1.8) | – |
| Livestock | 0 (0.0) | 8 (4.3) | 1 | 8 (4.1) | 0 (0.0) | 1 | 1 (3.6) | 8 (4.7) | 1 |

N, number of responses; OR, Odd ratio; CI, Confidence interval.

* $p < 0.05$.

**Table 4**
Factors associated with acceptance of BSF larvae composting technology in Greater Ahafo-Ano.

| Categories | Ahafo-Ano North | | | Ahafo-Ano South-East | | | Ahafo-Ano South-West | | |
|---|---|---|---|---|---|---|---|---|---|
| | High acceptance (%) | Low acceptance (%) | Univariate analysis OR (95% CI) | High acceptance (%) | Low acceptance (%) | Univariate analysis OR (95% CI) | High acceptance (%) | Low acceptance (%) | Univariate analysis OR (95% CI) |
| ***Gender*** (Female) | 41 (23.6) | 9 (40.9) | 0.44 (0.17–1.12) | 57 (33.3) | 8 (27.6) | 1.31 (0.55–3.15) | 49 (31.0) | 11 (26.8) | 1.23 (0.57–2.64) |
| Male | 133 (76.4) | 13 (59.1) | 1 | 114 (66.7) | 21 (72.4) | 1 | 109 (69.0) | 30 (73.2) | 1 |
| ***Age*** (15-25) | 3 (1.7) | 0 (0.0) | 1.32 (0.06–27.62) | 3 (1.8) | 2 (6.9) | 0.19 (0.02–1.44) | 3 (1.9) | 0 (0.0) | 2.27 (0.11–46.95) |
| 26–35 | 32 (18.4) | 7 (31.8) | 0.82 (0.28–2.43) | 26 (15.2) | 5 (17.2) | 0.67 (0.17–2.53) | 29 (18.4) | 4 (9.8) | 2.30 (0.68–7.77) |
| 36–45 | 50 (28.7) | 9 (40.9) | 1 | 39 (22.8) | 5 (17.2) | 1 | 41 (25.9) | 13 (31.7) | 1 |
| 46–55 | 73 (42.0) | 5 (22.7) | 2.63 (0.83–8.31) | 91 (53.2) | 16 (55.2) | 0.73 (0.25–2.13) | 70 (44.3) | 16 (39.0) | 1.39 (0.61–3.17) |
| 56–65 | 16 (9.2) | 1 (4.6) | 2.88 (0.34–24.51) | 12 (7.0) | 1 (3.5) | 1.54 (0.16–14.49) | 15 (9.5) | 8 (19.5) | 0.59 (0.20–1.72) |
| ***Education*** (Middle school) | 68 (39.1) | 7 (31.8) | 0.31 (0.02–5.83) | 81 (47.4) | 11 (37.9) | 0.47 (0.03–8.83) | 71 (44.9) | 12 (29.2) | 0.45 (0.05–3.81) |
| No education | 37 (21.3) | 5 (22.8) | 0.23 (0.01–4.53) | 33 (19.3) | 9 (31.0) | 0.24 (0.01–4.5) | 30 (19.0) | 9 (22.0) | 0.25 (0.03–2.24) |
| Non formal | 2 (1.1) | 1 (4.5) | – | 3 (1.7) | 1 (3.5) | 0.15 (0.00–4.86) | 1 (0.6) | 0 (0.0) | – |
| Primary school | 24 (13.8) | 1 (4.5) | 0.56 (0.02–14.76) | 23 (13.5) | 3 (10.3) | 0.45 (0.02–9.69) | 25 (15.8) | 7 (17.1) | 0.27 (0.03–2.48) |
| Secondary school | 19 (10.9) | 8 (36.4) | 0.79 (0.04–1.48) | 21 (12.3) | 5 (17.3) | 0.26 (0.01–5.30) | 14 (8.9) | 9 (22.0) | 0.12 (0.01–1.08)* |
| Technical | 10 (5.7) | 0 (0.0) | 0.72 (0.01–39.59) | 3 (1.7) | 0 (0.0) | 0.47 (0.00–28.73) | 4 (2.6) | 3 (7.3) | 0.10 (0.00–1.28)* |
| Tertiary school | 14 (8.1) | 0 (0.0) | 1 | 7 (4.1) | 0 (0.0) | 1 | 13 (8.2) | 1 (2.4) | 1 |
| ***Farming Type*** (Crop) | 96 (55.2) | 15 (68.2) | 0.37 (0.02–6.67) | 46 (26.9) | 21 (72.4) | 0.12 (0.00–2.31)* | 73 (46.2) | 19 (46.3) | 1.10 (0.21–5.72) |
| Crop & Livestock | 67 (38.5) | 7 (31.8) | 0.53 (0.03–10.12) | 116 (67.8) | 8 (27.6) | 0.81 (0.04–15.19) | 76 (48.1) | 17 (41.5) | 1.28 (0.24–6.70) |
| Crop, Livestock & Fish | 2 (1.1) | 0 (0.0) | – | 1 (0.6) | 0 (0.0) | – | 0 (0.0) | 1 (2.4) | – |
| Fish | 1 (0.6) | 0 (0.0) | – | 0 (0.0) | 0 (0.0) | – | 2 (1.3) | 2 (4.9) | 0.28 (0.02–3.52) |
| Livestock | 8 (4.6) | 0 (0.0) | 1 | 8 (4.7) | 0 (0.0) | 1 | 7 (4.4) | 2 (4.9) | 1 |

N, number of responses; OR, Odd ratio; CI, Confidence interval.

* $p < 0.05$.

**Table 5**
Factors influencing the application of BSF larvae composting technology in Greater Ahafo-Ano.

| Categories | Ahafo-Ano North | | | Ahafo-Ano South-East | | | Ahafo Ano South-West | | |
|---|---|---|---|---|---|---|---|---|---|
| | Practice [N (%)] | Never Practice [N (%)] | Univariate analysis OR (95% CI) | Practice [N (%)] | Never Practice [N (%)] | Univariate analysis OR (95% CI) | Practice [N (%)] | Never Practice [N (%)] | Univariate analysis OR (95% CI) |
| ***Gender*** (Female) | 0 (0.0) | 50 (25.5) | 2.9 (0.06–148.15) | 16 (32.0) | 49 (32.7) | 0.97 (0.49–1.92) | 0 (0.0) | 59 (30.6) | 0.45 (0.02–9.56) |
| Male | 0 (0.0) | 146 (74.5) | 1 | 34 (68.0) | 101 (67.3) | 1 | 2 (100) | 134 (69.4) | 1 |
| ***Age*** (15–25) | 0 (0.0) | 3 (1.5) | – | 1 (2.0) | 4 (2.7) | 0.85 (0.08–8.49) | 0 (0.0) | 3 (1.6) | – |
| 26–35 | 0 (0.0) | 39 (19.9) | 1.51 (0.03–77.50) | 9 (18.0) | 22 (14.7) | 1.39 (0.49–3.97) | 0 (0.0) | 32 (16.6) | 0.54 (0.02–13.62) |
| 36–45 | 0 (0.0) | 59 (30.1) | 1 | 10 (20.0) | 34 (22.7) | 1 | 1 (50.0) | 52 (26.9) | 1 |
| 46–55 | 0 (0.0) | 78 (39.8) | 0.76 (0.01–38.76) | 28 (56.0) | 79 (52.7) | 1.20 (0.53–2.75) | 1 (50.0) | 83 (43.0) | 0.63 (0.04–10.23) |
| 56–65 | 0 (0.0) | 17 (8.7) | 3.40 (0.06–177.65) | 2 (4.0) | 11 (7.3) | 0.62 (0.12–3.26) | 0 (0.0) | 23 (11.9) | 0.74 (0.03–18.96) |
| ***Education*** (Middle school) | 0 (0.0) | 75 (38.3) | 0.19 (0.00–10.07) | 26 (52.0) | 66 (44.0) | 0.15 (0.03–0.86)* | 1 (50.0) | 82 (42.5) | 0.49 (0.02–12.68) |
| No education | 0 (0.0) | 42 (21.4) | 0.34 (0.01–17.99) | 11 (22.0) | 31 (20.7) | 0.14 (0.02–084)* | 0 (0.0) | 38 (19.7) | 0.35 (0.01–18.55) |
| Non formal | 0 (0.0) | 3 (1.5) | 4.14 (0.07–247.52) | 2 (4.0) | 2 (1.3) | 0.40 (0.03–5.15) | 0 (0.0) | 1 (0.5) | – |
| Primary school | 0 (0.0) | 25 (12.8) | 0.57 (0.01–30.21) | 4 (8.0) | 22 (14.7) | 0.07 (0.01–0.51)* | 0 (0.0) | 32 (16.6) | 0.41 (0.01–22.03) |
| Secondary school | 0 (0.0) | 27 (13.8) | 0.53 (0.00–27.97) | 1 (2.0) | 25 (16.7) | 0.02 (0.00–0.21)* | 1 (50.0) | 20 (10.4) | 1.97 (0.07–52.16) |
| Technical | 0 (0.0) | 10 (5.1) | 1.38 (0.02–75.37) | 1 (2.0) | 2 (1.3) | 0.20 (0.01 –3.66) | 0 (0.0) | 7 (3.6) | 1.80 (0.03–100.29) |
| Tertiary school | 0 (0.0) | 14 (7.1) | 1 | 5 (10.0) | 2 (1.3) | 1 | 0 (0.0) | 13 (6.7) | 1 |
| ***Farming Type*** (Crop) | 0 (0.0) | 111 (56.6) | 0.07 (0.00–4.08) | 9 (18.0) | 58 (38.7) | 0.25 (0.05–1.27)* | 1 (50.0) | 90 (46.6) | 0.31 (0.01–8.28) |
| Crop & Livestock | 0 (0.0) | 74 (37.8) | 0.11 (0.00–6.13) | 38 (76.0) | 86 (57.3) | 0.74 (0.17–3.24) | 1 (50.0) | 89 (46.1) | 0.32 (0.01–8.38) |
| Crop, Livestock & Fish | 0 (0.0) | 2 (1.0) | – | 0 (0.0) | 1 (0.7) | – | 0 (0.0) | 1 (0.5) | – |
| Fish | 0 (0.0) | 1 (0.5) | – | 0 (0.0) | 0 (0.0) | – | 0 (0.0) | 4 (2.1) | 2.11 (0.03–124.53) |
| Livestock | 0 (0.0) | 8 (4.1) | 1 | 3 (6.0) | 5 (3.3) | 1 | 0 (0.0) | 9 (4.7) | 1 |

N, number of responses; OR, Odd ratio; CI, Confidence interval.

* $p < 0.05$.

manure on their farms. In Ahafo-Ano South-West, chicken manure constituted a significant fraction of waste generated by farmers (33%), with only 11% of the famers generating fruit/vegetable waste. The same trend was observed in Ahafo-Ano South-West, but here the frequency of farmers generating chicken manure was relatively very low (Fig. 3).

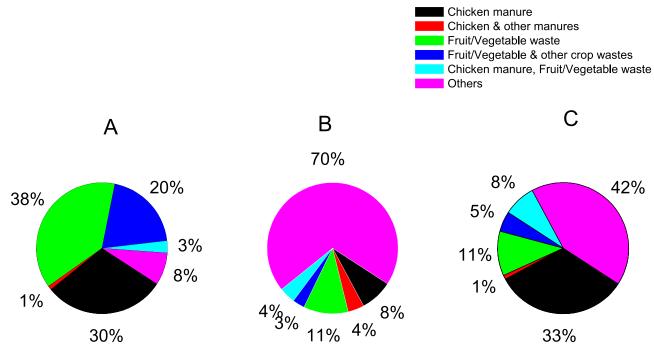


**Fig. 3.** Percentages of biowaste streams generated by farmers surveyed in Ahafo-Ano North (A), Ahafo-Ano South-East (B), and Ahafo-Ano South-West (C). *Others* – represents a category of bio-waste deemed unsuitable for BSF larvae composting.

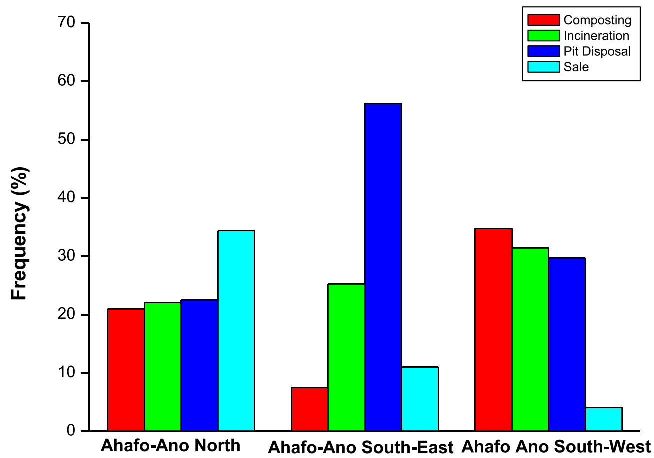


**Fig. 4.** Percentage of respondents considering waste disposal methods in Greater Ahafo-Ano.

Biowaste generated by farmers in the three districts are disposed of through many ways, but not necessarily for processing. In Ahafo-Ano South-East for example, 56.2% of farmers declared they threw their wastes into a pit. While only a small fraction of farmers practice composting (7.5%). This was also the case of Ahafo-Ano North where only 21% of the farmers surveyed declared that they practiced composting. Incineration was a very common disposal method in the three districts, with 22.1%, 51.3% and 31.4% of the farmers surveyed in Ahafo-Ano North, Ahafo-Ano South-East and Ahafo-Ano South-West respectively declaring that they dispose of their waste by incineration. Some farmers said they sell their waste (Fig. 4). Though, most of these farmers are those who generate chicken manure, which is commonly used for crop farming in the country [22].

### 3.5. Scale of food production

Fig. 5 shows information collected on the scale of food production in Greater Ahafo-Ano. Regardless of the district, most respondents declared the level of food production is still small-scale, with 70.4% in Ahafo-Ano North, 61.2% in Ahafo-Ano South-East and 61.2% in Ahafo-Ano South-West. According to the information on Fig. 6, the breeding system is the major limiting factor for food animal production in Greater Ahafo-Ano. Issues of health and feed are also contributing factors.

### 3.6. Land degradation issue

Farmers in Greater Ahafo-Ano have targeted land degradation as the main factor limiting food production in the district. We used a three-level scale (Important < Very important < Critical) to explore the extent of this degradation and the results are shown in Fig. 7.

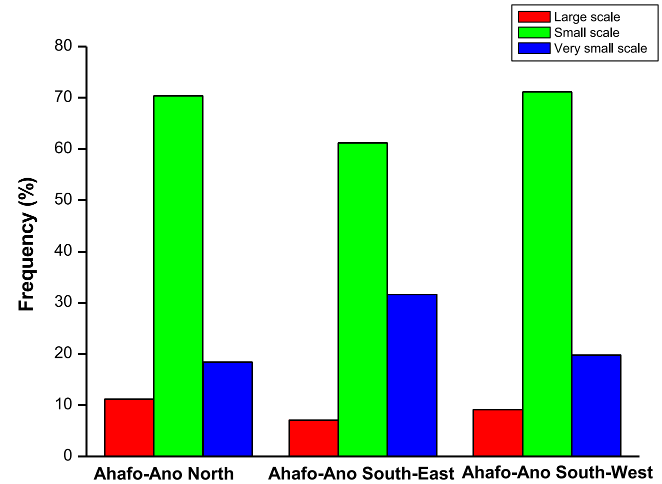


**Fig. 5.** Percentage of respondents considering the scale of food production in Greater Ahafo-Ano.

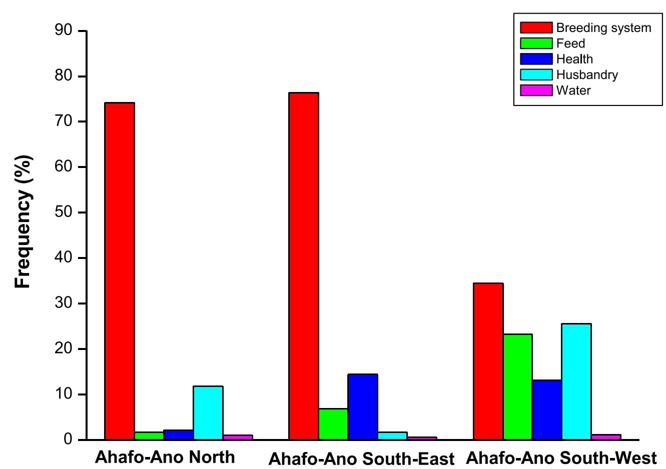


**Fig. 6.** Percentage of respondents considering limiting factors for food animal production in Greater Ahafo-Ano.

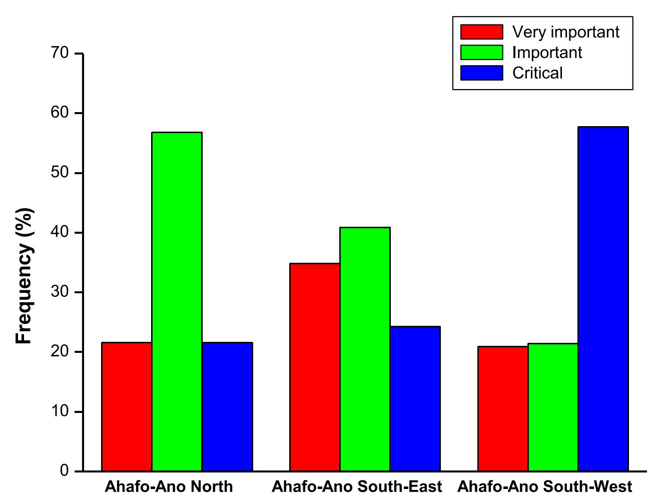


**Fig. 7.** Percentage of respondents considering land degradation issue in Greater Ahafo-Ano.

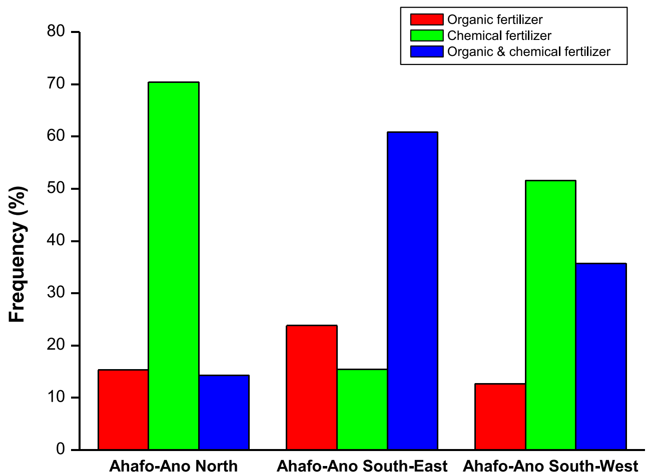


**Fig. 8.** Percentage of respondents considering dominant soil fertility techniques in Greater Ahafo-Ano.

Most respondents in Ahafo-Ano North (56.7%) and Ahafo-Ano South-East (40.9%) said that the issue of land degradation in the district is important. In Ahafo Ano South-West, on the other hand, 57.7% of respondents declared that the issue of land degradation in the district is critical. To overcome the issue of land degradation in the districts, farmers in Ahafo-Ano North (70.4%) and Ahafo-Ano South-West (51,6%) apply chemical fertilizers, while in Ahafo-Ano South-East, 60.8% of farmers apply both chemical and organic fertilizers as soil improvement techniques. Overall, very few farmers apply only organic fertilizers (Fig. 8).

## 4. Discussion

Acceptance as well as the level of knowledge of a population towards a given technology are important indicators to guide strategic decisions regarding its adoption [23]. With the aim of introducing BSF larvae composting technology in Ghana, this study assessed the levels of knowledge of BSF as well as its ecosystem services among smallholder farmers in the three districts of Greater Ahafo Ano in the Ashanti region of Ghana. Majority of farmers surveyed had never seen BSF (91.41%) and are unfamiliar with BSF larvae composting technology. This could be related to the level of education of the surveyed farmers where more than 20% were uneducated and only 12.77% had reached secondary level. This poor level of knowledge could also be justified by the fact that most of them live in rural areas with limited access to internet and social media, which are currently the most common ways used to communicate and disseminate technologies [24–26]. Nevertheless, after awareness raising, more than 90% of the farmers surveyed agreed that BSF larvae composting technology can be a sustainable route to mitigate the negative impacts associated with poor management of agri-food waste [27,28]. 58.15% of farmers surveyed also agreed that BSF larvae products can be used for human food. Indeed, Higa et al. [29] investigated the acceptance of BSF larvae as human food in America and found that they were relatively well-accepted by consumers. Although most of the currently published work on the BSF remains focused on animal nutrition, BSF larvae also have a great potential to provide sustainable sources of nutrients for human food [30]. In Ahafo Ano South-East district, more than 10% of farmers interviewed appeared to have good knowledge of the BSF. In this district, the level of knowledge was linked to the type of farming type, and farmers who combined crops and livestock farming tended to have a higher level of knowledge than those who practiced only livestock farming. This could be linked to the fact that BSF larvae composting is an integrated technology that offers a set of solutions addressing not only livestock-related issues, but also access to biofertilizers for crops farming as well as environmental sustainability [31,32]. It is therefore logical that farmers practicing integrated agriculture or organic farming have more knowledge on this subject.

Despite the low awareness of farmers interviewed in Ahafo Ano, more than 80% among them adopted a positive attitude towards BSF larvae composting technology. In Ahafo-Ano South-East, this attitude was influenced by the type of farming, while in Ahafo-Ano South-West, it was the level of education. In Ahafo-Ano South-East, where a few groups of surveyed farmers had practiced the technology, the univariate analysis revealed that livestock farmers were more likely to practice the technology than crop farmers. Also, farmers with higher level of education had good practice compared to others. Indeed, the level of education is an important factor for the adoption of BSF larvae composting technology. Like any agricultural operation, setting up a BSF farm may require certain prerequisites, which may depend on the farmer's level of education [33]. The farmer must understand the different stages of development of the insect, as well as the conditions required for its mating and reproduction [34]. Mastering all these steps may require some basic knowledge in life science. The age range is also an important factor to consider. Young people seem to be more interested in the BSF.

Out of the different proportions of agri-livestock waste generated in the study area, fruit and vegetable wastes and chicken manure constitute the largest fraction. This makes sense, given the socio-demographic characteristics of the participants (Table 1). 48.90% of the farmers surveyed were in crop and livestock. Chicken manure constitutes an important source of organic fertilizer in Ghana and is commonly purchased and applied by the majority of smallholder farmers to improve crop growth and yields [35–37]. Fruit and vegetable waste on the other hand are useless and are usually dumped on the roadside, which often results in environmental pollution [38]. In Ahafo-Ano South-East for example, 56.2% of farmers declared they throw their wastes into a pit. While only a small fraction of farmers (7.5%) practiced composting. Such behavior is dangerous and environmentally unsustainable. The application of BSF larvae composting technology could enable farmers in Greater Ahafo-Ano to recover and recycle their generated agri-livestock waste into useful products. Studies report agricultural waste as an excellent opportunity to initiate BSF larvae production [2,6]. Chicken manure also constitutes a good substrate for BSF larvae and can be used when available [39].

Over 60% of respondents stated that the food production level is largely subsistence in Greater Ahafo-Ano. Overall, food production in Ghana is constrained by several factors including climate change, unsustainable management practices and land degradation [40]. Agricultural production in Ghana is mostly open field and rainfed, making it highly sensitive to climate change and variability [41]. Production is also affected by the prevalence of unsustainable management practices, including soil, water, and waste management [42]. This leads to increased greenhouse gas emissions and land degradation [43]. The surveyed farmers also reported breeding systems as well as health and feed as limiting factors to food animal production in Ghana. The feed component could be addressed through the adoption of BSF larvae composting technology [44,45]. The frass generated through the composting process of BSF larvae also constitutes a way to address the issue of soil fertility. Farmers interviewed in Ahafo-Ano view land degradation as an important issue for food production in the district. Most of them apply chemical fertilizers as a soil fertilization strategy. This problem is not an isolated case in Ghana. Land degradation contributes to 36–75 billion tons of land depletion every year and threatens global food supply [46]. It negatively impacts plant growth, and agricultural yields [47]. During the survey, we sensitized farmers in Ahafo-Ano on this issue and encouraged innovative approaches to land management, as well as the appropriate application of agrochemicals. Although adding compost and manure to the soil helps replenish nutrients and capture organic carbon [48], we noted that only a few farmers applied organic fertilizers in the districts. We therefore hope that BSF larvae composting technology will be widely adopted to increase the production and application of organic fertilizers in Greater Ahafo-Ano.

## 5. Conclusions

This study was designed with the aim of gathering strategic information to ensure an effective transfer of BSF larvae composting technology in the locality of Greater Ahafo-Ano, Ashanti region of Ghana. Most of the study participants seem convinced that food production in the locality is largely subsistence and needs to be improved. Farmers target land degradation as the limiting factor for food crop production and the breeding system as well as health and feed as the main limiting factors to food animal production. Most of them were unaware of the BSF, as well as its multiple ecosystem functions. Nevertheless, they demonstrated a positive attitude towards the adoption of the technology. In Ahafo-Ano South-East, some of the farmers surveyed had previous contact with the BSF. We therefore believe this district will be a good entry point to introduce the technology into the community.

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## CRediT authorship contribution statement

**Daniel Dzepe:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Michael Y. Osae:** Writing – review & editing, Data curation, Conceptualization. **Janet O. Asabre:** Writing – review & editing, Project administration. **Ankrah Twumasi:** Writing – review & editing, Data curation. **Enoch S.K. Ofori:** Writing – review & editing, Data curation. **Gerald Atampugre:** Writing – review & editing. **Tahirou Abdoulaye:** Supervision, Funding acquisition. **Robert Asiedu:** Supervision, Funding acquisition. **Rousseau Djouaka:** Supervision, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The datasets generated during the current study are available in this paper and its supplementary files.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.grets.2024.100112.

## References

[1] Food and Agriculture Organization of the United Nations, Strategic work of FAO for sustainable food and agriculture, 2019, http://www.fao.org/3/ai6488e.pdf.

[2] D.A. Peguero, M. Gold, D. Vandeweyer, C. Zurbrügg, A. Mathys, A review of pretreatment methods to improve agri-food waste bioconversion by black soldier fly Larvae, Front. Sustain. Food Syst. (2022) http://dx.doi.org/10.3389/fsufs.2021.745894.

[3] M. Duque-Acevedo, L.J. Belmonte-Urena, F.J. Cortes-García, F. Camacho-Ferre, Agricultural waste: Review of the evolution, approaches, and perspectives on alternative uses, Glob. Ecol. Conservat. (2020) http://dx.doi.org/10.1016/j.gecco.2020.e00902.

[4] S. Sala, A. Anton, S.J. McLaren, B. Notarnicola, E. Saouter, U. Sonesson, In quest of reducing the environmental impacts of food production and consumption, J. Clean. Prod. (2017) http://dx.doi.org/10.1016/j.jclepro.2016.09.054.

[5] M. Gold, J.K. Tomberlin, S. Diener, C. Zurbrügg, A. Mathys, Decomposition of bio-waste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review, Waste Manage. (2018) http://dx.doi.org/10.1016/j.wasman.2018.10.022.

[6] D. Dzepe, H. Mube-Kuietche, O. Magatsing, F. Meutchieye, P. Nana, T. Tchuinkam, R. Djouaka, From agricultural waste to chicken feed using insect-based technology, J. Basic Appl. Zool. (2023) http://dx.doi.org/10.1186/s41936-023-00339-5.

[7] M. Gold, C.M. Cassar, C. Zurbrügg, M. Kreuzer, S. Boulos, S. Diener, A. Mathys, Bio-waste treatment with black soldier fly Larvae: Increasing performance through the formulation of bio-waste s based on protein and carbohydrates, Waste Manage. (2020) http://dx.doi.org/10.1016/j.wasman.2019.10.036.

[8] D. Dzepe, P. Nana, H. Mube-Kuietche, J. Mitsue-Kimpara, O. Magatsing, T. Tchuinkam, R. Djouaka, Feeding strategies for small-scale rearing black soldier fly Larvae (*Hermetia illucens*) as organic waste recycler, SN Appl. Sci. (2021) http://dx.doi.org/10.1007/s42452-020-04039-5.

[9] D. Mangindaan, E.R. Kaburuan, B. Meindrawan, Black soldier fly Larvae *Hermetia illucens* for biodiesel and/or animal feed as a solution for waste-food-energy Nexus: Bibliometric analysis, Sustainability 14 (13993) (2022) http://dx.doi.org/10.3390/su142113993.

[10] T. Klammsteiner, V. Turan, M. Fern, S. Oberegger, H. Insam, Suitability of black soldier fly frass as soil amendment and implication for organic waste hygienization, Agronomy (2020) http://dx.doi.org/10.3390/agronomy10101578.

[11] D. Dzepe, T.K. Mbenda, G. Ngassa, H. Mube, S.Y. Chia, Y. Aoudou, R. Djouaka, Application of black soldier fly Frass, Hermetia illucens (diptera: Stratiomyidae) as sustainable organic fertilizer for Lettuce, Lactuca sativa production, Open J. Appl. Sci. (2022) http://dx.doi.org/10.4236/ojapps.2022.1210111.

[12] A. Mertenat, S. Diener, C. Zurbrügg, Black soldier fly bio-waste treatment – assessment of global warming potential, Waste Manage. (2019) http://dx.doi.org/10.1016/j.wasman.2018.11.040.

[13] S. Smetana, E. Schmitt, A. Mathys, Sustainable use of *Hermetia illucens* insect biomass for feed and food: Attributional and consequential life cycle assessment, Res. Conserv. Recycl. (2019) http://dx.doi.org/10.1016/j.resconrec.2019.01.042.

[14] P.A. Williams, et al., Review of barriers to effective implementation of waste and energy management policies in Ghana: Implications for the promotion of waste-to-energy technologies, Waste (2023) http://dx.doi.org/10.3390/waste1020021.

[15] K. Adu-Boahen, et al., Waste management practices in Ghana: Challenges and prospect, Jukwa Central Region, Int. J. Dev. Sustain. 3 (2014) 530–546.

[16] E.A. Ewusie, et al., The black soldier fly, Hermetia illucens (Diptera: Stratiomyidae): Trapping and culturing of wild colonies in Ghana, Sci. Afr. (2019) http://dx.doi.org/10.1016/j.sciaf.2019.e00134.

[17] W. Lu, H.G.S.A. Kwasi, Transition of small farms in Ghana: perspectives of farm heritage, employment, and networks, Land Use Policy (2019) http://dx.doi.org/10.1016/j.landusepol.2018.10.048.

[18] European Commission, EIP-AGRI Workshop Opportunities for Agriculture and Forestry in the Circular Economy, Workshop Report 28-29 2015, Brussels, Belgium, 2015, https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_ws_circular_economy_final_report_2015_en.pdf.

[19] D.J.C. Hutabarat, D. Mangindaan, Cultivation of black soldier fly *Hermetia illucens* Larvae for the valorization of spent coffee ground: A systematic review and bibliometric study, Agriculture 14 (205) (2024) http://dx.doi.org/10.3390/agriculture14020205.

[20] S. Bracco, O. Calicioglu, S.J.M. Gomez, A. Flammini, Assessing the contribution of bioeconomy to the total economy: A review of national frameworks, Sustainability (2018) http://dx.doi.org/10.3390/su10061698.

[21] G. Atampugre, E. Mensah, E. Boateng, T. Mabhaudhi, O. Cofie, Situational analysis of a social-ecological landscape in the Ahafo Ano Southwest District of Ghana, in: CGIAR Initiative on West and Central African Food Systems Transformation, 2022, p. 57.

[22] I.K. Mpanga, E. Adjei, H.K. Dapaah, K.G. Santo, Poultry manure induced garden eggs yield and soil fertility in tropical and semi-arid Sandy-Loam soils, Nitrogen 2 (2021) 321–331, http://dx.doi.org/10.3390/nitrogen2030022.

[23] S.J. Czaja, N. Charness, A.D. Fisk, C. Hertzog, S.N. Nair, W.A. Rogers, J. Sharit, Factors predicting the use of technology: Findings from the center for research and education on aging and technology enhancement (CREATE), Psychol. Aging (2006) http://dx.doi.org/10.1037/0882-7974.21.2.333.
[24] A. Halloran, The social impacts of using black soldier flies for bioconversion: a preliminary assessment from South Africa, in: GREEiNSECT: Insects for Green Economy, University of Copenhagen, Denmark, 2018.
[25] D.T. Ardianto, R.H. Rifai, Campaign video for utilizing black soldier fly as organic decomposer in organic waste management, IOP Conf. Ser.: Earth Environ. Sci. 905 (2021) 012021, http://dx.doi.org/10.1088/1755-1315/905/1/012021.
[26] J.C.F. Van, et al., Integration of Internet-of-Things as sustainable smart farming technology for the rearing of black soldier fly to mitigate food waste, J. Taiwan Inst. Chem. Eng. (2022) http://dx.doi.org/10.1016/j.jtice.2022.104235.
[27] M. Rutten, M. Verma, The Impacts of Reducing Food Loss in Ghana; a Scenario Study using the Global Economic Simulation Model MAGNET, LEI Report 035, LEI Wageningen UR (University & Research centre, Wageningen, 2014, p. 42.
[28] R. Kour, et al., Ramamurthy, persistence, and remote sensing of agri-food wastes in the environment: Current state and perspectives, Chemosphere (2023) http://dx.doi.org/10.1016/j.chemosphere.2023.137822.
[29] J.E. Higa, M.B. Ruby, P. Rozin, Americans' acceptance of black soldier fly Larvae as food for themselves, their dogs and farmed animals, Food Qual. Preference (2021) http://dx.doi.org/10.1016/j.foodqual.2020.104119.
[30] L.W. Bessa, E. Pieterse, J. Marais, L.C. Hoffman, Why for feed and not for human consumption? The black soldier fly Larvae, CRFSFS (2020) http://dx.doi.org/10.1111/1541-4337.12609.
[31] M. Salam, F. Alam, S. Dezhi, G. Nabi, A. Shahzadi, S.U. Hassan, M. Ali, M.A. Saeed, J. Hassan, N. Ali, M. Bilal, Exploring the role of black soldier fly Larva technology for sustainable management of municipal solid waste in developing countries, Environ. Technol. Innov. (2021) http://dx.doi.org/10.1016/j.eti.2021.101934.
[32] K.U. Rehman, C. Hollah, K. Wiesotzki, R. Rehman, A. Rehman, J. Zhang, L. Zheng, T. Nienaber, V. Heinz, K. Aganovic, Black soldier fly, hermetia illucens as a potential innovative and environmentally friendly tool for organic waste management: A mini-review, Waste Manag. Res. (2023) http://dx.doi.org/10.1177/0734242X221105441.
[33] A. Walter, T. Klammsteiner, M. Gassner, C.D. Heussler, S. Kapelari, M. Schermer, H. Insam, Black soldier fly school workshops as means to promote circular economy and environmental awareness, Sustainability (2020) http://dx.doi.org/10.3390/su12229574.
[34] M. Salam, A. Shahzadi, H. Zheng, F. Alam, G. Nabi, S. Dezhi, W. Ullah, S. Ammara, N. Ali, M. Bilal, Effect of different environmental conditions on the growth and development of black soldier fly Larvae and its utilization in solid waste management and pollution mitigation, Environ. Technol. Innov. (2022) http://dx.doi.org/10.1016/j.eti.2022.102649.
[35] I.K. Mpanga, E. Adjei, H.K. Dapaah, K.G. Santo, Poultry manure induced garden eggs yield and soil fertility in tropical and semi-arid Sandy-Loam soils, Nitrogen (2021) http://dx.doi.org/10.3390/nitrogen2030022.
[36] K.E. Wehunt, H.L. Fuller, H.M. Edwards, The nutritional value of hydrolyzed poultry manure for broiler chickens, Poultry Sci. (1960) http://dx.doi.org/10.3382/ps.0391057.
[37] NRAES, Poultry Waste Management Handbook (NRAES-132). Natural Resource, Agriculture, and Engineering Service, Cooperative Extension, Riley-Robb Hall, Ithaca, NY, 1999, p. 152, 14853-5701.
[38] S. Cantera, et al., Technologies for the bioconversion of methane into more valuable products, Curr. Opin. Biotechnol. (2018) http://dx.doi.org/10.1016/j.copbio.2017.12.021.
[39] K. Rehman, et al., Enhanced bioconversion of dairy and chicken manure by the interaction of exogenous bacteria and black soldier fly Larvae, J. Environ. Manag. (2019) http://dx.doi.org/10.1016/j.jenvman.2019.02.048.
[40] G. Forkuor, W. Amponsah, P. Oteng-Darko, G. Osei, Safeguarding food security through large-scale adoption of agricultural production technologies: The case of greenhouse farming in Ghana, Clean. Eng. Technol. (2022) http://dx.doi.org/10.1016/j.clet.2021.100384.
[41] D.M. Mendes, L. Paglietti, D. Jackson, A.G. Altozano, Ghana: Irrigation Market Brief, FAO and IFC, Rome, Italy, 2014.
[42] G.B. Tesfahunegn, E.T. Ayuk, S.G.K. Adiku, Farmers' perception on soil erosion in Ghana: Implication for developing sustainable soil management strategy, PLoS One (2021) http://dx.doi.org/10.1371/journal.pone.0242444.
[43] G. Ashiagbor, et al., Toward sustainable land resources management with agroforestry: Empirical evidence from the Sunyani west district of Ghana, Agrofor. Syst. (2019) 1–11.
[44] S.A. Siddiqui, A.S. Gadge, M. Hasan, T. Rahayu, S.N. Povetkin, I. Fernando, R. Castro-Muñoz, Future opportunities for products derived from black soldier fly (BSF) treatment as animal feed and fertilizer - a systematic review, Environ. Dev. Sustain. (2024) http://dx.doi.org/10.1007/s10668-024-04673-8.
[45] M. Beyers, C. Coudron, R. Ravi, E. Meers, S. Bruun, Black soldier fly Larvae as an alternative feed source and agro-waste disposal route – a life cycle perspective, Res. Conservat. Recycl. 192 (2023) 106917, http://dx.doi.org/10.1016/j.resconrec.2023.106917.
[46] R. Gobinath, G.P. Ganapathy, E. Gayathiri, A.S. Ashwini, H.R. Pourghasemi, Chapter 18 - ecoengineering practices for soil degradation protection of vulnerable hill slopes, editor(s): Hamid Reza Pourghasemi, Comput. Earth Environ. Sci. (2022) http://dx.doi.org/10.1016/B978-0-323-89861-4.00002-6.
[47] R. Lebuy, D. Mancilla-Ruiz, H. Manríquez, F. De la Barrera, Degraded landscapes in hillside systems with agricultural use: An integrated analysis to establish restoration opportunities in central Chile, Land (2023) http://dx.doi.org/10.3390/land12010005.
[48] M.T. Löbmann, L. Maring, G. Prokop, J. Brils, J. Bender, A. Bispo, K. Helming, Systems knowledge for sustainable soil and land management, Sci. Total Environ. (2022) http://dx.doi.org/10.1016/j.scitotenv.2022.153389.