Asian Journal of Scientific Research

ISSN 1992-1454

OPEN ACCESS

Asian Journal of Scientific Research

ISSN 1992-1454
DOI: 10.3923/ajsr.2023.1.8

Research Article
Waste Reduction, Biomass Conversion and Growth Performance of Black Soldier Fly Larvae Using Organic Waste

[1]Desta Mulu, [2]Fantaw Yimer, [3]George Opande and [2]Tsegaye Bekele

[1]College of Agriculture, Food, Environment and Climate Science, University of Injibara, Injibara, Ethiopia
[2]Wondo Genet College of Forestry and Natural Resources, Hawassa University, Shashamene, Ethiopia
[3]School of Science, Kaimosi Friends University College, Kaimosi, Kenya

Abstract

Background and Objective: Municipal solid waste management has always been challenging in developing countries. Numerous waste management technologies, including landfill operations, pyrolysis and incineration are now available. However, these technologies frequently come with drawbacks (operational and maintenance issues) and have detrimental effects on the environment. In this regard, ongoing work is being done to create environmentally friendly technologies to address waste management issues. In response to these difficulties, Black Soldier Fly Larval (BSFL) biodegradation has emerged as an outstanding green waste management strategy. It hasn't, however, received much research. Therefore, the current study was to investigate the efficiency of larval treatment on a substrate containing varying proportions of water hyacinth, fruit waste and manure. **Materials and Methods:** Five feeding trays with different proportions of water hyacinth, fruit waste and manure were 65:25:10 (T1), 50:40:10 (T2), 35:55:10 (T3), 15:75:10 (T4) and 10:80:10 (T5), respectively. The percentage biomass conversion ratio (BCR), the effectiveness of waste reduction and the percentage growth of larvae were measured. Complete Randomized Design (CRD) was used in the experiment's design. **Results:** So, with a 2050% increase in initial larvae weight, 85.4% waste reduction efficiency and a biomass conversion rate of 30.71%, T3 had the best outcomes, followed by T5, T4, T2 and T1. The BSFL's growth performance, waste reduction effectiveness and biomass conversion ratio were remarkably high. The highest growth performance, reduction efficiency and conversion ratio of larvae reared on water hyacinth, fruit waste and manure may be attributed to a nutritionally balanced diet. **Conclusion:** Therefore, the different proportions of water hyacinth, fruit waste and manure fed to larvae significantly influence the percentage growth performance, waste reduction efficiency and biomass conversion ratio of the larvae.

Key words: Biomass conversion, growth performance, manure, waste reduction, water hyacinth, black soldier fly larvae

Citation: Mulu, D., F. Yimer, G. Opande and T. Bekele, 2023. Waste reduction, biomass conversion and growth performance of black soldier fly larvae using organic waste. Asian J. Sci. Res., 16: 1-8.

Corresponding Author: Desta Mulu, College of Agriculture, Food, Environment and Climate Science, University of Injibara, Injibara, Ethiopia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Mass production, mass consumption and mass waste disposal have undergone significant changes over the past few decades as a result of the growth of metropolitan area networks, economic development and consumerist lifestyles[1]. All of these elements play a part in the ongoing production of significant amounts of waste. Global waste production is expected to reach 3.4 billion tons by 2050, with biodegradable materials accounting for up to 44% of that combined amount, with a greater proportion in developing nations. Currently, the lion's shares of these wastes are disposed of in open dumps and landfills (37% and 33%, respectively)[2]. These methods of handling and disposal of biodegradable waste are considered to be major environmental threats because they release pollutants into the atmosphere, contaminate soil and water with toxic substances and contaminate nutrients with leachates[3]. Governments must recognize the adverse effects that improper waste management has on a nation’s society, economy and environment and implement more effective waste management strategies to achieve sustainability and the improvement of a circular bio-economy[4,5]. Improved technologies and procedures are urgently needed to address the problems related to waste generation.

The CORS (conversion of organic refuse by saprophages) is a potential and proven method of treating organic waste by feeding it to organisms (saprophages) that specialize in decaying matter. Vermicomposting, which involves worms and other microorganisms converting organic waste into nutrient-rich humus, is likely the most well-known application of CORS[6]. The Black Soldier Fly (BSF), a straightforward CORS technology, has been introduced as an organic waste converter that aims to combine waste treatment and the generation of a useful by-product, which is actually the organism feeding on waste. Dairy manure[7], food waste[8] and byproducts of the agro-industrial sector[9] are a few examples of the organic-rich waste that BSF larvae (BSFL) feed on. The essential proteins and fats needed for animal feed can thus be created from the nutrients in BSFL[10,11], reducing the shortage of conventional animal feed and its rising cost[12].

The byproducts of the BSFL bioconversion procedure can also be turned into fertilizer[11,12]. Another advantage of this technology is that BSF adults are not harmful to humans. Researchers found that harmful bactericidal substances secreted by BSFL stop house fly from laying eggs and lower foodborne pathogens like *Salmonella enterica* and *E. coli*[11,12]. Therefore, there is no worry about BSF farming spreading diseases on a large scale.

Water hyacinth, on the other hand, has recently begun to spread throughout the world's water bodies, such as lakes and rivers, causing significant ecological disruption[13]. For instance, since 2011, Lake Tana’s ecological existence in Ethiopia had been gravely threatened by the abrupt spread and quick expansion of water hyacinth weed. It is also suffocating Lake Victoria and endangering investments made there, including port operations[14]. Due to the severity of the issue, numerous coordinated initiatives, studies and campaigns have been launched to get rid of the weed and save the lakes[14,15]. The weed is reportedly posing a threat to rivers in the rift valley and dams built to generate electricity from these rivers. One of these rivers being overrun by hyacinths is the Awash River[16]. Studies indicated that water hyacinth causes the cessation of fishing operations, which therefore lowers fishermen’s income, employment and wealth, heightens poverty and decreases fishing efficiency[17], waterway blockages that result in flooding and harm to agriculture and recreational activities[18], greater evapotranspiration and poorer water quality as huge water hyacinth mats limit oxygen from reaching the water’s surface or reduce other plants’ and algae’s ability to produce oxygen[19]. Water hyacinth floating mats provide a habitat for organisms that are detrimental to human health, including an increase in snails that transmit Bilharzia (schistosomiasis)[20], fertile grounds for the mosquito that transmits malaria[21] and an effect on hydropower[22,23].

The most popular strategy for managing water hyacinths is physical control (both manual and mechanical removal), as biological and chemical methods have negative effects on the ecology. The harvested weed is discarded, which causes it to deteriorate and cause loss of aesthetic value, soil degradation and air pollution[24]. The waste gas produced by the biomass of water hyacinth when it is dumped in a landfill is primarily made up of methane and carbon dioxide[25] the main contributor to environmental pollution and global warming. Therefore, the weed control strategy should be linked to its economic gain and be environmental friendly. The larvae of the black soldier BSFL can grow on water hyacinth. The BSF breeders have so far used organic waste as growing media, including market waste, household waste, agricultural waste and livestock manure. The use of water hyacinth as BSFL feed is an interesting strategy because the harvested BSF larva can be used as a source of protein for animal feed and to prevent water hyacinth from having negative ecological and socioeconomic effects. The principles of a circular bio-economy, in which waste from one process is used as a resource in another product, are upheld by this approach[26].

Several studies have been undertaken on the rearing of BSFL using market waste, household waste, agricultural waste and livestock manure[10,11,27,28]. However, there is little information available about rearing BSFL using water hyacinths in combination with fruit waste and manure. This study was intended to provide answers to the following questions: 1) How effective is BSFL in reducing substrate containing water hyacinth and fruit wastes (apple, blackberry, orange, banana, pineapple, mango, watermelon, avocado and papaya) at different proportions and which combinations are the best substrate for BSFL rearing? Therefore, the objectives of this study were to investigate the BSFL's growth performance, identify which substrate is best for rearing the BSFL and assess the BSFL's waste decomposition efficiency and biomass conversion rate (BCR). This research contributes to a better understanding of waste combinations that improve the decomposition capability of the BSFL and provide a reasonably high BSFL yield.

MATERIALS AND METHODS

Rearing of BSFL using water hyacinth, fruit wastes and manure at different combinations was carried out in the Protein Master Agricultural Enterprise in Huruma, Nairobi, Kenya. Huruma Estate is a residential estate in Nairobi, Kenya's Capital. The Protein Master Company supplied the six-day-old BSFL used in the experiment. The experiment ran from May 27 to June 17, 2022 and ended before the larvae reached the pre-pupae stage.

Sample collection and preparation: The parts of fruits that weren't used in food preparation and were thrown in the trash can are referred to as waste. Apple, blackberry, orange, banana, pineapple, mango, watermelon, avocado and papaya were among the fruit wastes that were collected from juice houses, traditional markets and cafeterias in Huruma, a city in Nairobi's Northeast. Water hyacinth samples were taken from Lake Victoria in Kisumu and transported to the location of the experiment. Manure was collected from the nearby dairy farms located in Huruma Estate. Each collected sample was put in a plastic bag or sack and transported to the experiment site. The improper materials, such as plastic, glass and paper were manually separated. Freshwater hyacinth and fruit wastes were chopped separately into 3-5 cm sizes and were mixed thoroughly with manure at five different ratios which served as a source of feed for the BSFL.

Black soldier fly larvae: Protein Master Company in Huruma Estate provided a population of black soldier fly (Hermetia illucens) (Diptera: Stratiomyidae) kept in 10 different cages (60, 60 and 45 cm each) covered with transparent mosquito nylon net. An adult colony was kept in a four-feet-by-four-feet metallic cage inside mosquito nets inside a 20 m by 8 m wide greenhouse. The green house's top is made of transparent polythene paper and the inside is covered with netting. Furthermore, female adults lay eggs in plastic conduits and sanded wood joined together with a rubber band. Adult females were attracted to lay eggs using fermented blood waste, chicken droplets and pig manure as an attractant medium. In addition to this substrate, water and sugar were placed separately in a small container in the cage. The greenhouse had a temperature range of 28-38°C and a relative humidity of 40-60%. Eggs laid within two days were gathered and put in a plastic container with water that had been thoroughly mixed with an equal amount of fermented wheat and maize brew to achieve a moisture content of 60%. Four to five days later, hatching was observed. To ensure the best possible larval development, at five days old, the newly hatched neonates were given access to commercial wheat and maize brew[29]. The larvae were sieved on the sixth day using a 1.2 mm-mesh screen and those that passed were regarded as being the same size and weight. The larvae were then weighed using an electronic balance and approximately 200 g of larvae were transferred to each treatment or feeding tray. Each substrate treatment was tested in triplicates.

Ethical consideration

Statement of human and animal rights: All of the experimental procedures involving animals were conducted in accordance with animal care guidelines and approved by The Administration Committee of Experimental Animals, Kenya.

Statement of informed consent: There is no human subject in this article and informed consent is not applicable.

Ethical approval: This study was approved by the administration committee of experimental animals, Kenya.

Experimental design: Complete Randomized Design (CRD) was used in the experiment's design. Five feeding trays with different proportions of water hyacinth, fruit waste and manure were labeled. The larvae in treatment one (T1) were fed a substrate containing water hyacinth, fruit waste and manure mixtures in the ratio of 65:25:10, in treatments 2, 3, 4 and 5, the ratios were 50:40:10, 35:55:10, 15:75:10 and 10:80:10, respectively.

The empty feeding trays were weighed and recorded. About 200 g of larvae were added to the feeding trays after 8 kg of the waste had been added. All larvae were taken out of their containers every five days and the weights of fifteen randomly chosen larvae were weighed and recorded. The containers containing residual waste were weighed and recorded. After ten days of waste decomposition by the BSF and another 6 kg of fresh waste was added to each feeding tray. Each container received 14 kg worth of waste in total. The experiment lasted for 20 days, but it was stopped before the larvae reached the pre-pupae stage.

Determining growth performance, biomass conversion and waste reduction efficiency of the BSFL: In the present study, larval weight and residual weight are important factors for assessing waste reduction efficiency. The following equations provide the BSFL growth percentage, G, biomass conversion rate (BCR) and waste reduction rate (D) following the methodology of Lalander *et al.*[30]. The quantity of substrate consumed during the larval stage affects reduction efficiency:

$$G = \frac{W_T - W_t}{W_t} \times 100$$

where, W_t was the weight of BSFL at time t and W_T was the weight of BSFL after time t

$$BCR = \frac{\text{Total weight of larvae (kg)}}{\text{Initial waste weight (kg)}} \times 100$$

$$D = \frac{W - R}{W} \times 100$$

where, W represents the weight of the waste used at time t and R represents the residue leftover after time t.

Statistical analysis: A One-Way Analysis of Variance (ANOVA) with a subsequent LSD test was used to determine whether there was a difference between the treatments ($p<0.05$). The growth rate was determined as (weight of BSFL at time t minus the weight of BSFL after time t)/weight of BSFL at time t. Similarly, the reduction rate (D) was calculated using the formula (weight of the waste used at time t-the residue after time t)/weight of the waste used at time t. The SPSS Version 20 was used for all statistical analyses.

RESULTS AND DISCUSSION

Black soldier fly larvae growth: The weight of the larvae was recorded every five days in order to assess the percentage of BSFL growth and identify the appropriate proportions of the substrate for BSFL rearing. The BSFL growth rate for the experiment using 200 g of larvae was shown in Fig. 1. The graph depicted that there is only a slight difference in larval weight until the fifth day, after which the difference in weight increases for the following few days. The fact that the weight of the larvae increased daily suggests that the larvae were growing daily. The waste treatments differed significantly from one another in the growth of BSFL ($p<0.05$). The T3 and T5 larval growth were noticeably greater than T4 and T2, which came in second and third, respectively. Slower larval growth was observed on T1, a substrate with a higher proportion of water hyacinth and a lower proportion of fruit waste. Figure 1 showed that larvae fed a close proportion of water hyacinth and fruit waste (T3) grew by 2050% of their initial weight, followed by T5 (1950%), T4 (1850%) and T2 (1800%). On T1, however, BSFL grew at a slower rate, increasing by 1507.5% of their initial weight. This implied that the larvae were not getting the necessary nutrients by decomposing the waste in treatment one (T1). Slower larval growth appeared to be associated with poor feed quality[31,32]. The present result was supported by Ardiansyah *et al.*[33], who used molasses, fermented water hyacinth and fruit waste as a substrate for the rearing of BSFL in their investigation and found that the lowest yield of BSF larvae flour was produced by using the lowest proportion of fruit waste and the highest proportion of fermented water hyacinth.

The results of the present study showed that there was a close BSFL growth between T4 and T5, where the substrate contained a low proportion of water hyacinth and a high proportion of fruit waste. The weight of larvae fed a substrate containing less water hyacinth and high fruit waste proportion (T4 and T5) revealed improved BSFL growth but less than T3. Lalander *et al.*[30] reported that the balanced nutrient in the mixture substrates aids the BSFL in making better use of the available nutrients. The elements of life that larvae require led to the achievement of the optimum BSFL growth[34]. Throughout the experiment, the larvae fed a substrate with lower proportion of fruit waste and a higher proportion of water hyacinth (T1) grew slowly. The quality of the feed media will affect how well larvae are nourished during breeding[35].

Waste reduction efficiency and biomass conversion rate (BCR): The residual weight of water hyacinth, fruit waste and manure shows how well BSFL composting works. Throughout the 20-day experiment, a total of 14 kg of waste was added to each feeding tray. The waste reduction efficiency when 200 g of larvae are used as the starting weight was depicted in Fig. 2. The graph indicates that the weight of the waste that the larvae composted changed relatively little at the

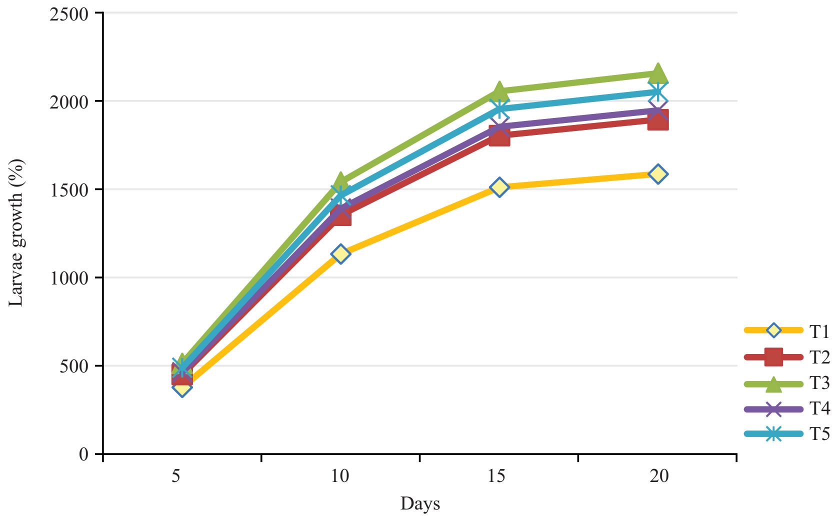

Fig. 1: Growth percentage of BSFL at different substrate combinations

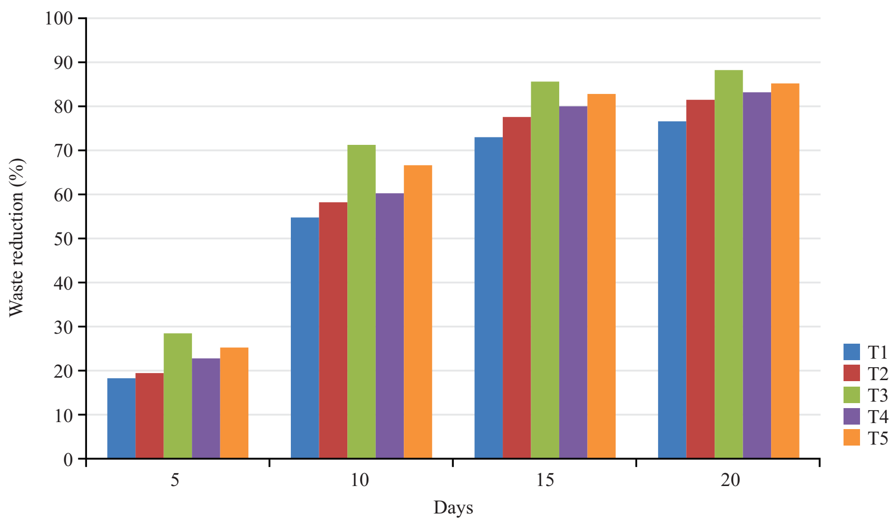

Fig. 2: Effectiveness of BSFL in waste reduction during 20-days experiment using a substrate containing a mixture of water hyacinth, fruit waste and manure at different proportion

beginning of the experiment until the fifth day, at which point the weight difference in the residue became very noticeable.

The waste reduction efficiency of BSF larvae ranged from 72.8% to 85.4%, with T3 (85.4%±0.05) showing the highest reduction, followed by T5 (82.6%±0.21), T4 (79.8%±0.23), T2 (77.4%±0.14) and T1 (72.8%±1.22) (Fig. 2). The T1 waste reduction efficiency differed significantly from T2, T3, T4 and T5 waste reduction efficiency at $p = 0.000$, $df = 4$ and F value = 140 (alpha level, $p = 0.05$). There was no statistically significant difference between T4 and T5 or T2 and T4 ($p > 0.05$). However, T3 did differ significantly from T2, T4 and T5. The waste reduction efficiency found in this study was higher than that reported in other research findings[30,36-38].

The bioconversion rate ranged from 22.96% to 30.71%, with T3 (30.71%) having the highest BCR, followed by T5 (28.57%), T4 (27.86%), T2 (27.14%) and T1 (22.96%) (Fig. 3). The T1 BCR differed significantly from T2, T3, T4 and T5 BCR at $p = 0.000$, $df = 4$ and F value = 140 (alpha level, $p = 0.05$). There was no statistically significant difference between T4 and T5 or T2 and T4 ($p > 0.05$). However, T3 did differ significantly from T2, T4 and T5. The percent waste reduction and BCR were found to have a positive correlation because the

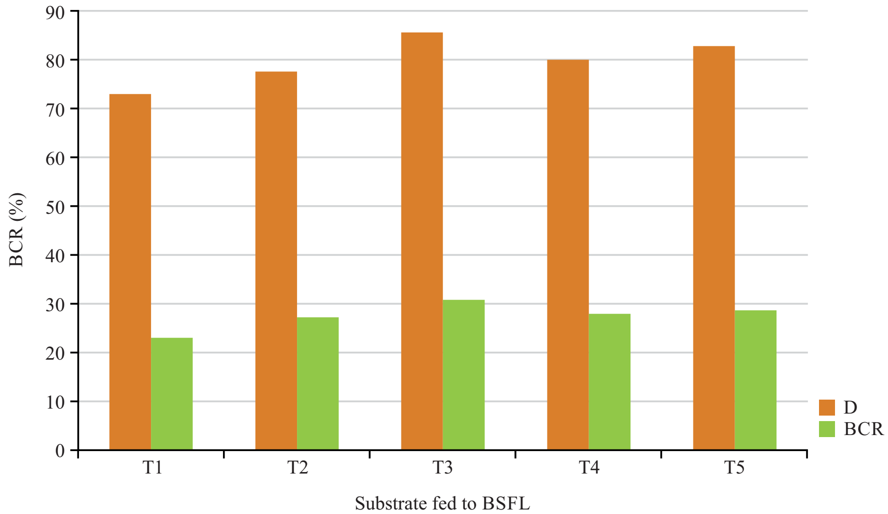

Fig. 3: Waste reduction effectiveness (D) and biomass conversion rate (BCR) of BSFL

maximum waste consumed corresponds to the total larval biomass. The same patterns were seen, with T3 exhibiting the highest levels of waste reduction and larval biomass.

The percentage of BCR found in this study exceeded that reported in the study by Lalander *et al.*[30], which showed that the maximum BCR for a mixture of abattoir waste and fruits and vegetables was 14.2 and 13.9% for food waste and the lowest for sludge and individual fruits and vegetables waste.

CONCLUSION

The different proportions of water hyacinth, fruit waste and manure fed to BSFL had a significant effect on BSFL growth, waste reduction effectiveness and biomass conversion rate. The T3 produced the best results through increase in initial BSFL weight, waste reduction efficiency and a BCR followed by T5, T4, T2 and T1. The results of the current study showed that BSFL is appropriate technology for managing organic waste because of its flexibility in feeding preferences and the voracious appetite of larvae, leading to a significant decrease in waste, increased larval growth and BCR.

SIGNIFICANT STATEMENT

The purpose of this study was to investigate the BSFL's growth performance, identify the best substrate for rearing the BSFL and assess the BSFL's waste decomposition efficiency and biomass conversion rate. The results indicated that treatment three (T3) had the best results, with a 2050% increase in initial larvae weight, an 85.4% waste reduction efficiency and a bioconversion rate of 30.71%, followed by T5, T4, T2 and T1. The results showed that BSFL is an effective technology for managing organic waste, leading to a noticeable decrease in waste as well as an increase in larval growth and bioconversion rate. The findings inform decision-makers about the potential of BSFL in reducing fruit and water hyacinth wastes, as well as the best BSFL rearing combinations.

ACKNOWLEDGEMENT

The authors acknowledge the funding provided by Organization for Women in Science for the Developing World (OWSD) and Mawazo Fellows Fund. The authors appreciated the constructive feedback provided by anonymous reviewers and supervisors.

REFERENCES

1. Ioannou, T., K. Bazigou, A. Katsigianni, M. Fotiadis and C. Chroni *et al.*, 2022. The "A2UFood Training Kit": Participatory workshops to minimize food loss and waste. Sustainability, Vol. 14. 10.3390/su14042446.
2. Mukama, T., R. Ndejjo, D. Musoke, G. Musinguzi, A.A. Halage, D.O. Carpenter and J.C. Ssempebwa, 2016. Practices, concerns, and willingness to participate in solid waste management in two urban slums in Central Uganda. J. Environ. Public Health, Vol. 2016. 10.1155/2016/6830163.
3. Koda, E., A. Miszkowska and A. Sieczka, 2017. Levels of organic pollution indicators in groundwater at the old landfill and waste management site. Appl. Sci., Vol. 7. 10.3390/app7060638.

4. Silva, A., M. Rosano, L. Stocker and L. Gorissen, 2017. From waste to sustainable materials management: Three case studies of the transition journey. Waste Manage., 61: 547-557.
5. Khan, A.H., N.A. Khan, S. Ahmed, A. Dhingra and C.P. Singh *et al*., 2020. Application of advanced oxidation processes followed by different treatment technologies for hospital wastewater treatment. J. Cleaner Prod., Vol. 269. 10.1016/j.jclepro.2020.122411.
6. Zurbrügg, C., B. Dortmans, A. Fadhila, B. Vertsappen and S. Diener, 2018. From pilot to full scale operation of a waste-to-protein treatment facility. Detritus, 1: 18-22.
7. Ji-Bin, Z., Z. Jia, L. Jia-Hui, J.K. Tomerlin and X. Xiao-Peng *et al*., 2021. Black soldier fly: A new vista for livestock and poultry manure management. J. Integr. Agric., 20: 1167-1179.
8. Nguyen, T.T.X., J.K. Tomberlin and S. Vanlaerhoven, 2015. Ability of black soldier fly (Diptera: Stratiomyidae) larvae to recycle food waste. Environ. Entomol., 44: 406-410.
9. Meneguz, M., A. Schiavone, F. Gai, A. Dama, C. Lussiana, M. Renna and L. Gasco, 2018. Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (*Hermetia illucens*) larvae. J. Sci. Food Agric., 98: 5776-5784.
10. Liu, X., X. Chen, H. Wang, Q. Yang and Kashif ur Rehman *et al*., 2017. Dynamic changes of nutrient composition throughout the entire life cycle of black soldier fly. PLoS ONE, Vol. 12. 10.1371/journal.pone.0182601.
11. Xiao, X., L. Mazza, Y. Yu, M. Cai and L. Zheng *et al*., 2018. Efficient co-conversion process of chicken manure into protein feed and organic fertilizer by *Hermetia illucens* L. (Diptera: Stratiomyidae) larvae and functional bacteria. J. Environ. Manage., 217: 668-676.
12. Ma, L., Z. Bai, W. Ma, M. Guo and R. Jiang *et al*., 2019. Exploring future food provision scenarios for China. Environ. Sci. Technol., 53: 1385-1393.
13. Harun, I., H. Pushiri, A.J. Amirul-Aiman and Z. Zulkeflee, 2021. Invasive water hyacinth: Ecology, impacts and prospects for the rural economy. Plants, Vol. 10. 10.3390/plants10081613.
14. Chia, S.Y., C.M. Tanga, I.M. Osuga, X. Cheseto, S. Ekesi, M. Dicke and J.J.A. van Loon, 2020. Nutritional composition of black soldier fly larvae feeding on agro industrial by products. Entomol. Exp. Appl., 168: 472-481.
15. Degaga, A.H., 2019. Water hyacinth (*Eichhornia crassipes*) biology and its impacts on ecosystem, biodiversity, economy and human well-being. J. Nat. Sci. Res., 9: 24-30.
16. Getnet, H., D. Kifle and T. Fetahi, 2020. Water hyacinth (*Eichhornia crassipes*) affects the composition and abundance of zooplankton in the Littoral Region of Koka Reservoir, Ethiopia. Afr. J. Aquat. Sci., 45: 486-492.
17. Asmare, E., 2017. Current trend of water hyacinth expansion and its consequence on the fisheries around north eastern part of Lake Tana, Ethiopia. J. Biodivers. Endanger. Species, Vol. 5. 10.4172/2332-2543.1000189.
18. Endebu, M., A. Lema, T. Genet, A. Mitike, B. Regassa, E. Dejen and H. Abegaz, 2015. Fisheries baseline survey describing status of fisheries in Lake Zeway, Ethiopia. J. Fish. Livest. Prod., Vol. 3. 10.4172/2332-2608.1000129.
19. Villamagna, A.M. and B.R. Murphy, 2010. Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): A review. Freshwater Biol., 55: 282-298.
20. Borokini, T.I. and F.D. Babalola, 2012. Management of invasive plant species in Nigeria through economic exploitation: Lessons from other countries. Manage. Biol. Invasions, 3: 45-55.
21. Minakawa, N., G.O. Dida, G.O. Sonye, K. Futami and S. Kaneko, 2008. Unforeseen misuses of bed nets in fishing villages along Lake Victoria. Malar. J., Vol. 7. 10.1186/1475-2875-7-165.
22. Ndimele, P.E. and A.A. Jimoh, 2011. Water hyacinth (*Eichhornia crassipes* (Mart.) Solms.) in phytoremediation of heavy metal polluted water of Ologe Lagoon, Lagos, Nigeria. Res. J. Environ. Sci., 5: 424-433.
23. Patel, S., 2012. Threats, management and envisaged utilizations of aquatic weed *Eichhornia crassipes*: An overview. Rev. Environ. Sci. Bio/Technol., 11: 249-259.
24. Gezie, A., W.W. Assefa, B. Getnet, W. Anteneh, E. Dejen and S.T. Mereta, 2018. Potential impacts of water hyacinth invasion and management on water quality and human health in Lake Tana watershed, Northwest Ethiopia. Biol. Invasions, 20: 2517-2534.
25. Nega, D.T., A.V. Ramayya, F. Manenti and A.F. Amaral, 2021. Turning curse into cure: Potential of water hyacinth for bio-refining-A contextual investigation of Lake Tana. Environ. Challenges, Vol. 5. 10.1016/j.envc.2021.100387.
26. Velenturf, A.P.M. and P. Purnell, 2021. Principles for a sustainable circular economy. Sustainable Prod. Consumption, 27: 1437-1457.
27. Sarpong, D., S. Oduro-Kwarteng, S.F. Gyasi, R. Buamah, E. Donkor, E. Awuah and M.K. Baah, 2019. Biodegradation by composting of municipal organic solid waste into organic fertilizer using the black soldier fly *(Hermetia illucens)* (Diptera: stratiomyidae) larvae. Int. J. Recycl. Org. Waste Agric., 8: 45-54.
28. Widyastuti, R.A.D., A. Rahmat, H.A. Warganegara, W.S. Ramadhani, B. Prasetyo and M. Riantini, 2021. Chemical content of waste composting by black soldier fly (*Hermetia illucens*). IOP Conf. Ser.: Earth Environ. Sci., Vol. 739. 10.1088/1755-1315/739/1/012003.
29. Tschirner, M. and A. Simon, 2015. Influence of different growing substrates and processing on the nutrient composition of black soldier fly larvae destined for animal feed. J. Insects Food Feed, 1: 249-259.
30. Lalander, C., Å. Nordberg and B. Vinnerås, 2018. A comparison in product-value potential in four treatment strategies for food waste and faeces-assessing composting, fly larvae composting and anaerobic digestion. GCB Bioenergy, 10: 84-91.

31. Gobbi, P., A. Martinez-Sanchez and S. Rojo, 2013. The effects of larval diet on adult life-history traits of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). Eur. J. Entomol., 110: 461-468.
32. Oonincx, D.G.A.B., S. van Broekhoven, A. van Huis and J.J.A. van Loon, 2019. Feed conversion, survival and development, and composition of four insect species on diets composed of food by-products. PLoS ONE, Vol. 14. 10.1371/journal.pone.0222043.
33. Ardiansyah, F., E. Susanto and Wahyuni, 2021. Use of water hyacinth and fermented fruit waste as bsf (black soldier fly) media on the quality of bsf maggot flour. J. Ilmu Produksi Teknologi Hasil Peternakan, 9: 1-6.
34. Sprangers, T., M. Ottoboni, C. Klootwijk, A. Ovyn and S. Deboosere *et al*., 2017. Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. J. Sci. Food Agric., 97: 2594-2600.
35. Newman, T., N. Jhinku, M. Meier and J. Horsfield, 2016. Dietary intake influences adult fertility and offspring fitness in zebrafish. PLoS ONE, Vol. 11. 10.1371/journal.pone.0166394.
36. Li, Z., G.Q. Shen and M. Alshawi, 2014. Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. Resour. Conserv. Recycl., 91: 27-39.
37. Siddiqui, S.A., B. Ristow, T. Rahayu, N.S. Putra and N.W. Yuwono *et al*., 2022. Black soldier fly larvae (BSFL) and their affinity for organic waste processing. Waste Manage., 140: 1-13.
38. Singh, A., B.H. Srikanth and K. Kumari, 2021. Determining the black soldier fly larvae performance for plant-based food waste reduction and the effect on biomass yield. Waste Manage., 130: 147-154.