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The Impact of Food Waste Mitigation with Black Soldier Fly Assistance on Climate Change in Indonesia – A Systematic Review

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ABSTRACT

Climate changes in the world and Indonesia cannot be separated from human activities. Food waste is an act of throwing away food which can result in climate change due to the high potential for global warming due to this activity. Therefore, there is a need for mitigation in the form of food waste processing, one of which is the black soldier fly (BSF) method. This study aimed to determine the development trend of the impact of food waste in Indonesia on climate change and determine the effect of mitigating food waste processing using the BSF method. The analysis used in this study was bibliometric, and a systematic literature review was applied to 298 published articles. It was found that the publication trend of articles regarding the impact of food waste on climate change in Indonesia is still tiny, namely seven publications. In the impact analysis of mitigating food waste processing using the BSF method was proven to reduce global warming potential by 1,201.58 kg CO_2eq and 1,143.4 kg CO_2eq. This value compares food waste processing using the BSF and landfilling methods. Results were also obtained from the processing of food waste using only the BSF method for global warming potential values of 0.38 kg CO_2eq, 6,687 kg CO_2eq, and 3.2 kg CO_2eq.

Keywords: food waste, climate change, BSF.

INTRODUCTION

Climate change is a condition with abundant greenhouse gases and aerosols in the atmosphere (Change, 2007). The cause of climate change is the result of natural changes by nature or the result of human behavior. The climate change caused by nature includes earthquakes, oceans, wetlands, and volcanoes (Xi-Liu & Qing-Xian, 2018). Meanwhile, the climate change caused by human activities, often called anthropogenic activities, includes industrial activities, land use, forest burning, and changes in land use (Edenhofer, 2015). It was also revealed that this anthropogenic activity has caused global warming of around 1.0°C, and the figure will reach 1.5°C from 2030 to 2052 if temissions continue to increase (Fawzy, Osman, Doran, & Rooney, 2020). In this case, the greenhouse gases that cause climate change are defined as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases such as hydrofluorocarbons (HFC), perfluorocarbons (Fawzy et al., 2020). One of the contributors to methane gas, which causes greenhouse gases, is the accumulation of rubbish. Waste also contributes to the methane gas generation, reaching 11,390 tons of CH_4/year. Besides methane gas, burning waste also contributes tot the emissions of CO_2, CO, N_2O, NOx, NH_3, and organic carbon gas. On the basis of the SIPSN data for 2022, the composition of food waste reaches 40.58% of the total waste in Indonesia. Indonesia is also estimated to produce 300 kg of food waste per capita per year which has a global warming potential of 1,702.9 Mt CO_2eq

(Farahdiba et al., 2023). The most straightforward treatment to prevent climate change is to reduce the number of gases that cause greenhouse gases. Before taking the final step of prevention, namely by processing food waste, the world community, especially Indonesia, must be highly aware of not leaving or throwing away food (Aydin & Yildirim, 2021). Food waste processing is carried out using various methods, from those that have a lot of impact on the environment to those with the most minimal impact. These methods include landfilling, composting, anaerobic digestion, and incineration (Gao, Tian, Wang, Wennersten, & Sun, 2017). One friendly food waste processing method that can be carried out in Indonesia is the Black Soldier Fly method (Farahdiba et al., 2023). The Black Soldier Fly is an insect that can break down organic waste, one of which is food waste, in the larval phase. The research by Lalander, Nordberg, and Vinnerås (2018) shows that processing food waste and faeces using BSF displays a lower methane production graph compared to without the help of BSF. This study tries to answer two research questions, namely:

1. RQ1. What are the trends in the impact of food waste on climate change?
2. RQ2. What is the impact of food waste mitigation through BSF processing?

The first research question provides the development of food waste in Indonesia, and the publication of articles discussing the impact of food waste on climate change. Meanwhile, the second research question provides the amount of value obtained from mitigating the impact of food waste through processing using the BSF method. These two research questions help the author to reveal the impact of food waste mitigation with the help of BSF on climate change in Indonesia.

METHODS

The writing of this article is a combination of a systematic literature review and bibliometric analysis to obtain the relevant impact of food waste mitigation in Indonesia with BSF assistance. These two reviews are considered practical and can solve the problems in this article (Wibowo, Ramadan, Taher, & Khairurrijal, 2023). Bibliometric analysis is used to determine trends in discussing mitigation of the impact of food waste in Indonesia when compared with the world, which is causing climate change, one of which is due to the high potential value of global warming. Meanwhile, a systematic literature review was used to reveal the impact of food waste mitigation as seen from the global warming potential value of processing with the help of BSF compared to processing using composting and landfilling.

The literature used in this writing includes articles indexed by Scopus (ScienceDirect, Elsevier, SpringerLink, Nature, and several others). The literature used in preparing this article was selected in stages. In order to find out the trends in discussion of mitigating the impact of food waste, which causes climate change, articles were screened using the method shown in Figure 1. The first research methodology used to answer RQ1, bibliometric analysis, was chosen as the form of analysis with the help of VOSviewer software (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021). Article searches were carried out by the author using keywords that are considered appropriate for the review to be made. The articles that have been obtained were then filtered according to the conditions of the review currently being made. The results of the filtering of the articles were then processed by the author using

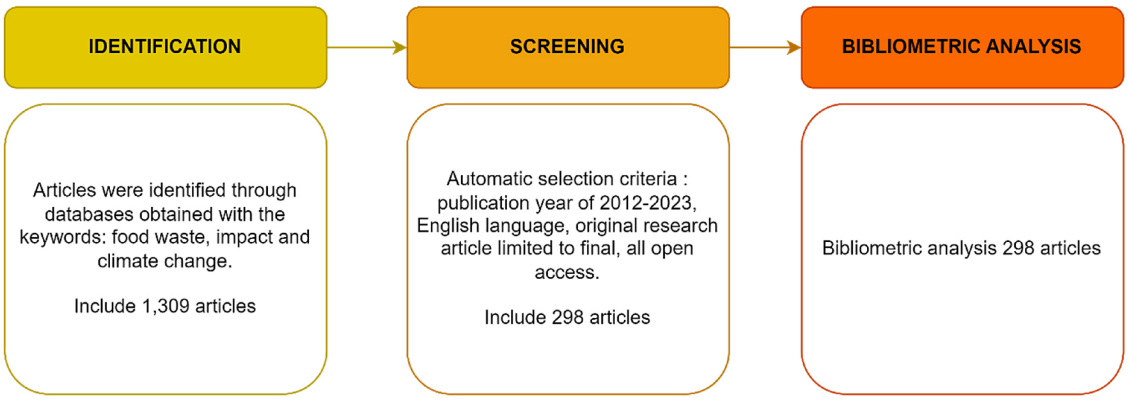

Figure 1. First research methodologies

bibliometric analysis. Meanwhile, to determine the mitigation of the impact of food waste, measured based on global warming potential, which is RQ2, the second research methodology was used, as in Figure 2. Searching for relevant articles with reviews is almost the same as before, namely using keywords. However, the difference is that the results obtained were not filtered based on year of publication, type of article, or something else, but rather, the author read the abstract and filtered the articles that can be used as reference sources in writing this review article. The article was read at a glance from the abstract. Then a comparison was made between several articles to obtain a value of the global warming potential of each processing method. At the end point, it will be possible to know the magnitude of the impact of climate change mitigation on food waste using the BSF processing method, which is taken into consideration from the magnitude of the global warming potential. The two methodologies used are almost the same in searching for articles to be used; the two are only differentiated in the filtering process and the article analysis process to support the review articles created. This combination of bibliometric analysis and systematic literature review is considered to have better value (Paul & Criado, 2020). In general, bibliometrics only reveals the trends and potential that the author can do based on current conditions. At the same time, systematic literature reviews display the methodology clearly, and there are results in the form of analysis of existing articles or comparisons of several articles that can conclude the results (Paul & Criado, 2020; Pautasso, 2019).

Food waste is produced from every human activity, from household kitchens, restaurants, offices, schools, hospitals, hotels, and others

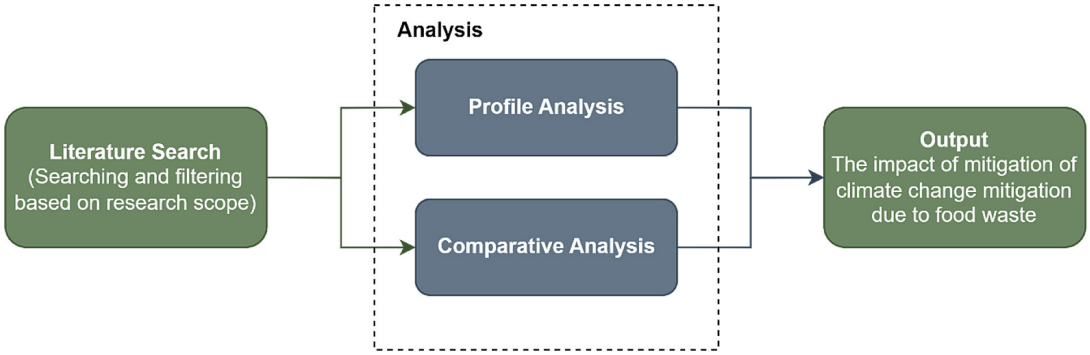

Figure 2. Second research methodologies

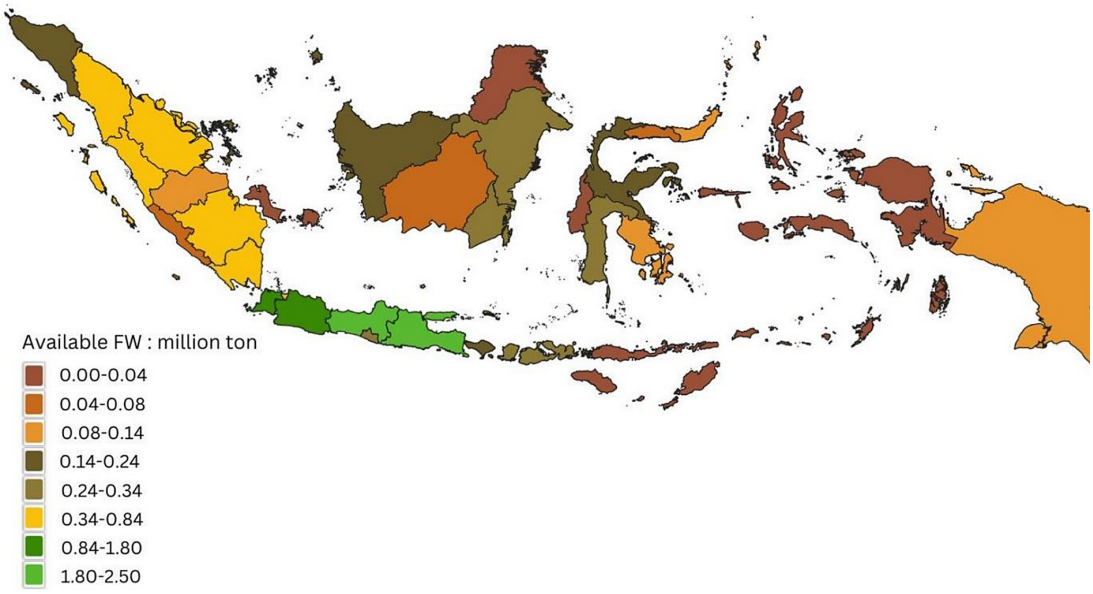

Figure 3. Available food waste in Indonesia

(Fig. 3). In Indonesia, the amount of food waste is 13,759,478.54 tons/year, with a percentage of 40.58% in 2022. Indonesia is divided into six large islands with different amounts of food waste: Sumatra, Java, Kalimantan, Sulawesi, Nusa Tenggara and Bali, Maluku, and Papua.

The food waste produced in each region in Indonesia is different; economic, social, and geographical factors also influence the amount of food waste produced. The regions with the highest amount of food waste are the provinces of Central Java and East Java. The factors causing the high food waste in these two provinces are the high population and increasing income (Lavany, 2022). After these two, there are the provinces of West Java and DKI Jakarta, which have the most significant amount of food waste generation. Java is the largest contributor to food waste generation, and almost all state government activities are centered on this island. The number of people on the island of Java is also the largest compared to other islands. Meanwhile, the lowest amount of food waste generation is in West Papua, East Nusa Tenggara, Maluku, North Maluku, North Kalimantan, and West Sulawesi.

Many factors cause large and small amounts of food waste, but it all depends on the consumption patterns of the people in the area. Waste generation is closely related to human lifestyle and thinking regarding consuming goods or food. Moreover, the existing food waste generation requires processing to reduce the environmental impact. The large amount of food waste generated in Indonesia can harm the environment if processing is not done. Each type of food waste has the potential for global warming, which can result in climate change. One example is vegetable waste in Lembang, West Java, which has a global warming potential of 55.1 t CO_2eq t^{-1} (Kashyap, de Vries, Pronk, & Adiyoga, 2023). Different figures are produced from different areas, namely Depok, West Java, where the global warming potential is 66.87 kg CO_2eq (Nugroho et al., 2023).

Food waste impact trend

This sub-chapter is the result of 1,309 articles obtained by searching using the keywords "food waste", "impact", and "climate change". Then, after elimination was carried out based on the desired criteria, namely the publication year 2012–2023, which was a limited to final research article and an open access article, 298 articles were produced. Bibliometric analysis was carried out to determine the number of articles (Figure 6) and keyword co-accuracy (Figure 7).

The number of articles discussing the impact of food waste on climate change in Indonesia is still far less than in other countries. Indonesia's contribution is only 2% compared to 98% of other countries worldwide. Several things may cause a significant difference in numbers. One of the reasons is the difference in research funding in each country. It is known that research funding has a very significant impact on the number of articles published (Ubfal & Maffioli, 2011). Each country has a different direction regarding the themes in published articles, so the number of articles on specific themes tends to be smaller (Liu, Liu, Jiang, Lin, & Xu, 2019).

Figure 4 illustrates the author's interest in writing an article about the impact of food waste on climate change. Publication of this article began in 2013, and there is no visible publication in the previous year. Existing publications do not all have the same direction, in 2013 the publication of this article discussed more about the impact of food waste in general and simple processing methods as a form of mitigation (Melikoglu, Lin, & Webb, 2013). Apart from that, other articles also discuss climate change and its impact on the environment

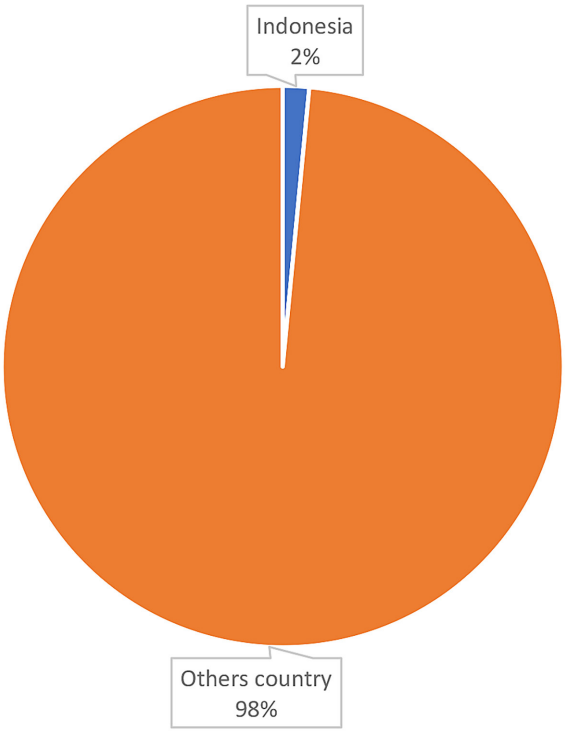

Figure 4. Indonesia vs others country in food waste impact on climate change literature

and human population (Fig. 5) (Moe et al., 2013). There is already an article discussing the comparison of food waste generation in Finland, Denmark, Norway and Sweden, in which the impact on the environment and humans is also explained in a review and the magnitude of the impact has not yet been stated (Gjerris & Gaiani, 2013). That is different from the article published in 2023, and it discusses one type of food waste and the risk of its impact on the environment, which is shown through several impact categories (Abu-Bakar et al., 2023). Apart from that, it also discusses how global food consumption can influence global warming in the future (Ivanovich, Sun, Gordon, & Ocko, 2023). Figure 6 depicts the trend of articles published by countries in the world. Indonesia, in this figure, published seven articles. This number is far less than the United Kingdom, which publishes up to 70 articles. Research funding is one of the things that influence it, as it was previously explained. In making this analysis, from 298 articles, only countries with at least five were taken, so only 26 countries were found with more than five articles. This review shows that the United Kingdom, the United States, and Italy are the three countries that have published articles.

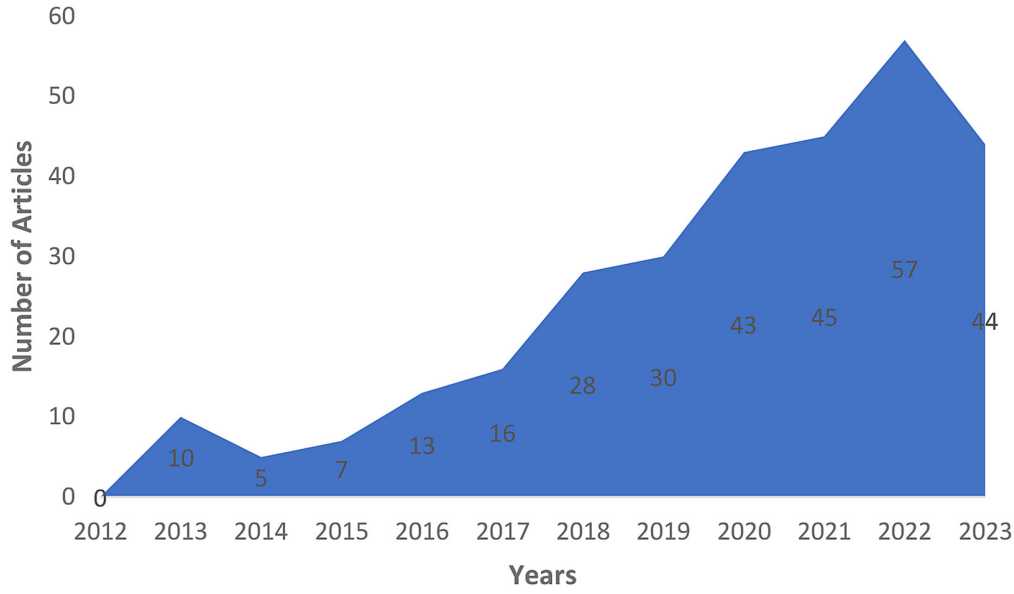

Figure 5. The trend of food waste impact on climate change literature

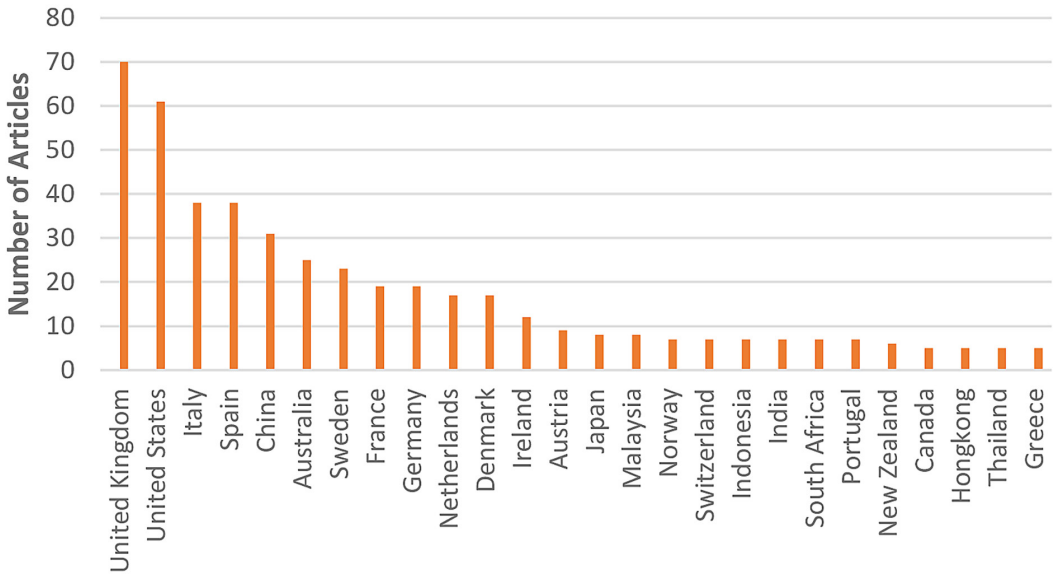

Figure 6. Food waste impact on climate change literature by countries

Seven articles were published in Indonesia based on the network that has been carried out, and based on the results of the author's review, it is known that the cities discussed or discussing this theme are West Bandung Regency, Bogor, Bali, and Jakarta. The four cities in Indonesia discussed are large cities in Indonesia. This may also be influenced by differences in food waste generation in each region as in Figure 3.

Trend analysis discussing the impact of food waste on climate change not only looks at the number of articles published each year and articles published from each country, but also displays the keywords that frequently appear. This analysis is helpful in knowing the topics often discussed and the relationship between each topic discussed. That way, the writer can then find out trending topics that can be written into articles by looking at trends that have existed over the past ten years. Thus, in the future, the articles published will be the articles that can strengthen previous publications or new articles that have never been discussed before.

As in Figure 6 and Table 1, climate change has the highest occurrence value (50) and total link strength (75). On the basis of the analysis of the network results, it can be seen that food waste (which is being discussed regarding its impact on climate change) has a network connection with specific keywords, namely climate change, life cycle assessment, sustainability, and carbon footprint. That shows the suitability of the impact of food waste on climate change, usually analyzed with a life cycle assessment.

The keyword with the lowest total link strength value is ecosystem services with a network link with food security and sustainability. That is related to the discussion of the impact of food waste on climate change. Apart from that, there are keywords with total link strength values of 5, 7, and 9: sustainable diets, resource recovery, food production, bioenergy, renewable energy, and COVID-19. Biomass, environmental

Table 1. Co-occurrences of keywords

Keyword	Occurrences	Total link strength
Climate change	50	75
Food waste	36	59
Life cycle assessment	41	59
Circular economy	23	41
Sustainability	25	31
Anaerobic digestion	13	29
Food security	18	29
Carbon footprint	18	28
Waste management	12	26
Greenhouse gas emissions	13	22
Food	9	20
…	…	…
Ecosystem services	5	3

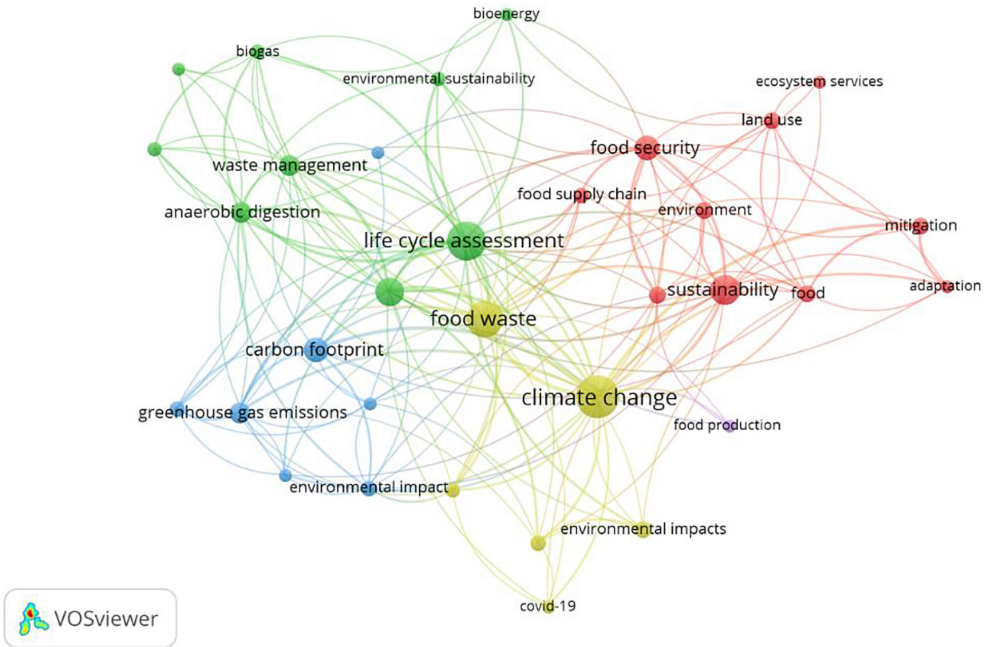

Figure 7. Co-occurrence networks

impacts, food loss, and waste are keywords with a total link strength value of 10. Moreover, many keywords still have a total link strength value of between 11 and 20.

Food waste processing

Considering the environmental impacts of unmanaged food waste, it is necessary to prevent them through processing. In Indonesia, there are several alternative processing methods for food waste, including compost, BSF, biodigester, incinerator, pyrolysis, gasification, and landfilling (Fig. 8). In 2022, in Indonesia, composting is a method that is widely used to process food waste. This method is chosen based on low operational costs and easy maintenance. The results can be bought and sold, and composting in the landfill can be an economical solution to close the waste cycle (Vaverková et al., 2020). The following widely used method is landfilling. Using this method is not recommended. Without processing, it causes landfills to show the presence of heavy metals, which pose a carcinogenic risk to humans (Mary et al., 2023). BSF and biodigester are the methods used to manage food waste in Indonesia. The number of uses of this method is smaller than composting and landfilling. That is due to maintenance and operational costs, which are quite more expensive when compared to composting and landfilling (Abduli, Naghib, Yonesi, & Akbari, 2011). The least used methods for processing food waste in Indonesia are pyrolysis, incineration, and gasification. This method requires relatively high capital and operational costs compared to previous methods. Therefore, only a few regions in Indonesia use these three methods.

Composting

Composting is an alternative method to decompose organic waste, especially food waste. There are several types of composting: vermicomposting, windrow, static pile aeration, and composting in containers (Palaniveloo et al., 2020). The process of processing food waste using the composting method also considers several factors in the success of processing. The factors that determine the success of the composting process include temperature, aeration, type of waste included, and pH (Dhamodharan, Varma, Veluchamy, Pugazhendhi, & Rajendran, 2019). Moreover, each type of composting has a different impact. Windrow composting has an acidification impact of $9.39 \times 10 - 1$ kg SO_2eq while composting with hybrid anaerobic incorporation has a human toxicity impact of 3.47×10 kg $1.4 - DB$ eq (Al-Rumaihi, McKay, Mackey, & Al-Ansari, 2020).

Black soldier fly

BSF is an alternative food waste processing that can be a solution for decomposing waste

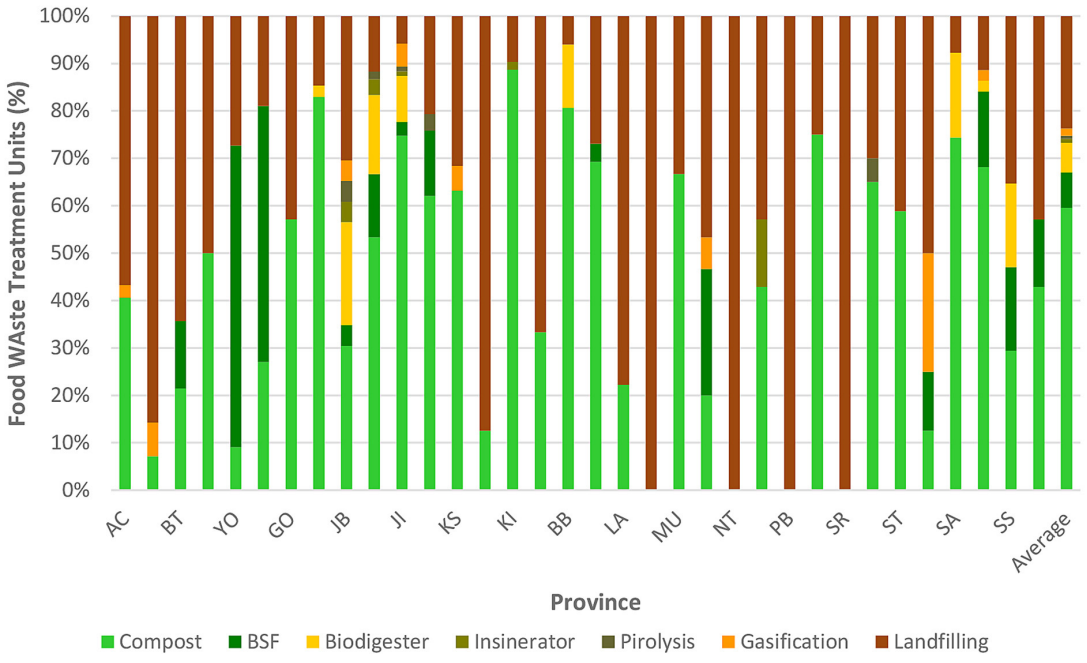

Figure 8. Food waste processing in Indonesia

by utilizing insects in their life process as larvae (Ojha, Bußler, & Schlüter, 2020). Apart from the food waste processing process, when using BSF, it is also necessary to pay attention to the life cycle of BSF larvae: egg – larva – prepupa – pupa – adult insect (Surendra et al., 2020). Ojha et al. (2020) also explained that this method efficiently breaks down several tons of food waste into valuable products such as animal feed and fertilizer. Even though it is competent in processing waste, BSF also impacts global warming by 0.281 kg CO_2eq (Kusumaningtiar, Vionalita, & Swamilaksita, 2023).

Biodigester

Biodigester is an alternative food waste processing method that is generally combined with waste from wastewater treatment plants (WWTP), activated sludge (WWTP), and activated sludge (Guimaraes, Maia, & Serra, 2018; Lee et al., 2019). Using a biodigester with combined processing of organic waste, wastewater, and biofuel production can reduce costs because the process is simultaneous (Mendieta, Castro, Escalante, & Garfí, 2021). In this method, methane gas production, considered an environmental pollutant, is used as biofuel (Rahman, Lee, Tamiri, & Hong, 2018).

Incineration

Incineration is a waste processing method that can reduce the amount of organic waste generated, especially food waste, by burning. This method is the most effective way to deal with waste generation due to the significant volume and weight reduction effect (Jiang, Zhao, & Yan, 2022). A separate drying process before burning creates a more significant economic burden (Mayer, Bhandari, Gäth, Himanshu, & Stobernack, 2020). On the basis of studies, processing waste by incineration will emit 3,688 kt-CO_2eq (Wang & Nakakubo, 2020).

Pyrolysis

Pyrolysis is a method of processing food waste using a thermochemical method that is easy to use and converts it into biofuel, biochar, or briquettes (Elkhalifa, Al-Ansari, Mackey, & McKay, 2019). However, this technology has a few obstacles in the process in the form of a need for standard processing procedures, considering the

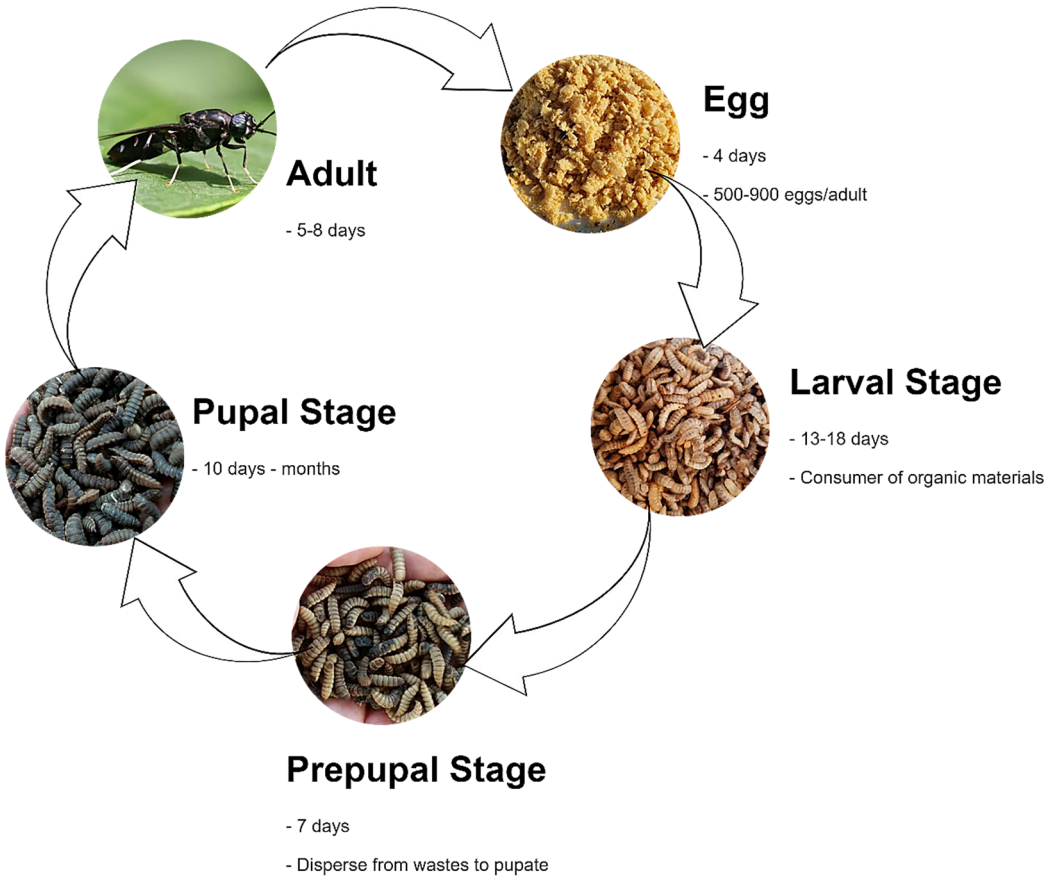

Figure 9. Life cycle of black soldier fly

diverse characteristics of food waste in Indonesia (Pour & Makkawi, 2021). The process also still produces the emissions that have the potential for global warming, ranging from -470 kg CO_2eq/t to -200 kg CO_2eq/t (Cheng, Luo, & Colosi, 2020).

Gasification

Processing food waste using the gasification method is a process of converting food waste into hydrogen. The efficiency of this processing is 64.86%, and the hydrogen production capacity from food waste is 1.2 t/hour H_2 (Xu et al., 2022). The process is also influenced by several factors, such as temperature, time, and concentration (Chen et al., 2020). This gasification method still impacts the environment with a global warming potential of 0.07 kg CO_2eq (Safarian, Unnthorsson, & Richter, 2020).

Landfilling

Landfilling is the most popular waste processing method because its costs are relatively low, but it has side effects on hygienic, social, and environmental issues (Vaverková, 2019). The accumulation of food waste in landfills contributes to a more significant impact on the environment. Every ton of waste produces -218 kg CO_2eq (Moazzem, Wang, Daver, & Crossin, 2021). Meanwhile, in Europe, the results of waste accumulation influence climate change values ranging from 124 to 841 kg CO_2eq (Sauve & Van Acker, 2020).

BSF performance for food waste processing

BSF, or the Latin name *Hermatia illucens*, is a detritivore insect (Surendra et al., 2020) that can grow and decompose various organic wastes, such as livestock manure, human faeces, household organic waste, food waste, agricultural waste, vegetable waste (Singh & Kumari, 2019). Specifically for food waste, BSF can decompose restaurant, fruit, vegetables, household, bread, canteen, and fish waste (Gold et al., 2020; Lopes, Lalander, Vidotti, & Vinnerås, 2020; Surendra et al., 2020). Please note that BSF decomposes organic waste during its life phase (Figure 9). The BSF phase that can help reduce the amount of organic waste in the world is the larval phase, so it is often referred to as Black Soldier Fly Larvae (BSFL) (Surendra et al., 2020). The growth and proliferation of BSF is influenced by several things such as temperature, pH and substrate characteristics (Meneguz et al., 2018; Pliantiangtam, Chundang, & Kovitvadhi, 2021). The tropical climate in Indonesia supports food waste processing using BSF, but the system needs to be maintained and monitored so that BSF larvae can survive and develop. In Indonesia, there are quite a lot of areas that process food waste using BSF and can describe the amount of waste generated. For example, the Wonorejo BSF Processing Unit in Surabaya City can process 40-50 tonnes/year, and the Bratang and Menur Units can process 1-7 tonnes/year of FW (Farahdiba et al., 2023). The ability of BSF to decompose organic waste, especially food waste, has also been proven in waste contaminated with bioplastics in food packaging (Grossule, Zanatta, Modesti, & Lavagnolo, 2023). It has been revealed that 40,000 BSFL can process 60 kg of organic waste with a land requirement of around 1 m^2 (Smetana, Schmitt, & Mathys, 2019). The food waste processing process, with a total of 10 tonnes, can decompose within 12 days and produce 3,346 kg of frass (Salomone et al., 2017).

Mitigation effects

There are many food waste processes in Indonesia, including BSF. This paper shows the

Table 2. Global warming potential from food waste treatment

No.	BSF (kg CO_2eq)	Composting (kg CO_2eq)	Landfilling (kg CO_2eq)	Reference
1.	35	111	NA	Mertenat, Diener, and Zurbrügg (2019)
2.	41.42	99	1243	Ferronato et al. (2023)
3.	38.6	60	1182	Mondello et al. (2017)
4.	17.36	NA	NA	Guo, Jiang, Zhang, Lu, and Wang (2021)
5.	0.38	NA	NA	Ermolaev, Lalander, and Vinnerås (2019)
6.	6.687	NA	NA	Nugroho et al. (2023)
7.	3.2	NA	NA	Salomone et al. (2017)

impacts of processing food waste using other methods. Food waste processing in Indonesia has contributed to reducing greenhouse gas emissions, estimated at 10.73 Gg CO_2eq/year by 2030 (Budihardjo, Humaira, Ramadan, Wahyuningrum, & Huboyo, 2023). The different numbers in Table 2 show the impact on global warming of food processing using the BSF, composting, and landfilling methods. In this case, landfilling has a more significant figure when compared to BSF and composting. The different global warming potential values for each type of processing indicate a form of climate change mitigation due to food waste. It can be seen that the global warming potential value of the BSF method is much less when compared to other methods, which means that the form of mitigation from processing food waste using the BSF method is the greatest. Compared to composting and open piling, waste processing with BSF can reduce greenhouse gas emissions (CH_4, N_2O, and NH_3). Therefore, it can help mitigate the greenhouse gas emissions that cause climate change (Pang et al., 2020).

If the global warming potential resulting from processing with BSF is compared with composting and landfilling, it has the lowest value (see Table 2). Table 2 shows that processing food waste using BSF can prevent climate change through a global warming potential of 1,201.58 kg CO_2eq (Ferronato et al., 2023). This value is also not much different when compared to the opinion of Mondello et al. (2017) that the mitigation that can be done from BSF processing is 1,143.4 kg CO_2eq. This value compares food waste processing using the BSF and landfilling methods. Another mitigation measure that can be applied is reducing the GWP value by 76 kg CO_2eq, which is the difference between the GWP value of the BSF method and the composting method (Mertenat et al., 2019). Other research also shows that processing food waste using the BSF method has a low global warming potential value, no more than 10 kg CO_2eq.

CONCLUSION

On the basis on the latest research and progress in mitigating the impact of food waste through processing using the BSF method, the following are recommendations and future research directions to be able to develop research studies on reducing the environmental impact that has the potential for climate change due to food waste by comparing the BSF processing method with the other waste processing method. Further research is needed to optimize the magnitude of the impact of mitigating food waste processing using the BSF method on potential climate change in Indonesia. There is still a need for more research in Indonesia, so the data obtained is still small, and references are still taken from countries worldwide. With the development of this research, the Indonesian government and society can find out more about how significant the impact of climate change is from food waste and the magnitude of the impact after processing food waste.

CONCLUSIONS

Climate change is one of the consequences of the large amount of waste generated worldwide, especially in Indonesia. One of the human activities that can cause climate change is food waste. It contains the potential for global warming as a cause of climate change. Processing food waste using the BSF method is a form of mitigation of the impact of food waste. It is known that the mitigation of the impact of food waste through processing using the BSF method is 1,201.58 kg CO_2eq and 1,143.4 kg CO_2eq when compared to landfilling and 76 kg CO_2eq when compared to the composting method. The reduced GWP value due to processing food waste using the BSF method is a form of mitigation for the current climate change. In the future, this research will be helpful in directing the government and society to prevent a more significant impact on climate change due to the generation of food waste in Indonesia and the world.

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