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Global Warming Mitigation Innovation Through Household Waste Management Becomes Eco-Enzyme: A Review

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Abstract: The dumping of fruit and vegetable waste into landfills contributes to an increase in methane gas that contributes to global warming. Waste materials in the form of fruits and vegetables can be used and processed into eco-enzymes. Fermented waste enzymes have a variety of benefits and add value to materials that have been tended to be wasted. This environmentally friendly enzyme has been utilized ranging from disinfectants, floor cleaners, dishwashers to liquid organic fertilizers. The production of eco-enzymes in addition to being able to reduce the volume of household waste, also contributes to the reduction of methane gas. During the fermentation process produces O_3 (ozone) which is beneficial in maintaining ozone content in the atmosphere. This means that eco-enzyme production becomes an innovation in mitigating global warming from the household level. The manufacture of eco-enzymes is an effort to provide economic value to waste that has a positive impact on the environment and is a step to maximize the utilization of natural resources better known as circular economies. The advantages of eco-enzyme production in the short term are the ability to maximize raw materials and provide economic value and reduce the cost of handling household waste.

Keywords: Eco-enzyme; Global warming; Innovation; Mitigation; Waste management

Introduction

The increasing amount of waste generated due to urbanization, population growth, and improving lifestyles is a major concern for many developing countries. The trend in waste generation shows a growth rate of 0.1343 million tons per year (Shams et al., 2017). Developing countries are adopting policies to reduce the negative impacts of the large amounts of waste generated by rapidly accelerating industrialization and urbanization. However, these actions are still far from establishing procedures that can meet society's needs, especially regarding urban solid waste management (Batista et al., 2021). Government-based solutions are only chosen by educated people. Lastly, individuals with the highest environmental awareness and effort prefer to pay, while those who are less environmentally conscious prefer government action (Triguero et al., 2016).

The demographic boom caused the centralized waste management system to be no longer adequate. Efforts to process and use waste become a solution and step to build the responsibility of waste producers in order to be responsible for their own waste. Jouhara et al. (2017). Governance innovation is needed by involving various stakeholders to transform waste into useful and economically valuable products (Abdillah, 2023).

Households are one source of waste, where low-income households tend to produce more waste than middle- or high-income households (Karim & Nawshin, 2014). Household waste has a composition of organic and inorganic types. Organic types are in the form of leaves, food waste, fruit residues, and wood. While

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inorganic types are in the form of plastic, paper, metal, rubber, styrofoam, and cloth (Septiningtiyas et al., 2018). The rate of household waste deposits for residential areas is an average of 0.271 kg/person/day (Ratya, 2017).

Waste management innovation at the household level is needed to have a positive effect on society (Hayat & Zayadi, 2018). Composting is a way of managing household waste that has been commonly done. Composting methods have been one of the solutions to overcoming the problem of organic waste. Composting is seen as a fairly economical and efficient technique among other existing management (Maskey & Singh, 2017). Waste processing efforts not only reduce the amount of waste but can also produce recycled products and also produce safe and low-emission energy (Karim & Nawshin, 2014).

Waste management such as utilization, recycling, and reuse are simple techniques that can be done to reduce disposal in landfills (Sarbassov et al., 2019). Recycling household waste of them can be done by making it an eco-enzyme. This approach will reduce the volume of waste and produce environmentally friendly multipurpose liquids that can be used as other cleaners, equipment washers, for gardening, and others (Vama & Cherekar, 2020).

Efforts to utilize waste in eco-enzymes are the first step in implementing zero waste at the household level. The term zero waste has the meaning of an ethical, economical, effective and forward-thinking concept where people can change their lifestyle and habits to imitate natural cycles, where all discarded materials are designed to become resources that can benefit others (Bogusz et al., 2021). Zero Waste is a good solution choice to minimize the increase in solid waste. However, in order to minimize solid waste, many efforts still need to be made in the future (Song et al., 2015). Zero residue waste management is a holistic waste management concept that views waste as a resource. The zero waste strategy can be applied to companies, communities, industrial sectors, schools, and households because it includes many stakeholders, not only environmental stakeholders but also technological aspects (Saplanca & Brigita, 2019).

Eco-enzyme production not only helps reduce waste volume but also reduces the use of artificial chemical products that are not environmentally friendly. The use of eco-enzymes will reduce household operating costs. Globally producing eco-enzymes is a form of contribution to climate change mitigation. Production at the household level indirectly becomes a form of household contribution to climate change mitigation efforts. Mass production efforts are very possible because raw materials are always available both at the household level and on an industrial scale.

Method

Article preparation is based on an information review approach through literature studies. A literature study or literature review can be a simple summary that has an organizational pattern, through the incorporation of summary and synthesis (Ramdhani et al., 2014). Literature studies have a fundamental role in uncovering theories or arguments that support statements, establishing and providing clear boundaries, and defining and clarifying the main concepts to be used in the empirical study section (Nakano & Muniz, 2018).

The information or theories gathered in this study relate to household waste, fruit and vegetable waste, and eco-enzyme manufacturing techniques and their impact on climate change mitigation efforts. Information and theory were obtained through an online search of scientific journals published between 2014-2023. Scientific journals are accessed through https://scholar.google.co.id/ site address using several keywords such as waste management, household waste, eco-enzyme, and climate change mitigation.

The data and theories collected are then grouped to perform mapping to make it easier to perform analysis. The next step is to combine theories that are aligned to bring up a research statement. The results of this literature study are expected to contribute and provide additional information to conduct research and as a basis for exploring problems related to the use of eco-enzymes. This study is also expected to be a reference in household waste processing and climate change mitigation efforts at the household level.

Result and Discussion

The approach that can be done in the face of global warming and climate change is to make adaptation and mitigation. Mitigation is becoming an important technical practice in the face of growing global warming (Zhao et al., 2018). In line with mitigation, adaptation efforts are also carried out on an ongoing basis. Successful adaptation depends not only on the availability of good information about climate change but also on the ability to implement and modify actions over time (Yulandhika & Nugrahanti, 2014).

Greenhouse gas emissions from the waste sector have long been accepted as an important component of climate change mitigation efforts due to the significant radiation pressure on methane (CH_4) production from municipal landfills and other emissions from waste management processes (Powell et al., 2018). About 90% of waste is disposed of in landfills which can release large amounts of greenhouse gases, especially methane gas and nitrous oxide gas, due to anaerobic decomposition of organic materials (Bong et al., 2016).

Effective waste management mitigates negative impacts on health and the environment, conserves resources, and improves urban livability. Meanwhile, unsustainable waste management practices, which are exacerbated by rapid urbanization and financial and institutional limitations, hurt public health and environmental sustainability (Abubakar et al., 2022).

Alternative strategies are needed to address climate change, including individual approaches to significant social change (Becker & Sparks, 2018). The selection of alternative means is a necessity because conventional mitigation is not enough to realize the targets set out in the Paris agreement. Moreover, conventional mitigation technologies focus on reducing fossil-based CO_2 emissions (Fawzy et al., 2020). Initiative in the face of climate change is essential to integrate human interests and environmental sustainability to expand existing mitigation strategies (Becker & Sparks, 2018).

Eco-Enzymes and Their Development

Eco-enzyme is an organic compound in the form of a complex solution resulting from the fermentation process of kitchen waste materials in the form of fruit peels and vegetable residues. The term Eco-enzyme was coined by Dr. Rosukon Poompanvong, a founder of the Organic Agriculture Association, Thailand who conducted research since the 1980s (Muliarta & Darmawan, 2021). A Naturopathy researcher from Penang, Malaysia, Dr. Joean Oon then introduced the term more broadly (Novianti & Muliarta, 2021).

Eco-enzymes are generally dark brown liquids that are fermented from the rest of the vegetables, fruit, and fruit peels. The composition of the manufacturing material consists of waste, water, and sugar in a ratio of 3: 10: 1 (Vama & Cherekar, 2020). The fermentation process to produce eco-enzyme fluids generally takes 3 months. Fermentation produce gas in the form of ozone gas (O_3) (Davenport et al., 2019). Other results are NO_3 (Nitrate) and CO_3 (Carbon trioxide) needed by the soil as nutrients (Utpalasari et al., 2020).

Eco Enzyme liquid is an acetic acid liquid (H_3COOH), which can kill germs, viruses, and bacteria. Contains enzyme lipase, trypsin, and amylase (Utpalasari et al., 2020). The characteristics of waste enzymes generally have a pH of about 3.07 with a BOD concentration of about 87.53 mg/l (Galintin et al., 2021). Acidic pH levels are indicators of the high content of organic acids, in the form of acetic acid or citric acid (Etienne et al., 2015). Fermentation time affects the color, aroma, and pH of eco-enzymes. The content of alcohol and acetic acid is the result of bacterial metabolic processes that exist naturally in the rest of fruits and vegetables (Rusdianasari et al., 2021).

The challenge so far there is no standard of eco-enzyme maturity, so it is feasible and safe to use. Generally, eco-enzymes are said to mature if they have passed the fermentation process for 3 months. Rahayu et al. (2021) experimented to accelerate the fermentation process by adding yeast. Fermentation with a maximum time of 10 days produces eco-enzymes with an alcohol content of 60-70% and a pH reached below 4.0. The resulting waste enzyme is claimed to have the potential to be a bio-disinfectant.

The production of these environmentally friendly enzymes can be part of the step of recycling at the household level. Reviewed waste management will help reduce waste volume and have a positive impact economically (Vama & Cherekar, 2020). Eco-enzyme production is also a part of realizing a clean environment and efforts to implement zero waste (Hemalatha & Visantini, 2020).

The use of different types of fruit and vegetable waste shows differences in enzyme activity and antimicrobial activity. The resulting enzyme exhibits the activity of antimicrobial properties with Gram-positive and Gram-negative bacteria (Neupane & Khadka, 2019). Enzymes such as protease, lipase, carbohydrase, tannase, and phytase are known to produce bioactive compounds. Enzymes from various sources such as plants, animals, and microbes including microorganisms from extreme habitats have demonstrated the ability to catalyze the production of bioactive compounds (Chourasia et al., 2020).

Availability of Raw Materials

One-third of global food production that human consumption consumes is lost or wasted each year. The loss of natural resources that should be consumed by humans along the food supply chain has a negative impact on food security (Nicastro & Carillo, 2021). The lack of food waste mixed in solid waste, especially in urban areas is one of the environmental problems. The decomposition process of food waste releases carbon dioxide and methane into the atmosphere and causes a greenhouse effect (Galintin et al., 2021).

Food processing contributes to the production of waste that tends to be disposed of in landfills. The fruit and vegetable processing industry became one of the largest and fastest-growing segments in the world market, the industry commercialized agricultural production with various products such as juices, jams, and was followed by cereal industry products such as chocolate, and beer (Del Rio Osorio et al., 2021). The fruit processing industry produces a large number of byproducts or waste. The inedible part of fruits and vegetables including skin, pods, seeds, peels, and others reaches about 10-60% of the total weight of fresh produce. Such waste gives rise to increased disposal and potentially severe pollution problems and represents the loss of biomass and valuable nutrients (Mani et al., 2018).

Fruit and vegetable waste occurs throughout the supply chain and varies greatly depending on processing (Omre et al., 2018).

A large amount of waste in liquid and solid forms are produced in the fruit and vegetable processing industry, which contains many reusable substances with high value with great economic potential (Kuyu & Gowe, 2015). Fruit and Vegetable processing waste is rich in organic matter, phytochemicals, and compounds with nutraceutical properties (Mani et al., 2018). Fresh fruits and vegetables contribute almost 50% of the food wasted by households. According to national studies conducted in EU countries, fresh fruits and vegetables contribute almost 50% of food waste generated by households (De Laurentiis et al., 2018). Skin waste generated from the fruit and vegetable industry as well as household kitchens in large quantities has caused great nutritional, economic losses, and environmental problems. The processing of fruits and vegetables produces considerable waste, reaching 25–30% of the total product (Kumar et al., 2020).

Failure or inability to save and reuse these fruit and vegetable waste materials economically impacts unnecessary waste and the depletion of natural resources (Kuyu & Gowe, 2015). Fruit and vegetable waste can be utilized in producing Eco-enzymes, so it is environmentally friendly and contributes economically. This enzyme has been widely used in household environments, especially in Southeast Asia and Japan (Tong & Liu, 2020). The possibility of creating alternative processes to benefit from the waste of materials should be considered. Most of the waste during the handling and processing of fruits and vegetables still consists of several important native plant materials, such as skin, fruit seeds, leaves, stems, bark, and roots (Kuyu & Gowe, 2015).

Mitigation Innovation through Household Waste Management

Households are one of the sources of waste that have a composition of 48% organic matter and 33% inert material. Inert is generally sand produced by household sweeps on unpaved surfaces, especially in low-income areas (Monney et al., 2015). The volume of waste generated by one family can be measured by looking at indicators of family size and income (Maskey & Singh, 2017). A small portion of the resulting garbage is still thrown into nearby bushes. This bad habit can trigger the spread of disease, so it needs intensive health counseling efforts (Monney et al., 2015).

Poor waste disposal habits have hampered progress towards integrated waste management at the household level. Knowledge of current practices and perceptions of household waste management is necessary for accurate decision-making in the direction of a more sustainable approach (Fadhullah et al., 2022). Masrida (2017) revealed that waste management efforts face many challenges because the waste deposits produced by producers and consumers are getting bigger. Garbage will generally come down to landfills. According to Jouhara et al. (2017), the population explosion has an impact on the ability of a centralized waste management system that is no longer adequate. Waste processing and utilization strategies are solutions and steps to build the responsibility of waste producers to be responsible for their waste.

Households are one source of waste, where the proportion of waste coming from low-income households tends to be higher than middle- or high-income households (Karim & Nawshin, 2014). The composition of household waste for organic types is in the form of leaves, food waste, fruit waste, and wood. While inorganic types are in the form of plastic, paper, metal, rubber, styrofoam, and cloth (Septiningtiyas et al., 2018). According to Ratya (2017), the rate of household waste generation in residential areas is on average 0.271 kg/person / day.

Waste management innovation at the household level is needed to have a positive effect on society (Hayat & Zayadi, 2018). Household waste management that has been commonly done by composting. Waste processing efforts not only reduce the amount of waste but can also produce recycled products and also produce safe and low-emission energy (Karim & Nawshin, 2014). Composting has been one of the solutions to overcoming the problem of organic waste. Composting is seen as a fairly economical and efficient technique among other existing management (Maskey & Singh, 2017).

Waste management practices such as utilization, recycling, reuse, and recovery are simple techniques that can be done to reduce disposal in landfills (Sarbassov et al., 2019). Innovation in recycling household waste can be done by becoming an eco-enzyme. This approach will reduce the volume of waste and produce environmentally friendly multipurpose liquids that can be used as floor cleaners, equipment washers, gardening and other benefits (Vama & Cherekar, 2020).

The production of eco-enzymes through the fermentation of waste leftover fruits and vegetables is a solution to minimize and reduce waste from the source. This effort is also an alternative method of biologically organic waste treatment (Verma, 2014). Sustainable eco-enzyme manufacturing in large quantities, in a short time, and at a low cost is an alternative solution to meet the needs of the increasing amount of industrial waste (Arun & Sivashanmugam, 2015b). Moreover, eco-enzymes can dissolve dissolved organic compounds into dissolved organic compounds (Arun & Sivashanmugam, 2015a). This waste enzyme is useful in lowering proteins, carbohydrates, and lipids in the decomposition process due to the presence of protease, amylase, and lipase enzymes (Arun & Sivashanmugam, 2017).

Processing waste into eco-enzymes is the first step in realizing zero waste at the household level. The basic concept of zero waste concerns the responsibility of waste producers to reduce waste, reuse, and recycle (Muliarta & Darmawan, 2021). Zero waste on the other hand is also an effort to manage waste in zero or non-existent conditions (Abidin et al., 2022). The concept of Zero Waste encourages consumers to reduce the consumption and recycling of acquired goods and materials, which economically and socially can bring regression under certain circumstances, which is detrimental to environmental progress (Seberini, 2020).

The manufacture of waste-based enzymes is part of the step of recycling the household environment. In addition to helping reduce the volume of waste also provides economic benefits (Vama & Cherekar, 2020). Eco-enzyme production on the other hand is part of realizing a clean environment and efforts to realize zero waste (Hemalatha & Visantini, 2020).

Eco-Enzyme Production and Methane Emission Minimization

Solid waste production is estimated at 0.4-1.62 kg /capita/day, with the composition of organic materials ranging from 42 to 80.2%. This condition is followed by a trend of increasing plastic waste that has no separation at the source, complicated collection processes, open landfills, and no control of gas emissions and Lindi in landfills (Dhokhikah & Trihadiningrum, 2012). The issue of environmental pollution as a result of the mismanagement of waste has become a global issue. Open disposal and open burning practices are sewage and landfill treatment systems implemented so far, especially in low-income countries (Ferronato & Torretta, 2019). Solid waste disposal sites in urban areas and their management are a challenge around the world. The main problem is the high content of the organic waste which has an impact on greenhouse gas emissions (Beltran-Siñani & Gil, 2021).

The use of waste as a resource can offer a variety of environmental benefits, including climate change mitigation. Reuse of waste by utilizing technology or changing behavior offers waste management that is beneficial to the environment and climate (Vergara, 2017). Composting is one of the preferred methods for reducing biodegradable organic matter. Composting can reduce more than 50% of organic matter on the spot. Some developing countries in Asia, such as India, the Philippines, and Thailand are trying to convert solid waste into energy (Dhokhikah & Trihadiningrum, 2012). Reduction of waste generation and energy exploitation from waste results in an indirect reduction of greenhouse gas emissions through conservation of raw materials, improvements in energy and resource efficiency, and reductions in fossil fuel use (Bogner et al., 2008).

Greenhouse gas emissions from waste management in developing countries are expected to increase exponentially. Emissions dominate due to methane released by landfills (Das et al., 2019; Zuberi & Ali, 2015). CH_4 from landfills and wastewater collectively accounted for about 90% of the waste sector's emissions, or about 18% of global anthropogenic methane emissions estimated to be about 14% of the global total in 2004 (Ramachandra et al., 2015.). Almost every step of waste management produces greenhouse gas emissions, therefore, it is very important to design the right processing method from source to a disposal site to reduce its environmental impact (Kristanto & Koven, 2019).

About two-thirds of global greenhouse gas emissions are directly and indirectly linked to household consumption, with a global average of about 6 tCO_2eq/cap. Household carbon footprint can be mitigated by the availability of low-carbon consumption options (Ruohomaa & Ivanova, 2019). The carbon footprint of food waste is estimated at 3.3 Gt CO_2e. About 54 percent of food wastage occurs during production practices, post-harvest handling, and storage, while 46 percent of this occurs at the processing, distribution, and consumption stages (Dickie et al., 2014). Each individual plays a role in efforts to reduce waste. Prevention should be emphasized because preventing waste is more profitable in everything than following it. The less food wasted, the less impact on the environment and the more awake the amount of food (Seberini, 2020).

Conventional mitigation efforts are insufficient to meet the target of limiting global temperature rise to 2°C by 2100, following the Paris agreement. Alternative efforts have been made to limit temperature rise to 1.5 °C (Fawzy et al., 2020). Climate change adaptation strategies through multidimensional and multi-sectoral approaches have become imperative as a result of gaps between developed and developing countries in terms of limited capital resources and expertise (Onoja et al., 2017). Processing waste from the source directly, by processing it into eco-enzyme is part of reducing waste disposal in a landfill. Landfill waste piles have been producing methane gas triggering greenhouse gases that have an impact on climate change. Rini et al. (2020) mentioned that the garbage pile contributes to greenhouse gas emissions in the form of CH_4 gas which has a potential for heating global 21 times greater than carbon dioxide (CO_2).

Eco-Enzymes and Circular Economy

Generally, garbage is still viewed as a "problem" rather than a resource. The issue of waste management in some countries seems to be driven more by political factors and the decentralized nature of waste management with multi-level management and responsibility (Hemidat et al., 2022). The fruit and vegetable sector is one of the sources that produce large amounts of waste, which causes environmental impacts and economic problems. Different strategies can be applied to increase fruit and vegetable waste by turning it into value-added products (Plazzotta et al., 2020). Households are also one of the sources of waste, where the user is still minimal. Household waste tends to end up in landfills (Muliarta & Darmawan, 2021).

New approaches to recycling and the natural reuse of waste into eco-enzymes will help reduce fruit waste and be environmentally friendly, and economical with multipurpose applications (Vama & Cherekar, 2020). The conversion of waste into value-added products in addition to being potentially profitable also creates a clean environment (Hemalatha & Visantini, 2020). Waste utilization represents a significant potential for the recovery of resources from the flow of organic waste through products such as biogas, solid fuels, insect larvae, and compost. In addition to contributing to energy and food safety, this product can replace traditional energy sources, fertilizers, and feed (Ddiba et al., 2022).

Efforts to process fruit and vegetable waste into eco-enzymes at the household level can be one form of climate change mitigation at the household level and at the same time a form of circular economic implementation. According to Jacobs et al. (2022), a circular economy is an attempt to reinterpret material recovery by promoting the waste design of products, retaining materials for reuse, and emphasizing key universally accepted elements for sustainability. Stankevičienė et al. (2020) revealed that a circular economy is based on environmental, economic, and social dimensions that aim to ensure sustainable development at every step of product creation, transformation and conversion by creating a closed-loop economy.

A new vision of how waste management systems can be transformed into circular economies is needed, for a paradigm shift from linear economic models to circular economic models (Hemidat et al., 2022). The transition to a circular economy remains a challenge. It is important to know circularity and sustainability, as they are two different segments. So, a circular economy can only be achieved from a long-term perspective (Di Vaio et al., 2022). Some studies assessing the potential of circular economies so far have mostly been conducted in high-income countries, but regions in low- and middle-income countries have different challenges when developing circular economies (Ddiba et al., 2022).

Processing waste into eco-enzymes at the household level can be a new source of income because, in addition to reducing waste treatment costs, it also reduces the cost of household needs. This small step can be a circular economic model at the household level. Xavier et al. (2021) stated that the circular economy is a new business model, and increases the level of sustainability for citizens through solutions that integrate practices within the economic bloc. According to Ruohomaa et al. (2019), the development of a circular economy should not be calculated in short business profits but seen as a long-term strategic investment that will bring long-term benefits to various sectors of society. Khatiwada et al. (2021) stated that the concept of circular economy can contribute to a paradigm shift in the transformation of traditional linear approaches that do not support the concept of reuse, and recycling.

The circular economy is a concept that seeks to promote a sustainable way of life, where resources are used more efficiently and maintained in the economy for as long as possible (Hahladakis et al., 2020). Maximum capacity and profitability in a circular economy must be designed in the face of increased demand and availability of natural resources (Di Vaio et al., 2022). Producing eco-enzymes is an effort to maximize raw materials or natural resources and provide economic value or added value to a material.

The paradigm shift from a linear economic model to a circular economic model is time to do so. Lack of planning, lack of proper disposal, inadequate collection services, improper use of technology, inadequate financing, and limited availability of trained and qualified personnel lead to non-maximal and sustainable management (Hemidat et al., 2022). Waste accumulation is an acute problem in all countries. Waste has an impact on soil destruction, quality of life of the population and damages the vital functions of all living organisms (Sultanova et al., 2021). Determining an economically effective and environmentally safe approach to waste reuse, recycling and reduction is an important goal, where environmental assessment of waste components and assessment of its long-term impact on the environment remain priority objectives (Guman & Wegner-Kozlova, 2020).

Circular economy is an integrated resource management system that aims to improve the efficiency of natural resource utilization and reduction of emissions and waste generation (Khatiwada & Golzar, 2021). Economic activity, in terms of circular economy targets the conservation of maximized product value, efficiency of materials and resources, and minimizing the amount of pollution emissions and waste produced simultaneously (Guman & Wegner-Kozlova, 2020). The benefits of applying the circular economy not only produce a positive impact economically, but at the same time contribute to reducing the burden of waste in landfills which has caused many environmental and social problems (Purwanto & Prasetio, 2021).

Residential waste management can be a simple circular economic model applied in various urban housing areas (Purwanto & Prasetio, 2021). The concept of a circular economy offers a path to sustainable growth, good health, and decent jobs while saving the environment and its natural resources (World Health Organization, 2018). The conception of a circular economy is the result of sustainable development (Banaite & Tamošiuniene, 2016). This concept is quickly becoming a new model for resilient growth. A circular economy is an economy in which products and materials are recycled, repaired, and reused rather than disposed of, and where waste from one industrial process becomes a valuable input into another (Preston et al., 2019).

The transition to a circular economy requires additional new technologies, infrastructure and innovation, social change, and changes in daily practice (Lehtokunnas et al., 2020). The implementation of the circular economy is trending because of concerns regarding the end of life of some products and the reduction of CO_2 emissions (Caldas et al., 2022). Its implementation has been proposed as a potentially significant catalyst to enhance the current response to the global climate crisis (Romero-Perdomo et al., 2022). Waste management is a circular economic approach that is strongly associated with climate change. Mitigation through waste management is a concrete action to prevent climate change and efforts to achieve sustainable development goals (Stankevičienė & Nikanorova, 2020). Circular economic strategies can contribute to climate change mitigation in terms of reducing greenhouse gas emissions in various sectors (Caldas et al., 2022).

Conclusion

Processing vegetable and fruit waste into eco-enzymes at the household level becomes an innovation or alternative solution to mitigating global warming. Eco-enzyme production is an innovation because in addition to reducing the volume of waste, it also contributes to reducing the production of methane gas produced from piles of organic matter. Making environmentally friendly waste enzymes on the other hand in the fermentation process produces ozone gas which is useful in preventing global warming and climate change. Producing eco-enzymes made from vegetable and fruit waste is a step in maximizing the utilization of natural resources and providing economic value to waste materials. The strategy of optimizing waste into more valuable materials is an effort to build a circular economic paradigm. The pace of eco-enzyme production as part of the circular economy in the short term has benefited through maximum efforts to use raw materials and reduce the cost of handling household waste. The long-term advantage of eco-enzyme production is that it reduces ecological losses from the effects of global warming.

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