



Fruit - Based Bio-Enzymes: An Ecofriendly Organic Sanitizer

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ABSTRACT:

The increasing accumulation of fruit and vegetable waste has become a major environmental concern worldwide. One effective approach to manage this waste is to utilize this waste for the synthesis of bio-enzymes. Bio-enzymes are complex organic substances composed of protein chains (enzymes), organic acids, and mineral salts produced through fermentation of fruit and vegetable waste or their peels. Conventional chemical cleaners and sanitizers often contain harmful chemicals such as chlorine, ammonia, and synthetic surfactants that may cause environmental pollution and health issues including skin irritation and respiratory problems. In contrast, bioenzyme based organic sanitizers are biodegradable, non-toxic, and environmentally friendly. Therefore, organic bio-enzyme cleaners/sanitizers are considered a safer and sustainable alternative to harmful chemical cleaners for household sanitation and cleaning purposes.

KEYWORDS: Bio-Enzymes; Multipurpose; Citrus Peel Waste; Fermentation; Organic waste management; Eco-friendly sanitizer.

INTRODUCTION:

Global food waste generation is estimated to be approximately 1.3 billion tonnes annually, with a significant proportion consisting of fruits and vegetables due to their high moisture content and short shelf life (FAO, 2019). The rapid growth of the global population and urbanization has resulted in a substantial increase in the generation of organic waste, particularly fruit and vegetable waste. Improper management of this organic waste leads to environmental pollution and resource loss. In many developing countries, a significant portion of this waste is disposed of in open dumps or landfills without proper treatment.

India is one of the largest producers of fruits and vegetables in the world and consequently generates a large amount of related waste. It is estimated that India produces approximately 50–60 million tonnes of fruit and vegetable waste annually, which contributes significantly to municipal solid waste generation (Rahman *et al.*, 2021). On average, about 450 g of solid waste is generated per person per day in India, and this amount continues to increase with population growth and changing consumption patterns. Improper disposal of fruit and vegetable waste not only occupies landfill space but also leads to serious environmental concerns.

When fruit and vegetable waste decompose under uncontrolled conditions, it releases greenhouse gases such as methane and carbon dioxide, which contribute to global warming and climate change. In addition, decomposition of organic waste produces foul odors, attracts insects and rodents, and promotes the growth of pathogenic microorganisms that may cause health problems. Leachate produced from decomposing waste can also contaminate soil and groundwater, thereby affecting ecosystems and human health (Nazim & Meera, *et al.*, 2013). Therefore, effective and sustainable management of fruit and vegetable waste has become a major environmental challenge worldwide.

Several approaches have been developed to manage organic waste, including composting, vermicomposting, anaerobic digestion, biofuel production, and the conversion of waste into value-added products. Among these methods, the production of bio-enzymes from fruit and vegetable waste has gained considerable attention as an eco-friendly and sustainable waste management strategy (Patel *et al.*, 2021). Bio-enzymes are natural organic solutions produced through the fermentation of fruit and vegetable waste with water and a sugar source such as jaggery or molasses under anaerobic conditions. During the fermentation process, microorganisms such as bacteria and yeast break down organic matter and produce various hydrolytic enzymes including amylases, proteases, lipases, and cellulases, which help degrade complex organic substances into simpler compounds (Arun & Siva Shanmugam, *et al.*, 2015).

The concept of producing bio-enzymes from organic waste was introduced by Dr. Rosukon Poompanvong from Thailand, who developed the idea of “garbage enzyme” as an environmentally friendly method for managing kitchen waste. Bio-enzymes are complex organic liquids containing enzymes, organic acids, alcohols, and mineral salts formed during the fermentation of organic waste (Novianti & Muliarta, *et al.*, 2021). These bioenzymes possess antimicrobial and cleaning properties, making them suitable for various domestic and environmental applications.

Bio-enzyme-based cleaners use beneficial microorganisms and enzymes to break down organic substances such as grease, stains, and waste materials into smaller molecules. Due to the presence of specific enzymes such as proteases, amylases, and cellulases, these cleaners can effectively remove different types of stains and organic residues. Compared with conventional chemical cleaning agents such as phenyl, bleach, and synthetic detergents, bio-enzyme cleaners are biodegradable, non-toxic, environmentally friendly, and cost-effective, as they are produced from easily available kitchen waste materials (Patil *et al.*, 2019). Therefore, enzyme-based cleaners are often referred to as “green chemicals”.

In addition to household cleaning applications, bio-enzymes have potential uses in wastewater treatment, textile processing, leather industries, food processing, and pharmaceutical applications (Neupane & Khadka, *et al.*, 2019). Some studies have also reported that bio-enzymes possess antibacterial and antioxidant properties, which further enhance their effectiveness as eco-friendly cleaning agents (Joshi *et al.*, 2012). Moreover, the residual biomass obtained after fermentation can be utilized as organic manure for agricultural purposes, promoting sustainable farming practices (Vama & Cherekar, *et al.*, 2020).

Thus, the conversion of fruit and vegetable waste into bio-enzymes represents a sustainable and environmentally friendly solution for organic waste management. This approach not only helps reduce the accumulation of biodegradable waste but also promotes the concept of “waste to wealth” by converting waste materials into useful products that support environmental protection and sustainable development.

BIO-ENZYME AND THEIR ORIGIN:

Definition of Bio-enzyme:

Bio-enzymes, also known as eco-enzymes or garbage enzymes, are complex organic liquids produced through the fermentation of organic waste materials such as fruit and vegetable peels with water and a sugar source such as jaggery or molasses. During the fermentation process, microorganisms including bacteria and yeast break down the organic matter and produce a mixture of enzymes, organic acids, alcohols, and mineral salts. These bio-enzymes contain various hydrolytic enzymes such as amylases, proteases, lipases, and cellulases that help degrade complex organic substances into simpler compounds (Arun & Siva Shanmugam *et al.*, 2015; Rahman *et al.*, 2021; Wei *et al.*, 2020).

The term “garbage enzyme” can sometimes be misleading, as it does not refer to a single purified enzyme but rather a fermented liquid containing a mixture of enzymes and bioactive compounds. Bio-enzymes produced from organic waste are mainly used for environmental applications such as household cleaning, waste management, and wastewater treatment (Tang & Tong, *et al.*, 2011; Rahman *et al.*, 2021). These formulations are considered environmentally friendly and serve as effective alternatives to synthetic chemical cleaners such as bleach and phenyl, which may cause environmental pollution (Arun & Siva Shanmugam, *et al.*, 2015; Jabhade *et al.*, 2022).

History and Origin of Bio-enzymes:

Bio-enzymes were first introduced by Dr. Rosukon Poompanvong from Thailand, who developed the concept of producing enzymes from organic kitchen waste in 2006. She produced bio-enzymes using organic solid waste and named the product garbage enzyme. Although it is referred to as an enzyme, it is not a single purified enzyme in the strict technical sense but rather a complex mixture produced through the fermentation of organic waste materials (Arun & Siva Shanmugam, *et al.*, 2015; Novianti & Muliarta, *et al.*, 2021).

The development of bio-enzymes was inspired by the need to reduce the accumulation of organic waste and transform it into useful products through biological processes. The fermentation process typically involves mixing fruit or vegetable waste with water and a sugar source in an airtight container and allowing it to ferment under anaerobic conditions for several months. During this process, naturally occurring microorganisms convert organic substrates into liquid rich in enzymes and organic acids (Arun & Siva Shanmugam, *et al.*, 2015; Novianti & Muliarta, *et al.*, 2021).

Over time, bio-enzymes have gained global attention due to their eco-friendly nature and wide range of applications. Researchers have demonstrated that bio-enzymes possess antimicrobial properties and can effectively break down organic matter such as grease, stains, and food residues. As a result, they are widely used as natural cleaning agents, odor removers, and wastewater treatment agents (Novianti & Muliarta, *et al.*, 2021; Rahman *et al.*, 2021).

In addition, citrus fruit peels such as orange, lemon, and lime are commonly used in bio-enzyme production because they contain biologically active compounds such as flavonoids and limonene, which exhibit

antimicrobial and antioxidant properties. These compounds enhance the effectiveness of bio-enzymes as ecofriendly disinfectants and cleaning agents (Liu *et al.*, 2012; Wang *et al.*, 2020).

Thus, the development of bio-enzymes represents an innovative approach to convert organic waste into valuable products, supporting sustainable waste management and environmental conservation.

METHODS FOR BIO-ENZYME PRODUCTION:

Bio-enzymes are produced through the fermentation of organic waste materials such as fruit peels, vegetable residues, and other biodegradable wastes. During fermentation, microorganisms convert organic matter into useful products including enzymes, organic acids, alcohols, and minerals. Different methods have been developed to produce bio-enzymes depending on the type of substrate, fermentation conditions, and desired enzyme activity (Arun & Siva Shanmugam *et al.*, 2015; Rahman *et al.*, 2021).

1. Natural Fermentation Method:

The natural fermentation method is the most commonly used technique for producing bio-enzymes from fruit and vegetable waste. In this method, organic waste materials are mixed with a sugar source such as jaggery or molasses and water in the ratio 1:3:10 (sugar: organic waste: water).

The mixture is stored in an airtight container and kept in a dark place at room temperature for about three months. Microorganisms naturally present on the surface of fruit peels initiate fermentation and produce enzymes and organic acids. This method is simple, inexpensive, and suitable for household or small-scale production (Arun & Siva Shanmugam *et al.*, 2015; Novianti & Muliarta, *et al.*, 2021).

2. Yeast-Assisted Fermentation Method:

In this method, a small quantity of yeast (*Saccharomyces cerevisiae*) is added to the fermentation mixture to accelerate the fermentation process. Yeast acts as a biocatalyst that converts sugars into alcohol and organic acids more rapidly than natural fermentation.

The addition of yeast can shorten the fermentation period and enhance enzyme production. This method is often used when faster production of bio-enzyme is required for laboratory experiments or small-scale applications (Janarthanan *et al.*, 2020; Patel *et al.*, 2021).

3. Controlled Microbial Fermentation:

Controlled microbial fermentation involves the use of selected microorganisms such as *Bacillus* species, lactic acid bacteria, or yeast cultures to enhance enzyme production. In this technique, the fermentation conditions including temperature, pH, and nutrient concentration are carefully controlled. The use of specific microbial strains allows better control over enzyme yield and activity, making this method useful for research studies and industrial applications where consistent product quality is required (Mavani *et al.*, 2020).

4. Solid-State Fermentation (SSF):

Solid-state fermentation is a method in which microorganisms grow on moist solid substrates such as fruit peels without free-flowing water. The organic waste material serves as both the nutrient source and support for microbial growth.

This technique is widely used in enzyme production because it provides high enzyme concentration and requires less water and energy. Solid-state fermentation is particularly suitable for utilizing agricultural and fruit processing wastes (Barman *et al.*, 2022).

5. Submerged Fermentation (SmF):

Submerged fermentation involves the growth of microorganisms in liquid media where organic waste materials are dissolved or suspended in water. This process is usually carried out in fermentation tanks or bioreactors under controlled conditions.

Submerged fermentation allows precise control of parameters such as temperature, aeration, and agitation, which improves microbial growth and enzyme production. This method is widely used in industrial biotechnology for large-scale enzyme production (Rusdianasari *et al.*, 2021).

6. Bioreactor-Based Production:

For commercial production, bio-enzymes can be produced using bioreactor systems. Bioreactors provide controlled environmental conditions that enhance microbial activity and enzyme synthesis. Parameters such as oxygen supply, pH, temperature, and nutrient concentration can be monitored and adjusted automatically.

This method enables large-scale production of bio-enzymes for applications in cleaning products, wastewater treatment, and agriculture (Samriti *et al.*, 2019).

FERMENTATION CONDITIONS:

Bio-enzyme is produced through the fermentation of organic waste materials such as fruit and vegetable peels. In the absence of an added microbial culture, the natural fermentation process generally requires three to four months for completion. To accelerate the fermentation process, a biocatalyst such as yeast can be added to the mixture. After preparation, the fermentation setup is kept in a closed container and stored in a dark place at room temperature, allowing microbial activity to initiate the fermentation process (Arun & Siva Shanmugam, *et al.*, 2015; Novianti & Muliarta, *et al.*, 2021).

During the first month of fermentation, alcohol is produced as an intermediate metabolite, which results in a characteristic alcoholic odor. From the second week onward, gases accumulate in the empty space of the container due to active microbial metabolism, indicating that fermentation is occurring. To prevent excessive pressure buildup and to maintain optimal microbial activity, the container lid should be opened once daily during the first week to release the accumulated gases (Janarthanan *et al.*, 2020; Patel *et al.*, 2021).

In the second month of fermentation, the odor gradually changes from alcoholic to acidic, which indicates the formation of acetic acid and other organic acids, along with various beneficial compounds such as minerals and vitamins. The fermentation process continues for approximately three months, after which the bio-enzyme solution is considered mature and ready for further analysis or application (Samriti *et al.*, 2019; Rusdianasari *et al.*, 2021).

Temperature plays an important role in enzymatic activity during fermentation. The optimal temperature range for protease enzyme activity is between 30–50 °C (90–130°F). Bio-enzymes have been reported to exhibit antimicrobial properties, as they can inhibit the growth of several microorganisms including

Escherichia coli, *Pseudomonas aeruginosa*, and *Staphylococcus* species, as well as microbes responsible for food spoilage and mold growth (Mavani *et al.*, 2020; Hasanah *et al.*, 2019).

For the preparation of bio-enzymes from organic waste, the commonly used ratio is 1:3:10 (sugar: organic waste: water). In this mixture, sugar acts as a carbon source that supports microbial fermentation, while organic waste materials such as fruit peels provide substrates for microbial degradation and enzyme production. The amount of reducing sugars naturally present in the waste may vary depending on the type and freshness of the organic material, but the addition of sugar ensures sufficient substrate availability for effective enzyme production during fermentation (Patel *et al.*, 2021; Barman *et al.*, 2022).

APPLICATIONS OF BIO-ENZYME EXTRACT:

Bio-enzyme extracts produced through the fermentation of fruit and vegetable waste have gained significant attention because of their eco-friendly nature and wide range of applications. These solutions contain a mixture of enzymes, organic acids, alcohols, and beneficial microorganisms produced during fermentation. Due to these bioactive components, bio-enzymes exhibit properties such as biodegradability, antimicrobial activity, and the ability to degrade organic matter. As a result, bio-enzymes are increasingly used in household, agricultural, environmental, and industrial applications as sustainable alternatives to chemical products (Arun & Siva Shanmugam *et al.*, 2015; Rahman *et al.*, 2021).

1. Household Cleaning Agent:

One of the most common applications of bio-enzymes is their use as natural cleaning agents in households. Bioenzyme solutions can be used for cleaning floors, kitchen countertops, bathroom tiles, sinks, toilets, and drains. The enzymes present in these solutions, such as proteases, lipases, and amylases, break down organic substances like grease, oil, food residues, and stains into smaller molecules that can be easily removed during cleaning. Unlike chemical cleaning agents such as bleach and phenyl, bio-enzymes are biodegradable and non-toxic, making them safer for human health and the environment. Their enzymatic action continues even after application, providing prolonged cleaning effects (Arun & Siva Shanmugam, *et al.*, 2015; Novianti & Muliarta, *et al.*, 2021).

2. Wastewater Treatment:

Bio-enzymes have been widely studied for their role in wastewater treatment because of their ability to degrade organic pollutants. The enzymes produced during fermentation help break down complex organic compounds such as fats, proteins, and carbohydrates that are commonly present in domestic and industrial wastewater. This degradation process reduces the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of wastewater, which are important indicators of water pollution. By reducing these parameters, bio-enzymes help improve water quality and make wastewater safer for discharge into the environment (Nazim & Meera, *et al.*, 2013; Tang & Tong, *et al.*, 2011).

3. Agricultural Applications:

In agriculture, bio-enzymes are used as soil conditioners and plant growth promoters. When applied to soil, bioenzymes improve microbial activity and enhance the availability of essential nutrients required for plant growth. The organic acids and minerals present in bio-enzyme solutions help improve soil structure and promote healthy root development. As a result, plants show improved growth, increased resistance to diseases, and better crop yields. Additionally, the solid residue obtained after fermentation can be used as organic fertilizer, further supporting sustainable agriculture practices (Sanghvi & Nair, *et al.*, 2019; Vama & Cherekar, 2020).

4. Odor Control:

Bio-enzyme solutions are highly effective in eliminating unpleasant odors caused by decomposing organic matter. The enzymes break down organic compounds that produce foul smells, such as proteins and fatty substances. Due to this property, bio-enzymes are widely used for odor control in garbage bins, sewage drains, livestock farms, and waste disposal areas. By decomposing odor-causing substances rather than masking them with fragrances, bio-enzymes provide a long-lasting and environmentally friendly solution for odor management (Tang & Tong, *et al.*, 2011).

5. Pest Repellent:

Bio-enzymes produced from citrus fruit peels contain natural bioactive compounds such as limonene, flavonoids, and essential oils. These compounds possess mild insect-repellent properties and help protect plants from pests and insects. When diluted and sprayed on plants, bio-enzyme solutions can act as natural pest control agents, reducing the need for chemical pesticides. This makes them particularly useful in organic farming and home gardening (Asikin *et al.*, 2012; Liu *et al.*, 2012).

6. Drain and Pipe Maintenance:

Bio-enzymes are also used for maintaining household drainage systems. Organic waste materials such as fats, oils, grease, and food particles often accumulate in pipes and drains, leading to blockages. The enzymes present in bio-enzyme solutions break down these organic materials into smaller components, preventing the buildup of waste and maintaining smooth water flow in drainage systems. Regular use of bio-enzymes in drains reduces the need for chemical drain cleaners, which can damage plumbing systems and harm aquatic ecosystems (Arun & Siva Shanmugam, *et al.*, 2015)

7. Composting Accelerator:

Bio-enzymes can accelerate the composting process by enhancing microbial activity during the decomposition of organic waste. When added to compost piles, the enzymes help break down complex organic materials such as cellulose, starch, and proteins more efficiently. This results in faster decomposition and improves the quality of compost produced. The use of bio-enzymes in composting systems therefore contributes to effective organic waste management and promotes sustainable recycling of biodegradable materials (Patel *et al.*, 2021).

8. Industrial Applications:

Bio-enzymes have potential applications in several industries due to their ability to break down organic substances. They are used in industries such as textile processing, leather treatment, food processing, and pharmaceuticals. For example, in the textile industry, enzymes help remove impurities and improve fabric quality. In leather processing, enzymatic treatments assist in removing unwanted proteins and fats from hides. These applications help reduce the use of harsh chemicals and make industrial processes more environmentally friendly (Neupane & Khadka, *et al* 2019; Rahman *et al.*, 2021).

9. Environmental Pollution Control:

Bio-enzymes play an important role in environmental protection by reducing the accumulation of organic waste. The fermentation process converts fruit and vegetable waste into useful products, thereby reducing landfill waste and preventing environmental pollution. Additionally, bio enzymes can degrade organic pollutants and contribute to the purification of contaminated environments. This sustainable approach supports the concept of

“waste-to-wealth,” where waste materials are converted into valuable and useful products (Wei *et al.*, 2020; Patel *et al.*, 2021).

10. Antimicrobial and Disinfectant Properties:

Bio-enzymes exhibit antimicrobial properties due to the presence of organic acids, alcohols, and bioactive compounds produced during fermentation. These substances inhibit the growth of certain pathogenic microorganisms, including bacteria responsible for infections and food spoilage. Because of these antimicrobial properties, bio-enzymes can be used as natural disinfectants for cleaning surfaces in households and public spaces. Their use reduces dependence on chemical disinfectants and contributes to a safer and healthier environment (Rahman *et al.*, 2021; Hasanah *et al.*, 2019).

LIMITATIONS OF ORGANIC BIO-ENZYME SANITIZER COMPARED WITH CHEMICAL SANITIZERS:

Although organic bio-enzyme sanitizers are considered environmentally friendly and biodegradable, they have several limitations when compared with conventional chemical sanitizers such as alcohol-based or chlorine-based disinfectants. These limitations may affect their efficiency, stability, and large-scale commercial use.

1. Slower Antimicrobial Action:

Bio-enzyme sanitizers generally act more slowly than chemical disinfectants. Chemical disinfectants such as alcohol or chlorine can rapidly destroy microorganisms within seconds, whereas bio-enzymes mainly degrade organic matter and may require longer contact time to inhibit microbial growth (Vama and Cherekar, *et al.*, 2020; Tang and Tong, *et al.*, 2011).

2. Lower Disinfection Strength:

The antimicrobial activity of bio-enzymes may be weaker compared to strong chemical sanitizers. Chemical disinfectants are specifically formulated to kill a wide range of microorganisms, including bacteria, viruses, and fungi, while bio-enzyme sanitizers may only inhibit certain microbes (Nazim and Meera, *et al.*, 2017).

3. Limited Spectrum of Activity:

Bio-enzymes have a limited spectrum of activity against all pathogenic microorganisms. Some pathogens, especially resistant bacteria, may not be fully inhibited by bio-enzyme solutions, whereas chemical sanitizers often exhibit a broader antimicrobial spectrum (Arun and Siva Shanmugam, *et al.*, 2015).

4. Longer Production Time:

The preparation of bio-enzymes requires a fermentation period of approximately three to four months. In contrast, chemical sanitizers can be manufactured rapidly through industrial processes, making them more readily available (Vama and Cherekar, *et al.*, 2020).

5. Variation in Product Quality:

The composition of bio-enzyme sanitizers depends on factors such as the type of organic waste used, fermentation conditions, and microbial activity. These variations may result in inconsistent antimicrobial effectiveness between batches (Tang and Tong, *et al.*, 2011; Nazim and Meera, *et al.*, 2017).

6. Limited Shelf Life:

Bio-enzyme sanitizers contain active enzymes and microorganisms that may lose activity over time. Exposure to sunlight, high temperature, or improper storage conditions can reduce the stability and effectiveness of the product (Arun and Siva Shanmugam, *et al.*, 2015).

7. Unpleasant Odor During Fermentation:

During the fermentation process, intermediate compounds such as alcohols and organic acids may produce a strong or unpleasant odor. This may reduce user acceptance compared with commercial chemical sanitizers that often contain added fragrances (Vama and Cherekar, *et al.*, 2020).

8. Lack of Standardized Formulation:

Unlike chemical sanitizers that follow strict industrial standards, bio-enzyme sanitizers often lack standardized preparation methods. Differences in preparation techniques may affect the concentration of enzymes and the antimicrobial effectiveness of the product (Arun and Siva Shanmugam, *et al.*, 2015; Nazim and Meera, *et al.*, 2017).

9. Limited Scientific and Clinical Evidence:

Although several studies have reported antimicrobial properties of bio-enzymes, extensive clinical and laboratory validation is still limited. Chemical sanitizers have been widely tested and approved for use in healthcare and sanitation applications (Tang and Tong, *et al.*, 2011).

10. Limited Commercial Availability:

Bio-enzyme sanitizers are still emerging products and are not yet widely available in the global market compared with established chemical sanitizers. Large-scale production technologies and commercial distribution systems are still under development (Mohan *et al.*, 2016; Vama and Cherekar, *et al.*, 2020).

FUTURE PERSPECTIVES AND RESEARCH GAPS:

Future research on bio-enzymes derived from fruit waste should focus on optimizing fermentation conditions such as temperature, pH, and substrate composition to enhance enzyme yield and efficiency. In addition, more studies are required to identify the microbial communities involved in the fermentation process and their role in enzyme production. Standardization of bio-enzyme formulations and evaluation of their long-term stability are also necessary to ensure product quality and effectiveness for large-scale commercial applications. Furthermore, detailed investigations on the antimicrobial efficiency of bio enzymes against different pathogenic microorganisms will help establish their potential as sustainable alternatives to chemical

cleaning agents. Development of cost-effective large-scale production techniques and improved fermentation technologies could further promote the industrial utilization of bio-enzymes for eco-friendly cleaning and environmental management. In addition, exploring the commercial potential of bio-enzyme based products such as floor cleaners, surface disinfectants, wastewater treatment solutions, and agricultural formulations could open new opportunities in the eco-friendly product market. The use of fruit and vegetable waste as raw materials also supports the concept of waste-to-wealth, making bio-enzyme production economically viable and environmentally sustainable. With increasing global demand for green and biodegradable products, bio-enzyme technology has strong potential for commercialization in both domestic and industrial sectors (Arun & Siva Shanmugam, *et al.*, 2015; Nazim & Meera, *et al.*, 2013; Sahu *et al.*, 2024).

CONCLUSION:

Bio-enzyme production from fruit waste represents a sustainable approach for converting organic waste into valuable eco-friendly cleaning agents. The enzymatic and antimicrobial properties of these formulations make them promising alternatives to chemical cleaners. Further research focusing on optimization of fermentation conditions and large-scale production could enhance their commercial potential.

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