Review of active methods of biological processing of organic waste

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Abstract. We have analysed data from domestic and foreign sources. As a result, it was found that the most effective methods of active biological processing were characterized by a higher rate of bioconversion and the quality of the final product, compared with analogues, due to which they became widespread in the agricultural sector. The results of the analysis of modern bioconversion methods contribute to improving the economic efficiency of waste recycling enterprises. The research was conducted in order to familiarize with the trends in the application and analysis of the features of active methods of biological processing, followed by the identification of the most promising ones. As a result of the assessment in the field of reuse of organic matter, enzymatic and vermicomposting (vermicomposting) methods are the most promising.

1 Introduction

In the modern world, biotechnological solutions play an important role in various industries such as pharmaceuticals, agrochemistry and the production of biologics. One of the key challenges for the biotechnology industry is the disposal of waste generated during the production of biological products. The relevance of this topic is due to several important aspects.

Population growth and increased demand for medical and agrotechnical products have led to a significant increase in the production of biological products, and with it the amount of waste requiring safe and efficient disposal. Waste from biological products may contain dangerous chemicals and pathogenic microorganisms that pose a threat to the environment and human health. The use of biotechnologies for the disposal of such waste helps to minimize their negative impact.

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There are strict international and national regulations governing the disposal of industrial waste, especially in the biotechnology and pharmaceutical industries. Compliance with these standards requires the use of advanced recycling technologies. Biotechnological methods of waste disposal can be economically beneficial. For example, biodegradation methods allow waste to be converted into useful products such as biogas or compost, which helps reduce disposal costs and generate additional sources of income.

Modern biotechnologies offer innovative solutions for waste disposal, including the use of modified microorganisms that are able to efficiently decompose complex organic compounds. In the context of global environmental challenges, sustainable development is becoming a priority for many companies and states. The use of biotechnologies in waste management contributes to reducing the environmental burden and achieving sustainable development goals.

Enterprises for the biological processing of organic waste have demonstrated significant efficiency gains in recent years. Due to the spread and growing popularity of ideas for the reuse of waste, methods of their active biological processing are constantly being improved. They are now considered as the main approach to increasing the value of organic by-products [1]. Modern technical capabilities of careful control and modification of bioconversion parameters make it possible to achieve optimal results among the entire range of recycling methods, which opens up opportunities not only for conventional waste disposal, but also for more complex production. Using various forms of bioconversion, the processes of soil restoration [2, 3, 4], biofuel production [5, 6], agricultural efficiency improvement and more are being implemented [7, 8]. However, the tasks of optimizing them have not lost their relevance and have become more multifaceted due to scientific and technical achievements of recent decades, as well as a better understanding of how humans affect the environment.

2 Purpose of the study

The purpose of our research is to analyze and identify the most promising methods of active bioconversion of organic waste based on the results of recent research and industrial experience.

3 Materials and methods

The paper uses theoretical research methods such as: an up-to-date review and systematic analysis of articles by foreign authors from various databases of electronic libraries such as Google Scholar, ScienceDirect, Web of Science, etc., routine methods of microbiological research and inductive conclusion.

4 Results and Discussions

The active methods of bioconversion include methods of composting, vermicomposting, aerobic and anaerobic fermentation, and biogas production.

Composting is the process of biological processing of organic waste into compost used as fertilizer. Composting methods cover a wide technological spectrum from single piles to complex industrial bioreactors [9]. Many composters often use simple solutions with natural aeration, which require minor engineering studies and capital investments, provide for convective aeration and natural decomposition, which is accompanied by an increase in the duration of the period of time required to obtain compost. In this case, the mixture of organic raw materials is placed in long narrow piles called burts, which are then regularly

mixed or turned over [10]. The size of the burts should be optimal to ensure good aerobic composting. To a large extent, it is determined by the organic substrate to be composted and the rotary equipment used. If it is too large, anaerobic conditions are created in the center of the stack and unpleasant odors will be released when turning over. If the burt is too small, it can quickly lose heat and will not reach a high enough temperature to evaporate moisture and destroy pathogenic microorganisms, as well as weed seeds. Therefore, dense materials that provide less active air movement are usually processed in smaller bursts, compared with more porous raw materials.

In the forced aeration of the material, air exchange is provided by perforated plastic pipes, aeration cones or a perforated floor embedded in the lower part of the processed raw materials. Aeration is carried out either by injection or by drawing air through the processed material. This system requires the presence of electricity at the facility, appropriate fans, air ducts and control equipment that determines the supply time, duration and direction of the air flow [7]

Composting in a tank combines the processes used in mechanical stirring and static composting. It overcomes the disadvantages of each method and uses their positive aspects [5]. Tank composting systems are speed-controlled aeration systems that are designed to provide optimal composting conditions, including mechanical mixing of compost under controlled environmental conditions. The various designs of such systems are similar in that they require significant capital and management costs [8].

The best example of active bioconversion methods is biohumus formation, which is the processing of organic materials by earthworms into a homogeneous and humus-like material (a complex mixture of worm feces and microorganisms). There are many options for systems for the production of biohumus, but all of them are aimed at maintaining an environment favorable to worms in the organic mass [10]. Biohumus formation is a non-thermophilic, bio-oxidative process involving earthworms and related microorganisms. As a result of this process of biological decomposition of organic waste, a biofertilizer is obtained, namely biohumus. Vermicompost (biohumus) is a finely dispersed material similar to peat, with high porosity, good aeration, drainage, moisture retention, microbiological activity, excellent nutrient condition and buffering ability, which provides the required physico-chemical properties favorable for soil fertility and plant growth.

Vermicompost mixtures contain higher concentrations of nutrients, but are less likely to cause salinization than compost. In addition, vermicompost has outstanding biological properties, and their microbial populations are much larger and more diverse than conventional compost. Plants grew better on the soil supplemented with vermicompost compared to soil treated with inorganic fertilizers or cattle manure. This method has also been studied by Z.A. Vaksman, I.V. Tyurin and other scientists.

Fermentation in a liquid medium (or "underwater", "liquid", "deep") involves the formation of enzymes, antibiotics, vitamins and other products by microorganisms developing in a liquid medium (in suspension), thanks to nutrients that are either dissolved or suspended as solid particles [6]. In liquid fermentation, loose and liquid substrates (molasses, broths) are used. When a large amount of oxygen is supplied, microorganisms, splitting nutrients, secrete synthesized bioactive compounds into the fermentation broth.

There are two common methods by which fermentation takes place in a liquid medium: periodic and continuous. During periodic feeding, sterilized nutrients are added to the culture for the growth of biomass in the fermenter.

At the same time, it is possible to add inductors to increase the yield of the product. The continuous method can be used to extract primary metabolites. The products of continuous liquid-phase fermentation may also include secondary metabolites. Alkaloids, flavonoids and other substances formed during continuous liquid-phase fermentation can be used as medicines, food additives and other products.

The advantages of fermentation in a liquid medium are a short period, low production cost and high productivity due to the higher reaction rate in an aqueous medium [3]. It simplifies the extraction of the final product from the broth and the control of fermentation, which, when conditions are optimized, can significantly reduce the time spent on the implementation of the fermentation process. However, the equipment itself is more complicated and more expensive than a similar one for solid-phase fermentation. In addition, this method is not suitable for all products, so the solid-phase method has also become commercially widespread.

Solid-phase fermentation is a cultivation process in which microorganisms grow on solid materials without free liquid. This method serves as an alternative to fermentation in an aqueous medium for the production of value-added products such as antibiotics, unicellular protein, polyunsaturated fatty acids (Omega-3), enzymes, biopesticides, biofuels and flavorings [5]. The most commonly used solid substrates are cereals (rice, wheat, barley and corn), legume seeds, and wheat bran, lignocellulose materials (straw, sawdust, wood chips, as well as a wide range of plant and animal materials). Along with the low cost of maintaining the fermentation process and the simplicity of the equipment, this makes solid-phase fermentation industrially attractive.

Solid-phase fermentation is a multi-stage process that includes the following stages: preliminary preparation of raw materials by mechanical, chemical or biochemical treatment to increase the availability of bound nutrients, as well as reduce the size of components, for example, grinding of plant materials (for example, straw); hydrolysis of predominantly polymeric substrates (for example, polysaccharides and proteins); disposal (fermentation) of hydrolysis products; separation and purification of final products.

The low moisture content makes it possible to reduce the volume of the reactor, compared with liquid-phase methods, and also simplifies the extraction of the product. However, due to the heterogeneity of the culture, serious problems with mixing, heat transfer, and oxygen movement are possible, which makes the measurement and control of many parameters (for example, humidity and pH gradients of nutrients and product) difficult and often inaccurate, thereby limiting the industrial potential of the technology. Therefore, microorganisms selected for processing must be resistant to varying conditions during cultivation. The use of solid-phase fermentation is possible in the processes of biological leaching, bio-enrichment, bioremediation, bio-cooking [1].

An analogue of photofermentation is the so-called dark fermentation - the conversion of an organic substrate into energy and hydrogen (or other metabolites) in the absence of light and oxygen – a complex process occurring in various groups of bacteria, including a series of biochemical reactions similar to anaerobic transformation. Gram-positive bacterial species such as Clostridium and Enterobacter have high potential in this area, which grow rapidly and are able to form endospores, which makes them easy to handle for potential large-scale production. In addition, some lactic acid (for example, Cellulomonas) or thermophilic (Caldicellulosiruptor saccharolyticus and Thermotoga neapolitana) bacteria can be used to produce hydrogen by dark fermentation.

In the context of bioconversion methods based on hydrogen-releasing bacteria, the enzymatic processing of organic fractions without the addition of an inoculum is interesting. The removal of the latter from the process, if such a need arises due to difficulties or excessive costs, is possible provided that the raw materials are properly pretreated. The most effective in this regard is an elevated temperature (50-90 °C). The essence of pretreatment is not to accelerate chemical reactions, but to select a hydrogen-producing microbial population by suppressing the vital activity of other groups of microorganisms, for example, lactic acid. This method does not require a start-up period and is relatively simple to perform.

5 Conclusion

Thus, in recent years, methods of active biological processing have significantly advanced in their diversity and effectiveness. The developed active composting systems in the tank ensure the flow of processes under controlled environmental conditions, thereby overcoming the disadvantages of static composting with natural and forced aeration.

The most effective methods of bioconversion, suitable for widespread use, can be considered liquid- and solid-phase fermentation in bioreactors using residues of certain cultures and microorganisms as substrates. The availability of extensive opportunities to create, modernize and configure such systems puts them above other processing methods when creating value-added products (including feed additives and medicines). Enzymatic and biohumus-forming methods are currently the most promising in the field of reuse of organic matter. Enzymatic bioconversion also has significant potential in the context of the promotion of «hydrogen energy», which is accompanied by an increasing need to create enterprises for the fermentation processing of organic waste into hydrogen.

References

1. D.A. Antonenko, I.S. Belyuchenko, V.V. Gukalov, Complex compost and its effect on soil properties and crop productivity (2015)
2. R. Strachel, J. Wyszkowska, M. Bacmaga, Water, Air, and Soil Pollution, **9**, 1-15 (2017)
3. V. Carabassa, X. Domene, J.M. Alcañiz, J. Environ. Manag, **255**, 109909 (2020)
4. X. Ren, G. Zeng, L. Tang, Waste manage, **72**, 138-49 (2018)
5. T. Sayara, R. Basheer-Salimia, F. Hawamde, Agronomy, **10(11)**, 1838 (2020)
6. M.S. Ayilara, O.S. Olanrewaju, O.O. Babalola, Sustainability, **12(11)**, 4456 (2020)
7. G. Agegnehu, A.K. Srivastava, M.I. Bird, APPL SOIL ECOL, **119**, 156-70 (2017)
8. B. Lukic, A. Panico, D. Huguenot, Environ. Technol. Reviews, **1**, 94-116 (2017)
9. Composting - Methods, Types, Factors, Importance, Microbiology Note: Environmental Microbiology
10. L. Fernandes, M. Sartaj, Compost Sci. Util., **5(4)**, 65-77 (2013)