Circular bioeconomy of pea processing residues

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Abstract. Waste generated annually in agricultural production has a negative impact on the environment and public health. The circular economy concept aims to minimize waste generation in this economic sector. The objective of this study is to assess the level of agricultural waste recycling, identify recycling options and the benefits of reusing pea grain processing waste, and propose a pea grain processing waste management model in the context of the circular economy concept. The material for this scientific article included regulatory documents, scientific publications on the research topic indexed in the Scopus and Web of Science databases, as well as the author's developments in the field of waste recycling. In preparing the article, methods of searching, selecting, systematizing and interpreting information, as well as methods of analysis, synthesis, and design were used. It has been established that a linear economic model functions in modern agricultural production. A tendency is observed towards an increasing share of grain processing waste subject to recycling and neutralization. Applying circular economy principles to grain processing waste allows for the production of value-added products. Directions for establishing a closed-loop economy for the reuse of pea grain processing waste are proposed. Their environmental, economic, and social benefits are demonstrated. A model for recycling pea shells to produce biodegradable packaging is presented. The most promising areas of waste recycling include biotechnology, biofuel and bioenergy production, bioconversion, and nanotechnology. In the near future, an approach to waste management that integrates various subsystems of agricultural production will be particularly relevant.

1 Introduction

Every year, agriculture generates significant amounts of waste, posing environmental and sanitary-epidemiological risks to areas due to the release of toxic compounds and greenhouse gases. Uncontrolled waste disposal negatively impacts soils and groundwater, contaminating them with pathogenic microflora, organic matter, nitrogen-containing substances, and heavy metals.

According to the FAO, modern food production systems operate within a linear economic model, following the “take-make-consume-dispose” approach, which inevitably generates waste. Up to 40% of the world's food is lost or wasted annually, leading to deforestation,

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depletion of wild fish stocks, greenhouse gas emissions, and other negative environmental impacts.

The concept of a circular economy (closed-loop economy) in agricultural production is considered a driver of economic growth, a business strategy plan, or a multi-level approach to ensuring sustainable development [1]. It enables the production of value-added products from waste, including biodegradable packaging and renewable energy, significantly mitigating the sector's environmental impact [2].

Statistics published annually by the Ministry of Natural Resources and Environment of the Russian Federation show that agricultural sectors are seeing a trend toward increasing the proportion of waste recycled and rendered harmless. This necessitates increasing the reuse of agricultural waste.

In accordance with the industry program "Use of Secondary Resources and Secondary Raw Materials from Agricultural Waste for 2022-2030" approved in the Russian Federation, the share of secondary resource use in agriculture should reach 25% by 2025 and 50% by 2030. The priority areas for using agricultural waste recommended by this program are presented in Figure 1.

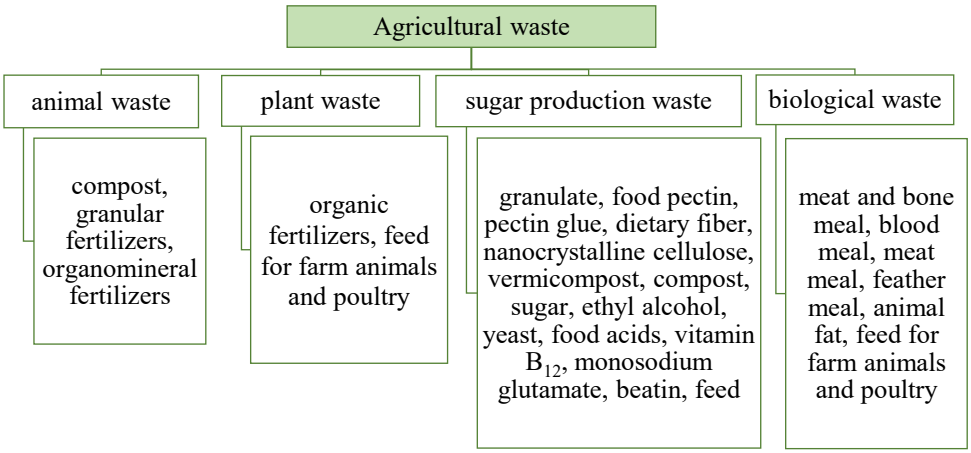

Fig. 1. Priority areas for recycling agricultural waste.

Agricultural producers, who are responsible for fostering a culture of waste management, must strive to minimize waste generation, including through recycling. The concept of a circular economy, which focuses on the reuse, recycling, and recovery of resources [3], is the most promising approach to agricultural waste management.

2 Materials and methods

The materials used to prepare this scientific article included federal regulatory documents, national standards, scientific publications on the research topic over the past 5 years, indexed in the Scopus and Web of Science databases, and original developments in the field of waste recycling.

Methods of searching, selecting, systematizing, and interpreting information from regulatory documents and scientific publications were used. Information analysis and synthesis methods, as well as a design approach, were used to build the circular economy model. Diagrams were created using the built-in Microsoft Word diagram editor.

3 Results and discussion

Circular agriculture is based on three key aspects:

– efficient use of resources and waste prevention;
– promoting environmental, economic and social sustainability;
– restoring systems, thereby closing nutrient cycles and minimizing waste outputs [4].

Based on the above, we proposed a model for the reuse of grain processing waste, using pea grain as an example.

During pea grain processing, a significant amount of waste is generated in the form of shells, germ, chaff, and bran, which contain, among other things, dietary fiber, proteins, lipids, vitamins, and biologically active substances. Because of this, the germ and bran can be used to produce value-added products, including food products, food and feed additives, and pharmaceuticals. Shells can be considered as a raw material for the production of adsorbents, packaging materials, and feed products (according to N. Shelepina, 2024). Cellulose, the main component of grain shells, is a renewable source of biofuel and bioenergy to alleviate fossil fuel shortages and address climate change [5], as well as a raw material for the production of biochemicals, resins, and bioplastics [6].

The concept of a closed-loop economy system, presented in the national standard GOST R 70089-2022, offers a number of tools for its implementation. In our opinion, the following circular economy principles are applicable to pea grain processing waste:

– industrial symbiosis;
– renewable energy and energy efficiency;
– organic products.

Figure 2 presents the areas for implementing circular economy principles as applied to pea grain processing waste. Products obtained directly from pea grain waste or with the addition of components contained in it can find application in the food, processing, pharmaceutical, fuel and energy industries, animal husbandry, water treatment, and other sectors.

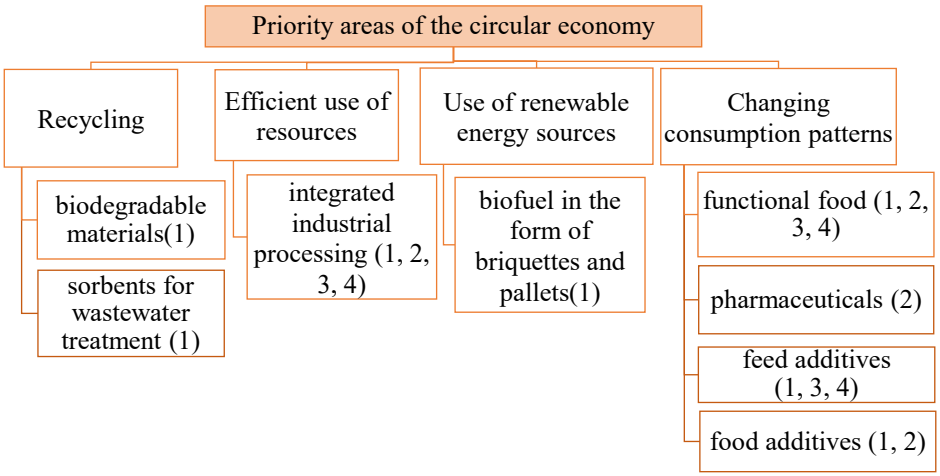

Fig. 2. Priority areas for recycling pea grain waste.
1 –shell; 2 – germ product; 3 – chaff; 4 – bran.

We grouped the key benefits of reusing pea grain processing waste into three categories: environmental, economic, and social.

The environmental benefits include:

– reducing carbon dioxide emissions;

– slowing global warming and climate change;
– improving energy efficiency;
– reducing landfill waste;
– improving waste management;
– processing and disposal of waste;
– reducing the use of natural resources;
– improving soil fertility.

Economic benefits include:
– new value chains;
– new market opportunities;
– increased production profitability;
– raw material savings;
– reduced production costs;
– reduced waste disposal fees.

From a social point of view, reusing pea grain processing waste allows:
– creating new jobs;
– using local raw materials;
– improving social welfare and public health benefits.

Figure 3 shows one example of the practical implementation of circular economy approaches in relation to pea grain shells as a by-product in pea groats production. The basis of biodegradable materials obtained from pea grain shells is cellulose, which can be used both in pure form and as a matrix [7, 8].

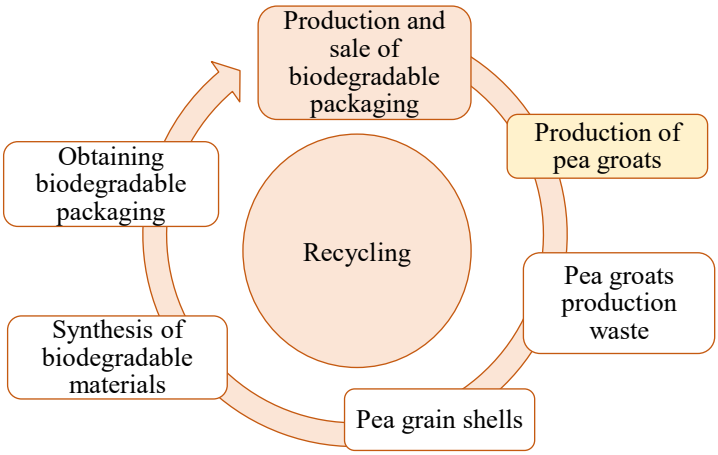

Fig. 3. Recycling of pea groats production waste.

A SWOT analysis of the conversion of agricultural waste into value-added products revealed that, while this approach to waste recycling has its strengths, it also has limitations. Recycling efficiency strongly depends on the quality of the waste. The use of waste recycling technologies can lead, for example, to increased market competition and changes in the composition of products derived from waste [9].

Nanotechnology is currently considered one of the most promising methods for managing grain processing waste. Thermochemical and biochemical processing methods [10] are proposed, as well as integrated methods, such as a combination of anaerobic digestion and microbial fermentation, which will allow, for example, the production of renewable energy in the form of biogas and biochemicals [11, 12].

The most sustainable technology for managing agricultural waste is bioconversion, which involves the co-production of two or three value-added products [13].

In the coming years, a waste management approach that integrates various subsystems of agricultural production will gain particular relevance. An example is the crop-livestock-biogas-crop (CLBCR) system proposed by scientists from China and the United States [14]. It includes three subsystems: crop production, livestock production, and biogas production. Circular use of agricultural waste links these subsystems and expands the capabilities of traditional agricultural systems toward highly efficient recycling.

4 Conclusion

Modern agricultural production operates within a linear economic model, in which the level waste recycling remains insufficient. Circular economy agriculture enables the production of value-added products from grain processing waste.

The proposed methods for recycling pea grain waste offer a number of environmental, economic, and social benefits. The presented pea shells recycling model allows for the production of biodegradable cellulose-based packaging, transforming cereal production waste into a value-added product.

The most promising areas for grain waste recycling include biotechnology, biofuel and bioenergy production, biological conversion, and nanotechnology. As a basis for resource management, circular economy models integrate multiple subsystems, thereby expanding the capabilities of traditional agricultural systems toward highly efficient waste recycling. Promoting and implementing the circular economy concept in agricultural production is an effective waste management tool.

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