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# Food waste and its valorization into value-added products (case-study of the international experience of Asian countries)

© 2024. O. V. Baykova ORCID: 0000-0002-4859-8553,
V. N. Pugach ORCID: 0000-0003-1220-4062,
A.V. Kazakov ORCID: 0000-0001-5522-4624,
Vyatka State University,
36, Moskovskaya St., Kirov, Russia, 610000,
e-mail: olga-baykova@yandex.ru, kazakov.andrey.bonus@yandex.ru

With the changing lifestyle and rapid urbanization of the world's population, the amount of food waste from various industrial, agricultural and household sources is increasing. Food waste is rich in organic substances, so traditional approaches to its disposal in municipal solid waste landfills and incineration can lead to serious consequences for the environment and human health. The use of biological methods for the treatment of such waste offers a sustainable way to valorize them. Being rich in nutrients, food waste can serve as a substrate for the growth of microorganisms and the subsequent production of various value-added products. The article provides an overview of international research in the agricultural sector of India and China on the valorization of fermentation-based waste for the production of various value-added bioproducts. It should be noted that these countries were not chosen by chance, they are the leading countries in Southeast Asia in the field of recycling organic compounds with benefits for the economy and the environment. To achieve this goal, we have used a review and analytical method, which makes it possible to visually illustrate how, based on the use of valorization, food waste can be advantageously used as raw materials or resources for the production of new products, including biofuels, electricity, biosurfactants, etc.

As part of the ongoing work, data on case studies of the agricultural sector in India and China on successful repurposing of food waste for the production of new products is being further summarized.

***Keywords:*** waste disposal, waste recycling, valorization, food waste, household waste, agricultural waste, India, China.

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# Пищевые отходы и их валоризация в продукты с добавленной стоимостью (обзор международного опыта азиатских стран)

**© 2024. О. В. Байкова, д. ф. н., зав. кафедрой,**
**В. Н. Пугач, к. э. н., ректор,**
**А. В. Казаков, к. ф. н., доцент,**
Вятский государственный университет,
610000, Россия, г. Киров, ул. Московская, д. 36,
e-mail: olga-baykova@yandex.ru, kazakov.andrey.bonus@yandex.ru

С изменением образа жизни и быстрой урбанизацией населения планеты увеличивается количество пищевых отходов из различных промышленных, сельскохозяйственных и бытовых источников. Пищевые отходы богаты органическими веществами, поэтому традиционные подходы к их захоронению на полигонах твёрдых коммунальных отходов и сжиганию могут привести к серьёзным последствиям для окружающей среды и здоровья человека. Использование биологических методов для обработки таких отходов предлагает устойчивый способ их валоризации. Будучи богатыми питательными веществами, пищевые отходы могут служить субстратом для роста микроорганизмов и последующего производства различных продуктов с добавленной стоимостью. В статье представлен обзор международных исследований сельскохозяйственного сектора Индии и Китая по валоризации отходов на основе ферментации для производства различных биопродуктов с добавленной стоимостью. Необходимо отметить, что данные страны выбраны не случайно, они являются передовыми странами Юго-Восточной Азии в области утилизации органических соединений с пользой для экономики и окружающей среды. Для достижения поставленной цели нами задействован обзорно-аналитический метод, который даёт возможность наглядно проиллюстрировать, как на основе применения валоризации можно выгодно использовать пищевые отходы в качестве сырья или ресурсов для производства новых продуктов, в том числе биотоплива, электроэнергии, биосурфактантов и т. д.

В рамках проводимой в настоящее время работы обеспечивается дальнейшее обобщение данных о тематических исследованиях сельскохозяйственного сектора Индии и Китая, касающихся успешных мероприятий по перепрофилированию пищевых отходов для производства новых продуктов.

***Ключевые слова:*** утилизация отходов, переработка отходов, валоризация, пищевые отходы, отходы домохозяйств, сельскохозяйственные отходы, Индия, Китай.

In recent years, the topic of food waste has increasingly attracted the attention of the world community. This is due to the fact that this environmental problem has a significant impact not only on the economy, social sphere and the environment, but also on world resources in general [1–5]. Daily nutrition is an important component for maintaining life. Living organisms at different evolutionary levels consume food in various forms, for example, microorganisms absorb food in the form of macromolecules such as carbohydrates, fats, nitrogenous compounds, while humans eat a complex version of food, that is, in the form of fruits, vegetables, cereals, legumes, meat and dairy products. The problem arises when food is wasted or misused, which leads to serious social, economic and environmental consequences [6].

Food products that have completely or partially lost their original consumer properties in the processes of their production, processing, use or storage are called food waste [6]. According to the definition formulated by the Food and Agriculture Organization of the United Nations (FAO), food waste is “the loss of quality and quantity of food products during the chain of stages of production, processing and storage”. In particular, food waste is defined as losses at the end of the life cycle of food products [6]. Food losses are also defined as the unintentional loss or intentional elimination of food suitable for consumption [7]. According to [7–9], “food losses” are defined as losses during preparation and post-harvest processing, while “food waste” refers to losses at the stages of distribution and consumption.

According to FAO, the world generates 1.3 billion tons of food waste every year, which accounts for a third of the total amount of food produced worldwide, accounting for 28% of agricultural area, 1.4 billion hectares of fertile land [6, 10, 11]. It is predicted that economic growth and population growth in Asian countries will lead to an increase in food waste production in the next 25 years. It is also expected that by 2025 the volume of urban food waste will increase by 138 million tons compared, for example, with 2005 [6, 11]. Of the total waste generated in the world, Asia accounts for 278 million tons of food waste, while, for example, Vietnam generates approximately 11.55 million tons of food waste [12]. These wastes, which include waste from households, the hotel sector, the food industry and agriculture, contain fresh fruits, vegetables, dairy products, bakery products and meat [10, 12].

Food waste is an element of municipal solid waste (MSW), which is disposed of by fermentation, composting, burial and incineration at MSW landfills [13]. When burning food waste with a high moisture content, dioxins and furans are formed, which affect human health [6]. At the same time, dumping food waste in an open area leads to environmental pollution problems. According to FAO estimates, more than 3.3 billion tons of $CO_2$ are generated annually as a result of the disposal of food waste, which contributes to the emission of greenhouse gases [11]. The valorization of food waste, which includes the process of converting waste into useful products, including chemicals, materials and fuels, is an ideal approach to improve environmental sustainability and overcome socio-economic problems in the world.

In the Russian Federation, namely in the Kirov region, the annual volume of waste generation is approximately 5 million tons, of which more than 2.5 million tons (50%) are livestock waste, about 2 million tons (40%) are industrial waste and 0.5 million tons (10%) are solid municipal waste [14].

As world practice shows, the secondary use of useful fractions of MSW is a source of raw materials for industrial production. One of the main conditions for using MSW as secondary resources is their centralized collection and extraction of useful fractions. The government of the Kirov region is ready to create joint ventures with China for processing low-grade wood, as well as enterprises for processing milk, including the production of products with a long shelf life. As for cooperation with India, the potential areas for joint activities today are mechanical engineering, chemical industry, agriculture. For a country with a population of more than a billion people, the problem of food shortages is quite acute. Back in 2008, the Kirov region, with the personal participation of the regional leadership, was ready to supply environmentally friendly products of agricultural enterprises produced at joint ventures to India. To date, in the Kirov region there is a huge number of enterprises working in the sphere of agriculture, but the number of enterprises for processing agricultural products (especially deep processing) is extremely insufficient. Namely Uralchem Innovation has opened the first pilot plant in Russia for the production of pea protein, which is suitable for the production of alternative meat, milk and sports nutrition [15]. However, unlike other world producers – India, China – the Kirov region does not have technologies for deep processing of agricultural products.

In our work, we analyze case studies of the Indian food industry and the Chinese agricultural industry to illustrate how enterprises in highly developed Southeast Asian countries use food waste, expanding entrepreneurial initiative and creating value-added products. In our opinion, for the effective use of food waste, it is necessary that the food industry and agriculture of the Kirov region follow the example of Indian and Chinese agriculture, in particular, the use of entrepreneurial initiative in solving the problems of further valorization of food waste.

The presented review of international research on the problems of the emergence of food waste, as well as their processing into vital human resources, aims to identify the sources and nature of food waste that can be effectively converted into high-quality products with added value. The article examines in detail the sources of food waste generation in the food industry of India and the agricultural industry of China, as well as their valorization by introducing biomass containing bacteria into high-quality value-added products.

## Objects and methods of research

A review and analytical method have been used to achieve this goal. The selection of information for the study have been carried out by keywords in the bibliographic databases of scientific citation Web of Science Core Collection (Clarivate Analytics). The search for sources took place in the Yandex and Google search engines. The review includes sources published from 1998 to the present. The information was searched in international interdisciplinary scientific peer-reviewed open access journals devoted to environmental and economic issues by keywords: waste disposal, waste recycling, valorization, food waste, kitchen waste, agricultural waste, India, China.

## Analytical review of international studies

**Waste from the Indian food industry and its valorization.** A significant proportion of the human diet in India consists of cereals such as wheat, rice, barley, corn, sorghum, millet, oats and rye [6]. According to FAO, the total global crop production in India, for example, reached 2577.85 million tons in 2016 [16, 17]. India, being the world's largest producer of grain legumes, produces a significant amount of husk during processing as a by-product [18], which is subsequently processed to produce high-quality products. For example, along with the use of straw, husks and dried leaves as animal feed, these products are traditionally used for the manufacture of roofing, baskets, brooms, hand fans and decorative products. The above-mentioned wastes are also used as cleaning and polishing agents in the metalworking and machine-building industries. Rice husk is used as a vegetable fiber for pet food, fertilizer and substrate for vermicomposting technology, as well as in the production of building materials, for example, light bricks [19, 20]. The husk obtained as a result of processing cocoa pods is used to extract pectin and produce vermicompost, oyster mushrooms, livestock feed and other value-added products [21]. In addition, coconut husks are used in the manufacture of household products such as ropes, brooms, mats, tiles, fishing nets and mattresses. By-products obtained in the process of barley purification serve as a rich source of bioactive compounds such as phytates, insoluble dietary fiber, phenolic compounds, which contain 2.7 times more vitamin E than in whole barley grain [16]. Rice husks are used in the fermentation process to regulate humidity, as well as to maintain the porosity of the fermenting material used for gas exchange during distillation [22].

Fruit and vegetable waste is generated at different stages of the food supply chain: production, processing, packaging, storage and transportation [23]. India is the second largest producer of vegetables and fruits in the world, accounting for 10 and 14% of global production [24]. The resulting waste is recycled by composting, burial, incineration or used as animal feed. These disposal methods cause serious environmental problems, such as emissions of toxic substances and greenhouse gases, as well as the proliferation of microbes due to the high moisture content and filtrate from landfills [23, 25].

Growing public concern about the preservation of the environment from pollution, as well as socio-economic factors, have accelerated research in the field of food waste processing, namely in the search for more effective ways to use fruit and vegetable waste. Starch, cellulose and/or hemicellulose of fruit and vegetable waste are hydrolyzed to soluble carbohydrates for further fermentation to produce ethanol and hydrogen [26]. Microbiological waste recycling has opened up new ways to increase the value of defective fruits and vegetables. Also, by processing waste from fruits and vegetables, high-quality goods are produced, such as fermented beverages (vinegar), polysaccharides, dietary fibers, polyphenols, biopigments (carotenoids), flavors (vanillin), biopesticides, plant growth regulators, enzymes (cellulase, amylase, protease, phytase, etc.), biohydrogen, bioethanol and biogas [27–31]. Acidogenic fermentation of waste fruits and vegetables results in lactic acid [32], and the process of hydrolysis using crude enzyme mixtures results in succinic acid [25].

India is the largest milk producing country in the world. While manufacturing dairy products, the country produces 1–3 times more wastewater for each volume of processed milk. Thus, 3.739–11.217 million $m^3$ of waste is generated per year [33]. For example, cheese production produces a by-product in the form of whey. As a result, 1 kg of finished cheese accounts for 9 kg of whey [34]. Another component of dairy products, namely raw milk, contains ammonia, nitrogen and nitrates, which turn into nitrites, causing methemoglobinemia, which can further lead to groundwater contamination [35–38].

It should be noted that dairy waste has a rich organic composition, which promotes the growth of microorganisms. It follows that a large number of value-added products can be obtained by using dairy waste products such as lactose and protein [39]. These wastes are a suitable substrate for the production of ethanol using unicellular microscopic fungi (*Saccharomyces cerevisiae*) using enzymatic hydrolysis of fermented sugar [34]. Filamentous fungi produce a variety of enzymes capable of hydrolyzing complex carbohydrates to simple sugars. This ensures high-quality biomass production, which can be used not only as animal or fish feed, but also in human food in the form of a single-celled protein with GRAS status (GRAS stands for the US Food and Drug Administration, according to which a chemical or substance added to food is considered by experts safe) [33].

The fat and oil industry in India produces waste at various stages of the processing process: degumming, neutralization, bleaching, deodorization, oxidative or hydrolytic rancidity resulting from lipid oxidation [40]. As noted in [41], the Indian fat and oil industry annually produces 350.9 million tons of low-fat cake, which is a concentrated source of protein, as a by-product. After pretreatment, these wastes are further used to prepare food, animal feed and fertilizers.

As a rule, wastewater from the oil processing industry enters directly into the soil and groundwater, which leads to the formation of an oily film on the water surface, seriously endangering the lives of inhabitants of aquatic ecosystems. In addition, the authors of the work [40] note that this leads to clogging of wastewater, as well as to the methanization of oil, which in turn exacerbates the greenhouse effect. As part of the advanced methods of processing the above-mentioned waste, microbial cells are used to biodegrade organic matter from wastewater, thereby ensuring the production of various high-quality products, for example, biologically based zwitterionic biosurfactants [42, 43]. It has been established that waste products from the fat and oil industry, such as tocopherols, sterols and squalene, are a cheap resource for the production of healthy food products, as well as pharmaceuticals and cosmetic products [44].

The meat, poultry and egg processing industry in India is a huge segment of the food chain system. At the same time, a huge number of animal by-products, slaughterhouse waste and wastewater are produced [45, 46]. The main industrial wastes are feathers, hair, skin, horns, hooves, soft meat, bones, etc. In addition, slaughterhouse wastewater contains blood, protein, animal fat (lard), detergent residues, as well as organic substances (carbon, nitrogen and phosphorus). The processing of perishable animal waste makes it possible to use an alternative way to eliminate an environmental problem and obtain value-added goods. The processing industry of India produces meat and bone meal, hydrolyzed feather flour, blood meal, fish meal [47]. Lactic acid fermentation of slaughterhouse waste is a promising approach to using these wastes to grow a culture of lactic acid bacteria that can be used to create probiotic drugs [48]. Due to its rich nutritional composition, slaughterhouse waste can be used to produce various value-added products. For example, the biomass of *Scenedesmus* sp. It can be used as fish feed [47], a substitute for clean energy, i.e. methane produced during anaerobic digestion of wastewater [47], biogas production from bird droppings and non-food applications (fertilizer, binder) [46]. Biodiesel can be obtained in various ways:

from chicken manure by a pseudocatalytic transesterification reaction; from pork fat waste by fermentation using the bacterium *Staphylococcus xylosus*; from eggshells by transesterification of triglycerides with methanol using homogeneous catalysts [49]. All this has multifactorial applications in the pharmaceutical and cosmetic industries.

**Household and agricultural industry waste in China and its valorization.** Urbanization, rapid economic development and uncontrolled population growth have increased food consumption, which has led to a multiple increase in so-called kitchen waste [50], which is a type of anthropogenic organic waste, usually dumped by households, etc. [51–53]. Currently, China annually produces more than 30 million tons of kitchen food waste outside the food supply chain [51].

Kitchen waste includes fruits, vegetables, boiled food waste, meat, waste fat, oil and lard. In percentage, kitchen waste mainly consists of fruits – 38.2%, vegetables – 41.5%, basic foodstuffs – 7.6%, eggshells – 7.2%, shells and bones – 2.5% and meat – 2.3% [51, 54]. The chemical composition of kitchen waste includes carbohydrate polymers (cellulose, hemicellulose, pectin and starch), protein, lignin, fats, organic acids, inorganic salts, etc. [53, 55]. Kitchen waste is generated during the processing of food products: processing, production, storage, transportation and consumption. Wastewater from home kitchens is generated during various activities, such as washing and rinsing food, cooking, washing dishes, kitchen utensils and in the process of general household management. Traditional methods of kitchen waste disposal, such as backfilling, composting, incineration and direct or indirect discharge of wastewater into the ecological system cause significant damage to the ecosystem and human health [56, 57]. Kitchen waste is a biodegradable biomass with high moisture content and a supply of nutrients that provoke the growth of pathogenic microorganisms that cause rotting and reproduction of flies and mosquitoes. At the same time, toxic substances, greenhouse gases are released, a huge amount of filtrate is drained into reservoirs, and an unpleasant smell of ammonia and hydrogen sulphide is formed. Uncontrolled formation and improper disposal of kitchen waste can lead to life-threatening consequences in the environment. Kitchen waste can be used as a substrate for the production of numerous products, namely butanol produced by the bacterium *Pseudomonas aeruginosa* [56] by enzymatic hydrolysis [55], lactic acid produced by the bacterium *Lactobacillus amylophilus*, volatile fatty acids and hydrogen [52], as well as ethanol in the process of sequential liquefaction [58]. Kitchen waste can also be used to produce biogas, bioelectricity, biodiesel, etc. Nanocomposites, biopolymers and food film-like materials can be synthesized using food waste as a substrate [56]. Food waste can also be converted into a huge number of value-added products, including antioxidants, pigments, nutraceuticals, dietary fibers, organic acids, vermicompost, biofertilizers, xanthan gum and wax esters [52, 56]. All of the above significantly reduces the environmental burden [5, 52]. As the authors of the article [56] note, household waste can also be used as a substrate for the production of biosurfactant, which helps to reduce cost and at the same time reduce the level of environmental pollution.

China's agricultural waste is an organic substance that includes straw, cake, molasses, grain pellets, husks (rice, corn and wheat), shells (walnuts, coconut and peanuts), peel (banana, avocado), stems of crops (cotton), vegetable waste, as well as livestock manure and birds [54, 59, 60]. According to FAO estimates, annually about 250 million tons of inedible plant waste are converted into agro-industrial waste during the processing of various crops [61]. China, being the world's largest grain producer, annually produces $1.75 \cdot 10^9$ tons of agricultural waste, of which $9.93 \cdot 10^8$ tons are obtained from straw crops, $4.52 \cdot 10^8$ tons from livestock and poultry manure and $3.03 \cdot 10^8$ tons of forest residues [59, 62].

As a rule, agricultural waste is either burned or left to rot in the fields, which causes air, soil, and water pollution. The use of traditional approaches to the disposal of agricultural waste contributes to the release of toxic and greenhouse gases, as well as other carcinogenic chemicals such as dioxins, furans and polycyclic aromatic hydrocarbons. All of the above causes damage to the environment, as well as human health [63]. Agricultural waste is biodegradable and organic, and also has a supply of nutrients such as polysaccharides (starch, cellulose, hemicellulose), proteins, lignins, fibers, minerals, vitamins and others [64–66]. In addition, the chemical composition of agricultural waste proves that they are a universal source for the synthesis of a number of products, for example, bioplastics from the cuticle, a protective layer that is formed with the help of epidermal cells on the outer layer of plant parts: leaves, stems, etc. [61].

Agricultural waste, namely, the use of peel, seeds, cake, field residues and bran, can be a cheap and natural material for the production of high-quality products such as pigments, phytochemicals, antibiotics, various enzymes (endoglucanase, -glucosidase, amylase, glucoamylase) [67–69]. For example, xanthan, synthesized by the bacterium *Xanthomonas campestris*, is a type of exopolysaccharide and is used as a food additive in the Chinese food industry [70].

Food additives in China play a significant role in improving the technological properties of food products. For example, mushrooms are an ecologically balanced crop obtained using lignocellulose agricultural waste (banana leaves, cotton stalks) [70, 71].

Waste from the agricultural industry can be used to produce substitutes for building materials such as fiber board, thermal insulation walls and roofs, as well as bricks made from recycled paper and cotton, the advantages of which are lightness, biodegradability and environmental friendliness of use. For example, a cement substitute is produced in China from sugar industry waste (sugar cane pulp) and oil palm shells [64, 72, 73].

From the analyzed material, we have selected and presented in the table individual examples of research in the field of valorization of food waste into value-added products (Table).

## Conclusion

Thus, with the growth of knowledge and research, it has become possible to increase the value of food waste generated during technological processes that can be safely processed into value-added bio-products. The examples presented in the article illustrate potential ways to further solve the problems associated with the processing of food waste. The analyzed experience of Asian countries on the valorization of food waste shows that valorization may be in demand at the present time due to the rapid depletion of natural resources, an increase in waste generation and disposal worldwide and the need to develop more sustainable and cost-effective waste management methods, and may also prove to be an effective tool for the disposal of organic compounds with benefits for economy

**Table**

Research in the field of valorization of food waste into value-added products

| Substrate | Biological process | Microorganisms | Final product | Link |
|---|---|---|---|---|
| Waste from cooking olive oil | Fermentation | *Penicillium expansum* | Biodiesel fuel | [73] |
| Mixed food waste (banana peel, household waste) | Enzymatic hydrolysis and fermentation | *Saccharomyces cerevisiae* | Bioethanol | [31] |
| Food waste | Enzymatic hydrolysis | *Bacillus licheniformis*, *Thermomyces lanuginosus* (L0777) | Biooil | [31] |
| Waste vegetable oil | Enzyme immobilization | *Proteus mirabilis* | Biodiesel fuel | [75] |
| Cane molasses and starch-rich food waste | Fermentation | *Clostridium acetobutylicum*, *Clostridium beijerinckii* P260 | Bioethanol | [76] |
| Mixed food waste | Microbiological electrolysis cell and anaerobic digestion | *Methanosarcina thermophile*, *Methanobacterium formicicum*, *M. beijingense*, *M. petrolearium*, *Clostridia* sp., *Bacteroidia* sp., etc. | Methane | [77] |
| Carbohydrate-rich food waste | Fermentation | *Clostridium* sp., *Enterobacter* sp. | Biohydrogen | [12] |
| Industrial and domestic wastewater | Anaerobic digestion | *Scenedesmus* sp. | Methane | [47] |
| Waste from the meat processing industry | Fermentation | *Staphilococcus xylosus* | Biodiesel fuel | [49] |
| Kitchen waste oil | Fermentation | *Pseudomonas aeruginosa* | Biosurfactant | [41] |
| Dairy waste | Enzymatic hydrolysis | *Saccharomyces cerevisiae* | Ethanol | [34] |
| Nutrient-rich food waste | Hydrolysis, fermentation and biosynthesis | *Halomonashydr othermalis*, *Halomonascamp aniensis* | Polyhydroxy-butyrate (PHB) | [13] |

and environment. The lack of technologies for deep processing of agricultural products in the Kirov region forces us to look for a solution to this problem, using a range of measures, including Indian and Chinese agriculture, and in the future developing industrial cooperation, creating joint projects, building new logistics chains.

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