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RESEARCH ARTICLE
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Optimisation of Municipal Waste Transshipment Scheme in Tashkent for Compost Production and Sustainable Agriculture

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ABSTRACT

This article focuses on optimising the process flow diagram for a solid municipal waste handling and recycling station in Tashkent. Probabilistic waste models, developed using the "quartering" method, served as the foundation for the experiments. The studies revealed that food waste constitutes approximately 34.5% of the total waste volume; however, the current mixed collection practice results in its disposal in landfills. To develop and create a prototype bag breaker, physical modeling methods, specifically dimensional analysis using the π-theorem, were employed. The experimental results were analyzed, and mathematical models for bag breaking and sorting food waste were created using the surface response method (the Box-Behnken design). The proposed integrated waste sorting system is expected to increase overall waste sorting by 25-30%, while the sorting of organic waste could reach up to 95%. Additionally, by improving the waste sorting percentage, the number of garbage trucks used to transport waste to landfills could be reduced by approximately 25-30%. Implementing these research results across the Republic of Uzbekistan will facilitate the successful adoption of circular economy policies and provide a renewable source of raw materials for agricultural needs.

Keywords: Municipal solid waste, Compost, Bag breaker, Cylindrical screen, Waste sorting.

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INTRODUCTION

The volume of humus in frequently used soils is steadily decreasing, resulting in a decline in crop yields. This issue cannot be resolved solely through the use of conventional fertilizers, such as peat and manure, or chemical additives. To address this problem, it is essential to diversify the types of fertilizer used while lowering their cost (Dasgupta et al., 2022). In this context, compost produced by processing household waste at waste processing facilities has the potential to be an effective and affordable way of improving agricultural soil quality. The rapid growth of the urban population has resulted in a significant accumulation of household waste. Rakhmatullaev et al. (2021) reported that approximately 14.0–14.5 million tons of municipal solid waste (MSW) are generated each year in Uzbekistan. Tashkent, the country's largest city, has over 3 million permanent residents. Based on standard MSW accumulation rates, waste produced from apartment buildings is estimated at approximately 0.75 kg per resident per day. Therefore, Tashkent generates approximately 2,250 tonnes of solid waste daily, totalling around 821,000 tons annually (Shipilova and Turakulova, 2022). Common waste components include paper, plastic, metal, leather, rubber, textiles and animal and plant waste (Baraev and Radkevich, 2020). Of these, organic components constitute the largest share, accounting for 30–40% of the total waste volume (Khankelov & Mukhamedova, 2023; Khankelov et al., 2025).

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According to Lardinois and Klundert's (1993) classification of waste, organic waste includes agricultural waste, as well as human and animal waste. As the global population continues to grow, including in the Republic of Uzbekistan, the generation of organic waste inevitably increases, leading to greater environmental and agricultural challenges. These issues are particularly severe in developing countries like Uzbekistan, where waste management practices are often primitive and ineffective. Furthermore, the Republic's use of mixed collection and transportation methods for household waste exacerbates the situation. Numerous scientific studies (Baraev & Radkevich, 2020; Roland & Frank, 2022) suggest that the efficiency of solid waste processing methods is largely dependent on the morphological composition of the waste. In order to evaluate the resource potential of solid waste generated in Tashkent, studies were conducted to analyze the qualitative composition of household waste. The average morphological composition of solid waste was determined and can be used as a probabilistic model for future experimental studies focused on sorting and processing waste materials. Analysis of the morphological composition of municipal solid waste arriving at waste handling and disposal stations in Tashkent showed that, in recent years, there has been an increase in packaging materials such as cardboard, paper and polymer products. These materials have material value, but they also pose a significant obstacle to processing organic waste and producing organic fertilizers. One of the main causes of low waste management efficiency is the mixed collection method, whereas in developed countries, waste is collected and transported separately (Arowosegbe et al., 2024).

Numerous studies have focused on processing food waste to produce energy, organic fertilizer and livestock feed. Vermicomposting, which uses earthworms to produce organic fertilizer and fish feed, has become widespread in developed countries (Guerro et al., 1999). Various approaches include mechanical-biological setups (Oumaima et al., 2024) and classical composting methods involving heap formation and controlled decomposition (Roche et al., 2025). Ojukwu and Egbuchulam (2020) demonstrated the production of organic fertilizer using samples of cow rumen, wood debris, ash, fish waste and poultry manure. They tested the final product for its nitrogen, phosphorus and potassium content, as well as its acidity. Damara et al. (2023) analyzed the morphological composition of food waste to develop optimal management strategies, concluding that compost production provides economic and environmental benefits. Ferdinan et al. (2021) found that community involvement in waste management correlates with its effectiveness. They emphasized that producing compost from organic waste is a key way to manage waste sustainably and reduce environmental and health impacts.

This work is relevant because existing mixed collection and waste processing methods at waste processing plants yield a mixture that is unsuitable for use as compost. To improve the quality of this material for subsequent use, the authors have developed modernization schemes for existing organic waste processing plants, based on technological solutions for enriching the compost mixture and separately collecting food and non-food waste (Zabolotskikh et al., 2016). Soma et al. (2022) assessed the feasibility of producing organic fertilizers through the anaerobic fermentation of municipal waste. There are many ways to obtain various materials from organic waste. Tahir et al. (2023) provided an overview of the potential use of orange peel waste as a source of natural pigments and flavours in the food industry, particularly in the production of confectionery and beverages. Due to the significant volume of biologically active organic compounds, it is possible to produce organic fertilizers from orange peels.

Compost made from household solid waste can benefit crop productivity when specific requirements are met. Organic fertilizers transform soil structure, improving productivity and water retention while reducing the demand for chemical additives. However, not all household waste is suitable for composting, and production processes must be organized properly to avoid negative environmental and health impacts (Shen et al., 2025).

Organic fertilizers improve soil composition, creating loose, air-permeable substrates that promote rapid plant growth. Due to their content of nitrogen, phosphorus, potassium and microelements, they can partially or completely replace mineral fertilizers, thereby reducing costs. The water-resistance of compost is valuable in southern regions with irrigation shortages, as it allows crops to endure periods without precipitation. Additionally, compost treatment reveals plant disease resistance due to beneficial microorganisms that prevent the development of pathogenic bacteria. Only organic waste consisting of food waste, paper products and garden waste is suitable for composting. Toxic substances such as plastic, glass and metals are prohibited (Khankelov et al., 2024). Research has been conducted to study the composition of compost and its influence on agricultural product yield, as well as the effect of waste composition on yield depending on the type of plant. Regardless of the municipal waste collection method used, uniform technical conditions must be maintained for compost production. According to the state standards GOST R 5557-2013, titled *"Organic Fertilizer Based on Municipal Solid Waste. Technical Conditions"*, the raw materials derived from municipal solid waste must meet specific quality criteria. These include a moisture content not exceeding 50%, an organic matter content of at least 45%, and a pH range of 6.0–8.0. The permissible content of paper ranges from 20% to 45%, while the glass content must not exceed 8%. The total amount of inert materials such as metal, glass, wood, leather, rubber, stones, and plastic should remain below 25%. Moreover, the presence of pathogenic microorganisms, including coliform bacteria and enterococci, is strictly prohibited (Korzhakova & Molodkina, 2021).

In the city's existing waste management system, the Production Association *Makhsustrans* oversees waste collection and transportation across all 12 city districts. Its divisions handle waste generated from residential buildings, public institutions, cafés, and restaurants. The collected municipal solid waste (MSW) is delivered to three main waste transshipment stations located in the Yakkasaray, Yunusabad, and Yashnabad districts. Upon arrival, the waste is weighed and unloaded at designated sites, where bulky items are manually separated from the rest. The remaining waste is transferred into a receiving bin using loaders. Subsequently, powerful hydraulic presses compact the waste at a ratio of 1:5, significantly reducing its volume. The compressed waste is then loaded onto heavy-duty garbage trucks with a capacity of 27 m^3 (HD-130 brand) and transported to designated landfills for final disposal. A schematic representation of this waste management process is illustrated in Fig. 1.

Analysis of this technological scheme shows that the waste is not sorted or processed in any way. It is simply collected and taken to a landfill for burial, thereby losing valuable secondary raw materials for agriculture. Additionally, the productivity of the three aforementioned stations does not correspond to the current accumulation volumes. Therefore, to avoid queuing for hours at the weighbridge and for waste unloading, it is necessary to enter into direct contracts for the disposal of waste generated by the population. Statistical data from waste transfer and disposal stations in Tashkent shows significant variations in annual waste volumes: The Yunusabad station processes 165,687 tons per year, the Yakkasaray station handles 193,944.4 tons, and the Yashnabad station processes 148,815.5 tons, totalling 508,447.2 tons. Assuming that 60% of waste has a marketable appearance, approximately 305,068.3 tons could be suitable for sorting, with a minimum of 5% actually being sorted, totalling 15,253.4 tons.

The data indicating that 60% of the total waste volume will have a marketable appearance is primarily due to the mixed waste collection practices in Tashkent. Here, solid waste from apartments, private residences, catering establishments and institutions is collected in bags and placed in containers. Consequently, approximately 40% of valuable secondary raw materials are lost during the initial processing stage. The low usefulness rate of 5% is due to operators and individuals removing highly liquid waste components at collection points (Khankelov et al., 2023). Despite decrees and resolutions adopted by the President and government of the Republic of Uzbekistan, foreign investors are reluctant to invest in the solid waste recycling market. One main reason for this is the 'poverty of waste', i.e. the very small percentage of valuable components and the poor marketability of waste. A comparison of data from open sources reveals that approximately 312,553 tons of solid waste do not reach waste transshipment stations in Tashkent. This suggests that divisions of 'Makhsustrans' and private transport enterprises are bypassing waste transfer stations and taking waste directly to landfills or dumping it at unauthorized sites. It should be noted that, since 2021, the fleet of specialized waste collection vehicles has not been replenished, while waste accumulation volumes have increased significantly. Consequently, waste is not removed from accumulation sites for days, thereby becoming a source of environmental pollution. Waste contains organic elements, the percentage of which varies from 25 to 40%, depending on the season, climate, standard of living, mentality and food culture (Okwor et al., 2012). These organic components can serve as a source of secondary raw materials for compost production, meeting various requirements.

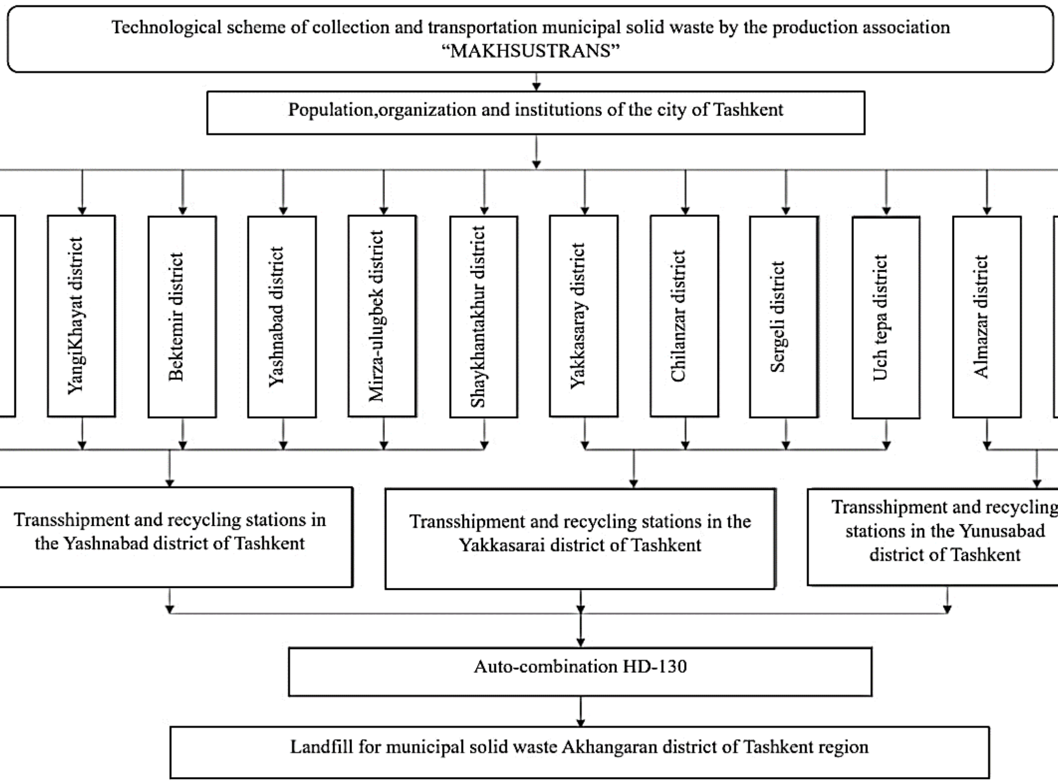

Fig. 1: Technology for collecting and transshipping solid waste generated in Tashkent.

A study by Li et al. (2025) analyzed factors influencing university students' attitudes toward food waste. The findings indicate that increasing awareness and fostering positive attitudes can effectively reduce food waste. An analysis conducted by Agamuthu & Agamuthu (2023) of waste properties in landfills across India, Indonesia, Thailand, and Vietnam revealed that food waste comprises approximately 40 to 50% of the total waste volume. The study also proposed several recommendations for achieving sustainable waste management. Additionally, Archana et al. (2025) provide an economic justification for using cow manure as a mineral fertilizer in agriculture, presenting a practical approach for closed-loop bio resource management in decentralized rural settings.

Despite progress in mechanical-biological treatment and composting of waste, optimizing the flow schemes of waste transfer stations to enhance food waste sorting efficiency in Central Asia remains underexplored. Thus, research focusing on optimizing the technological schemes of waste transfer stations by determining the optimal values for the main parameters of bag breakers and cylindrical screens is crucial.

MATERIALS & METHODS

Bioethical Statement

This study only involved the analysis of municipal solid waste samples and the testing of mechanical equipment. No human or animal subjects or biological samples were used in this research. All waste samples were collected from public waste collection points in accordance with standard safety protocols.

Research Design

Experimental studies were conducted at the Technology and Machinery for Municipal Solid Waste Processing Laboratory in the Department of Engineering at Tashkent State Transport University from September 2022 to July 2024. These comprised two stages: first, determining the morphological and fractional properties of municipal solid waste; and second, determining the rational parameters of the bag breaker and cylindrical screen.

The experimental studies to determine the morphological and fractional composition of municipal solid waste followed the methodology developed by the K. D. Panfilov Academy of Public Utilities (Russia). Studies to determine the rational parameters of the bag breaker and cylindrical screen were conducted according to the Box–Behnken experimental design (Augambaev et al., 1993).

Bag breaker optimization involved investigating three factors: the ratio of roller width to diameter (X_1), ranging from 1.2 to 1.5; shaft rotation frequency (X_2), ranging from 175 to 225rpm; and receiving table inclination angle (X_3), ranging from 20° to 40°. The experimental design employed coded values (-1.682, -1, 0, +1, +1.682), where -1 represents minimum values, 0 represents average values and +1 represents maximum values. The design included fifteen experimental runs, covering all factor combinations, with the output parameter being the percentage of bag tearing. The specific factor levels examined were roller width-to-diameter ratios of 1.1, 1.2, 1.35, 1.5 and 1.6, shaft speeds of 160, 175, 200, 225 and 240rpm, and inclination angles of 13°, 20°, 30°, 40° and 47°.

To optimise the cylindrical screen, three factors were examined: cylindrical screen hole diameter (X_1), ranging from 60 to 80mm; screen inclination angle relative to the horizontal (X_2), ranging from 15° to 25°; and screen rotation frequency (X_3), ranging from 3 to 7rpm. The same coding system was applied to these fifteen runs. The specific factor levels were as follows: hole diameters of 53mm, 60mm, 70mm, 80mm, and 87mm; inclination angles of 12°, 15°, 20°, 25°, and 28°; and rotation frequencies of 1.5rpm, 3rpm, 5rpm, 7rpm, and 8.5rpm. The output parameter was the percentage of food waste sorted.

Selection of Research Objects

Determining the probability model of the morphological and fractional composition of municipal solid waste generated in Tashkent required an understanding of the complexity of the city's structure. The city consists of 12 districts with varying numbers of residential houses (improved and unimproved) and public buildings that differ significantly in terms of the activities they host. A two-stage cluster sampling approach was employed for this complex system. For sampling purposes, Tashkent's territory was treated as a single cluster encompassing all twelve administrative districts: Bektemir, Chilanzar, Hamza, Mirabad, Mirzo-Ulugbek, Sergeli, Shaykhantakhur, Uchtepa, Yakkasaray, Yashnabad, Yunusabad and Yangihayot. The required number of districts and solid waste collection points was determined using the methodology developed by Aslanov et al. (2021).

Statistical analysis was conducted to optimize sampling efficiency.

1. Average organic component determination: The mean value of organic components in municipal solid waste (MSW) across seasons was calculated as $\bar{X}_{sr}$ = 33.3%, based on three years of experimental data.

2. Variance calculation. The dispersion was determined using the formula:

$$\delta = \sum (X_i - X_{av})^2 = 0{,}446 \tag{1}$$

3. Standard deviation determination:

$$\sigma = \sqrt{\frac{\delta}{n-1}} = \sqrt{\frac{0{,}446}{11}} = 0{,}23\ \% \tag{2}$$

4. Sample size calculation. The required number of districts was determined using:

$$n = \frac{t^2\sigma^2 N}{N\Delta_x^2 + t^2\sigma^2} \tag{3}$$

Where t = 2 (confidence coefficient from the Laplace table with a probability of 0.954), N = 12 (total number of administrative districts) and Δ_x = 0.2% (sampling error).

Substituting these values gives *n = 2.208/0.64 = 3.5*. The results indicated that a sample size of four districts was sufficient.

The Mirabad, Chilanzar, Mirzo-Ulugbek and Yunusabad districts were selected based on the largest standard deviations. The sixteen collection points were distributed equally across the four districts, with four in each. This two-stage cluster sampling approach ensured the data on the organic waste content of Tashkent's solid waste was highly representative while remaining feasible in terms of time, labour and material costs. In the first stage, the entire city territory was represented as a unified cluster containing all administrative districts. In the second stage, systematic selection was performed within the chosen districts. This sampling methodology provided the necessary statistical power to determine the composition of waste components by type and size across the selected districts. This enabled a comprehensive assessment of municipal solid waste characteristics to be made for subsequent processing optimization studies.

Determination of the Morphological and Fractional Composition of Municipal Solid Waste

An established quartering methodology was used to assess municipal solid waste by component size. Fresh waste samples weighing 30 kg were placed on solid surfaces and spread to a uniform thickness. One quarter of each sample was retained for analysis, and the remaining three quarters were discarded.

The remaining mass was spread in a thin layer on a tarpaulin to determine the morphological composition through component separation. The fraction of each component was calculated as follows:

$Y_1 = (A_1/B_1) \times 100\%$, (4)

Where Y_1 is the fraction of each waste component, A_1 is the weight of the waste component under study (kg) and B_1 is the total weight of the waste (kg).

The fractional composition by size was determined by sieving 30 kg of waste in stages using sieves with mesh sizes of 250×250mm, 150×150mm, 100×100mm and 50×50mm. Ten 30 kg samples were selected for experiments assessing component size.

The proportion of each component relative to specific size ranges was calculated as follows:

$Y_2 = (A_2/B_2) \times 100\%$ (5)

where Y_2 is the fraction of each waste component relative to a specific size range, A_2 is the weight of the particular waste component relative to the total sample mass (kg), and B_2 is the total waste mass weight relative to a specific size range (kg).

Where Y_2 is the fraction of each waste component relative to a specific size range (%), A_2 is the weight of the particular waste component relative to the total sample mass (kg) and B_2 is the total weight of the waste relative to a specific size range (kg). Each series of experiments was conducted three times. In each repetition, all parameters (probability model values) and external conditions were kept constant to ensure the comparability of results. The outcomes of each repetition were recorded, and the average values for the three repetitions were calculated.

Flow Chart of Tashkent Waste Transshipment Station

The improvement of the Tashkent waste transshipment station flow chart should be based on the principles of the circular economy (Roland & Frank, 2022), whereby most MSW components are returned to circular processing cycles through methods that are economically viable, environmentally acceptable and legally supported.

Analysis of the existing waste transfer and recycling station flow chart revealed low efficiency due to three main factors. First, the total throughput capacity is significantly lower than the current waste volumes. Second, manual labour is required for bag tearing, which hinders the automation of the main recycling processes. Third, the cylindrical screens are inefficient, resulting in significant food waste losses during fractional sorting. The primary cause of the low efficiency is design flaws.

An analysis of solid municipal waste processing technology in Tashkent enabled us to develop a comprehensive waste processing scheme (Fig. 2). This scheme provides a clear understanding of the sequence of individual operations as well as the relationships between them.

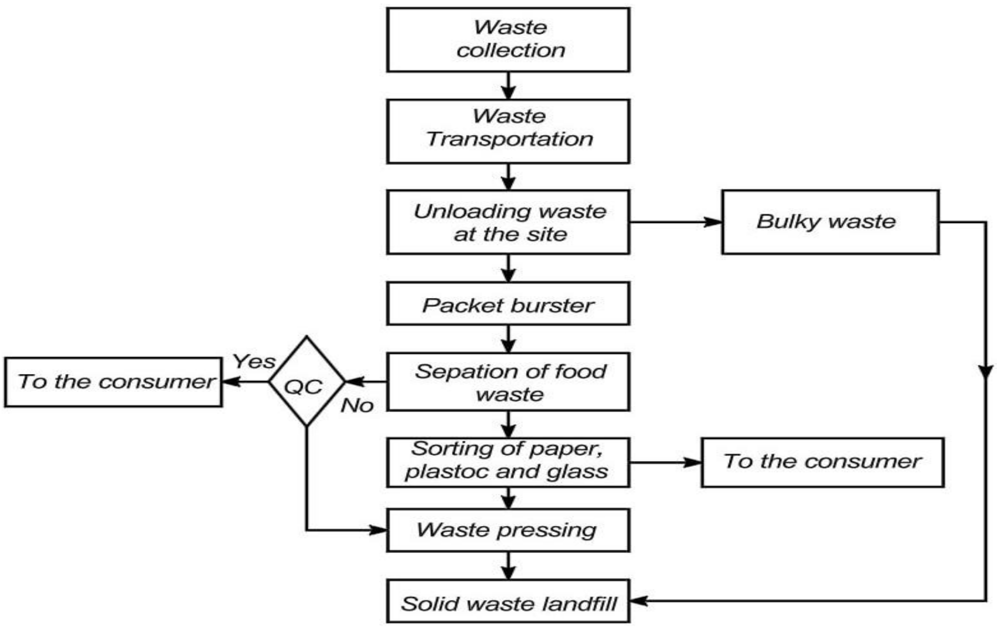

Fig. 2: Flow chart of the integrated processing of municipal solid waste generated in Tashkent. One key aspect of this processing scheme is the validation stage, during which the compost is tested for its chemical composition, followed by an assessment of its morphological and fractional composition.

Solid Waste Bag Breaker

The bag breaker machine is a critical component in the flow chart as the productivity of the entire waste transshipment station depends on its performance. Physical modelling methods were employed to determine and justify key parameters of the bag breaker, specifically dimensional analysis without changing the properties of the medium (Khankelov et al., 2024). The advantage of this method lies in performing almost the entire bag tearing process on a developed physical model with minimal material and time costs, while justifying rational parameter values. Simple transition formulas enable these values to be scaled to full-size machines. Three factors were selected to determine the bag tearing process: the roller width-to-diameter ratio, the shaft rotation frequency and the receiving table angle. A physical bag breaker model was developed and manufactured to study bag-breaking patterns and validate the theoretical results (Fig. 3).

Fig. 3a shows a general view of the bag breaker developed at the Department of Technological Machinery Engineering at Tashkent State Transport University. The device has the following specifications:

- Overall dimensions (Length, Height, Width),mm - 650; 400; 700;
- Productivity, t/hour - 1.0;
- Drive motor power, kW - 1.5;
- Number of knives, pieces - 4.

Fig. 2b shows a front view of the bag breaker's design, providing a visual representation of the relative positions of its components. Fig. 2,c shows a rear view of the bag breaker's design, providing an overview of the relative position of the drive elements. The bag breaker machine features a 3mm thick steel body (1) supporting all mechanisms. The front section uses organic glass to enable visual observation of the process and parameter optimization. Receiving table (2) is positioned in the left-hand opening and feeds waste batches into the working chamber. Initially positioned at a 45° angle to the horizontal, the receiving table ensures uniform feeding of waste. The thirty-millimetre-high sides on both sides of the table centre the bag feed into the working chamber. The grate bars (8) are welded to the lower section of the receiving table with spacing selected based on the properties of the bags. These steel bars have a thickness of 6mm. The machine's drive system ensures the functionality of the bag tearing mechanism, with all drive elements installed on base (5). This comprises an electric motor (4), driving and driven sprockets (10 and 12), a worm gear (11) and a tensioner (13). The worm gear significantly reduces shaft speed, and changing the sprocket diameters allows the speed of the shaft rotation to be adjusted within the desired ranges.

The machine's design facilitates efficient bag opening while maintaining structural integrity and operational safety. The component materials and dimensions were selected based on the anticipated load conditions and durability requirements. The transparent front section enables real-time monitoring of the process and adjustment of parameters during experimental studies.

This physical modelling approach provides a comprehensive understanding of bag-breaking mechanisms while minimizing development costs. The experimental setup enables the systematic investigation of parameter interactions and the optimization of operational conditions for maximum efficiency. Results from the physical model can be reliably scaled to industrial applications using established engineering principles.

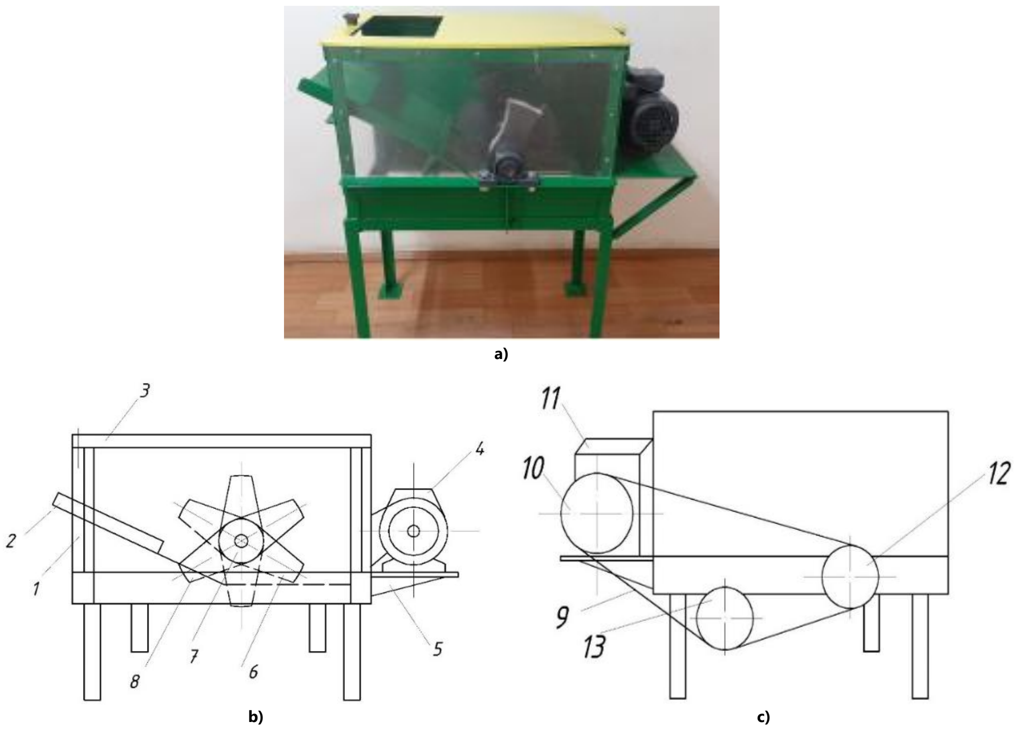

Fig. 3: Bag breaker machine: a) general view of the machine; b) structural diagram of the machine for bag breaking (front view); c) rear view of the machine for bag breaking; 1 - body; 2 - receiving table; 3 - cover; 4 - electric motor; 5 - base; 6 - knives; 7 - shaft; 8 - grate; 9 - plate chain; 10 - drive sprocket; 11 - worm gear; 12 - driven sprocket; 13 - tensioning device

Cylindrical Screen for the Fractional Sorting of Food Waste

To determine the fractional composition of food waste and justify the range of diameter variations of the cylindrical screen holes, a standard sieve developed by the K.D. Panfilov Academy of Public Utilities (RF) was used. A probabilistic model based on the morphological composition of waste was used to determine the probabilistic model of food waste. Experimental research on defining and justifying rational values for key parameters was conducted using a physical model of a cylindrical screen manufactured by the "ECO WORLD" company. Experiments were conducted over the course of a year to account for seasonal changes in waste properties. To adjust the hole diameters, cylindrical rims made of 6mm thick Steel 3 were used. To adjust the angle of the cylindrical screen's installation, built-in mechanical lifts were employed. Gears of the appropriate diameter were used to adjust the speed of the cylindrical screen's shaft.

Data Analysis and Processing

Experimental studies were conducted to validate the rational values for the key parameters of a bag breaker. These studies utilized a physical simulation setup developed in the Department of Technological Machinery Engineering at Tashkent State Transport University, specifically the SMD-1 model with a machine capacity of 1 tonne per hour. Additionally, research on sorting food components from household waste was carried out using a cylindrical screen supplied by ECO WORLD, which is the TR3/10/12 model with a capacity of 1.5 tonnes per hour. The results of these experimental studies, which determined the morphological and fractional composition of the waste, as well as validated the optimal parameters for both the bag breaker and the cylindrical screen, were analyzed and processed using Design Expert version 7.1.5 software.

RESULTS

Experimental studies on the morphological composition of municipal solid waste generated in Tashkent enabled the creation of a probabilistic waste model, which was then used to calculate the percentage of torn bags in municipal solid waste. Table 1 presents the experimental results for the morphological composition of waste generated in Tashkent.

Table 1: Morphological composition of municipal solid waste generated in Tashkent

Waste composition	2022 year	2023 year	2024 year	Average value
Paper, cardboard	23.5	26.0	26.3	25.2
Food waste	35.1	34.9	33.6	34.5
Metal	2.1	2.0	1.2	1.8
Bones	2.7	2.5	2.3	2.5
Leather, rubber	3.3	3.5	3.5	3.4
Plastic	5.8	4.9	6.2	5.6
Textile	3.6	3.7	2.4	3.2
Glass	3.1	3.5	4.9	3.9
Other	20.8	19.0	19.6	19.9
Total	100	100	100	100

The probabilistic model for determining the percentage of torn bags in experimental studies comprises the following materials: paper and cardboard (25.2%), food waste (34.5%), metal (1.8%), bones (2.5%), leather and rubber (3.4%), plastic (5.6%), textiles (3.2%), glass (3.9%) and other materials (19.9%). Fractional analysis revealed significant size-dependent distribution patterns. Waste components with dimensions greater than 250mm or less than 15mm were excluded from the analysis. Paper and cardboard were predominantly found in the 150–250mm (28%) and 100–150mm (27%) ranges. Food waste showed concentrated distribution in smaller fractions: 65% in the 15–50mm range and 33% in the 50–100mm range, totalling approximately 88% within the 15–100mm size range. Metal components were distributed across multiple fractions, with the highest concentrations found in the 50–100mm (14%) and 15–50mm (12%) ranges. Other waste materials showed varied distribution patterns across different size ranges.

Bag Breaker Optimization

Response surface methodology (RSM) was employed to determine rational parameter values for the bag breaker by investigating three factors: the roller width-to-diameter ratio (x_1), the shaft rotation frequency (x_2), and the receiving table inclination angle (x_3). Table 2 presents the experimental results for the percentage of torn bags in municipal solid waste. It is important to note that the last columns of Table 2 and 3 present the response function *γ*, which characterizes the efficiency of packet breaking. This function indicates the ratio of the sum of the original components to the sum of the components remaining after packet breaking.

Table 2: Results of bag tearing experiments

Run	Width/Diameter (x_1)	Shaft Speed (x_2,rpm)	Table Angle (x_3, °)	Torn Bags (γ, %)
1	1.2	175	20	73
2	1.5	175	20	74
3	1.2	225	20	78
4	1.5	225	20	81
5	1.2	175	40	84
6	1.5	175	40	83
7	1.2	225	40	85
8	1.5	225	40	79
9	1.1	200	30	81
10	1.6	200	30	89
11	1.35	160	30	81
12	1.35	240	30	83
13	1.35	200	13	77
14	1.35	200	47	93
15	1.35	200	30	97

Table 3: Results of food waste sorting experiments

Run	Hole Diameter (x_1,mm)	Inclination Angle (x_2, °)	Rotation Speed (x_3,rpm)	Food Waste Sorting ($γ_{11}$, %)
1	60	15	3	57
2	80	15	3	69
3	60	25	3	71
4	80	25	3	81
5	60	15	7	77
6	80	15	7	81
7	60	25	7	70
8	80	25	7	85
9	53	20	5	71
10	87	20	5	83
11	70	12	5	79
12	70	28	5	92
13	70	20	1.5	83
14	70	20	8.5	91
15	70	20	5	95

Analysis revealed that the optimal bag tearing performance was achieved with a width-to-diameter ratio of 1.35, a shaft rotation speed of 200rpm and a receiving table inclination angle of 30°, resulting in 97% bag tearing efficiency. Statistical processing of the experimental data yielded the following mathematical model:

$$Y=82{,}5+0{,}7X_1-0{,}83X_2+3{,}47X_3-0{,}73X_1X_3-1{,}0X_2X_3+0{,}65X_2^2+12{,}0X_3^2 \quad (6)$$

Formula (6) shows that the receiving table inclination angle has a significant effect on bag tearing efficiency. Increasing the angle enhances the percentage of bags that tear; however, excessive angles cause unacceptable grinding of the bag contents, which compromises subsequent sorting efficiency. The significant factor interactions confirm the quadratic nature of the adopted process model.

Cylindrical Screen Optimization

Three factors were investigated for cylindrical screen optimization: screen hole diameter (x_1), screen inclination angle (x_2), and shaft rotation frequency (x_3). Table 3 presents the results of the food waste sorting experiments. The optimal food waste sorting performance was achieved with a 70mm hole diameter, a 20° inclination angle and a 5rpm rotation speed, yielding a sorting efficiency of 95%. Statistical analysis produced the following mathematical model:

$$Y = 79{,}0 + 4{,}1X_1 - 3{,}0X_2 + 3{,}2X_3 - 3{,}3X_2X_3 + 16{,}81X_1^2 - 9{,}0X_2^2 + 10{,}24\,X_3^2 \quad (7)$$

Formula (7) indicates that all three factors significantly affect food waste sorting efficiency. The substantial nonlinearity of the process, evidenced by factor interactions, confirms the correctness of the selected quadratic model.

Technological Scheme Improvement

Optimizing the parameters for the bag breaker and cylindrical screen improved the existing waste transshipment station technological scheme. The enhanced scheme is presented in Fig. 4 and incorporates rational parameters that eliminate the need for manual labour and mechanize the bag breaking process.

Implementing the optimized bag breaker and cylindrical screen systems will increase the productivity of the waste sorting station by 25–30%. Improved food waste separation achieves 90–95% sorting efficiency, with the sorted food waste being suitable as raw material for compost production for agricultural use. This technological advancement supports the principles of the circular economy while enhancing operational efficiency and environmental sustainability.

DISCUSSION

Numerous studies have been conducted to optimize the parameters of devices used for processing solid municipal waste. For instance, in the research conducted by Zavrazhnov et al. (2008), the height of the bio fermentation chamber and the spacing between the device's cables were optimized for varying moisture contents and waste particle sizes. These optimizations led to reduced compaction of the composted material, which in turn accelerated the compost maturation process. Additionally, the study by Ganesh et al. (2017) focused on optimizing the parameters of a portable food waste disposer using the response surface method (RSM). The research justified the need for an electric drive for the portable disposer, and the parameters were fine-tuned using RSM. For example, the electric motor shaft speed was set to 700rpm, achieving the highest shredding efficiency of 90%.

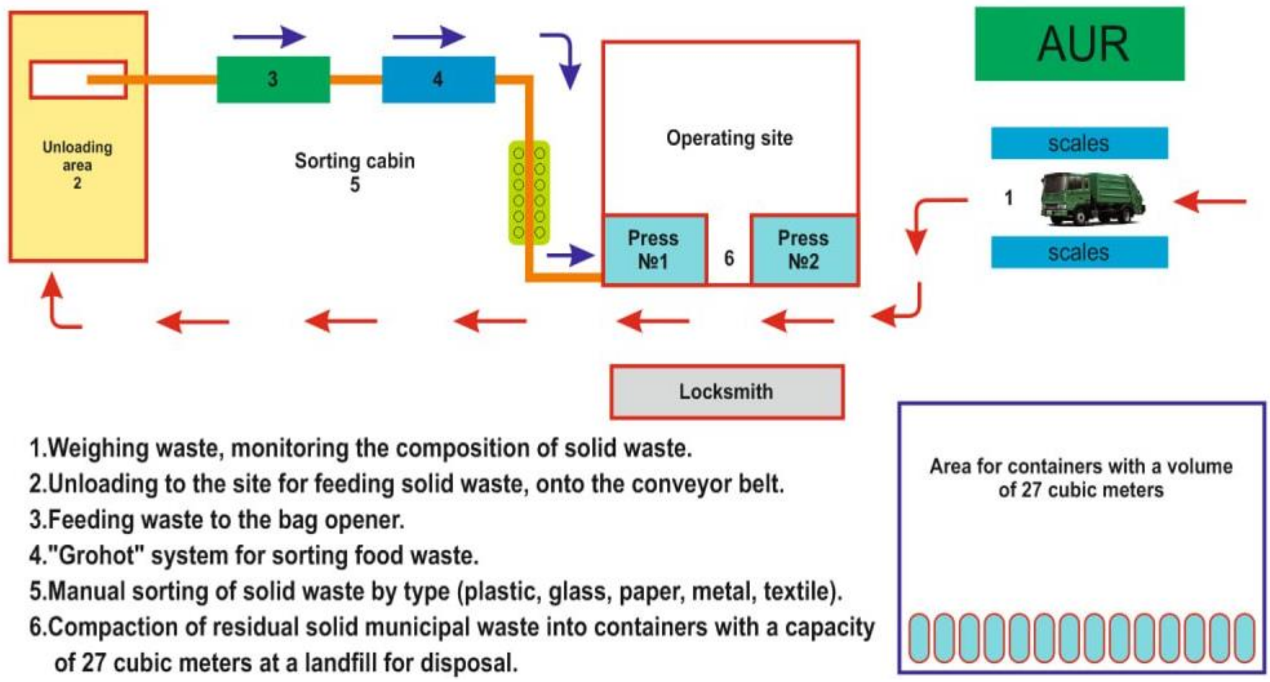

Fig. 4: Improved technology for waste disposal and transshipment at the station.

The experimental results demonstrate the superior efficiency of the optimized bag breaker, which achieves a 97% success rate in tearing bags compared to manual methods. This mechanized approach offers three key advantages: a high shredding percentage, reduced operational costs and significantly increased productivity with minimal material expenses. The machine's design meets energy and material consumption requirements through the optimal selection of parameters: a roller width-to-diameter ratio of 1.35; a shaft rotation speed of 200rpm; and a receiving table inclination angle of 30°. It is important to note that at a 30° angle of inclination for the receiving table, the cutting force is maximized due to the direct contact between the rotor blade tip and the bag surface. A rotor shaft width-to-diameter ratio of 1.35 was determined to ensure consistent bag-breaking performance, preventing bags from wrapping around the blade. As a result, a specific combination of optimized parameters leads to high bag-breaking efficiency, significantly enhancing the device's overall productivity (Manea et al., 2024).

Response surface methodology (RSM) optimization of cylindrical screen parameters revealed complex interactions between screen inclination angle and rotational speed. The synergistic effects of these variables emphasize the importance of multi-factor optimization for maximizing food waste sorting efficiency. The optimal performance was achieved with a 70mm hole diameter, a 20° installation angle and a 5rpm rotational speed, resulting in a 95% food waste sorting efficiency. An analysis of the compozition of food waste revealed that approximately 95% of the waste is smaller than 70mm. This size distribution allows for a nearly complete separation of about 97% of the food waste. The installation of a cylindrical screen at a 20° angle promotes a uniform flow of waste to the next stage without reducing the throughput of the sorting system. A key aspect of this study is that increasing the throughput of the waste sorting system not only helps minimise the negative environmental impact caused by the combustion of fuel and lubricants—due to fewer garbage trucks needed for transporting waste to landfills—but also reduces the overall volume of waste sent to landfills.

The RSM model demonstrated high accuracy, with deviations of less than 2% between the predicted and observed values confirming its usefulness in optimizing multi-parameter systems. The reliability of the quadratic model, validated through normal parameter distribution, supports its application in developing industrial machine prototypes. Both mathematical models (equations 7 and 8) effectively captured the non-linear relationships and factor interactions that govern these processes (Roudneshin & Sosa, 2024).

Plans for future integration include incorporating bag breaking and fractional sorting systems into comprehensive automated sorting complexes and waste recycling plants. This technological advancement supports the principles of the circular economy while enhancing operational efficiency and environmental sustainability. Improvements in the quality of organic waste separation, achieved through optimization of the technological process, will significantly boost soil fertility in agriculture. Research by Cherif et al. (2009) showed that applying compost from solid domestic waste at doses of 40–80 mg/ha increased wheat grain yield from 17.65 mg/ha in control plots to 58.96–60.21 mg/ha in treated plots (an increase of 234–241%). This increase in crop productivity can be attributed to higher levels of organic carbon and available nitrogen in the soil, as well as an improvement in its overall structure, which enhances water retention and nutrient cycling.

However, it is important to note that the increased yield was accompanied by a rise in heavy metal particle content. To address this issue, the authors proposed an efficiency index, which is calculated by dividing the pollutant increase factor by the grain yield factor. The treatment efficiency index indicated a reduction in manure and heavy metal contamination, which in turn contributed to a positive increase in wheat yield. Furthermore, Weber et al. (2014) discovered that applying municipal solid waste compost to sandy soils significantly enhances the efficiency with which plants uptake nitrogen, while also increasing soil microorganism biomass and enzymatic activity. The long-term benefits extend beyond the immediate supply of nutrients, as composted organic waste promotes the accumulation of organic matter in the soil. This provides a slow release of nutrients and improves the soil's physical properties, such as aggregation, porosity, and water retention capacity (Hargreaves et al., 2008). These results confirm the agricultural value of sorted organic waste obtained using the optimized sorting system developed in this study, suggesting that the achieved sorting efficiency of 90–95% could contribute significantly to sustainable soil management and reduce the agricultural sector's dependence on synthetic fertilizers in Uzbekistan.

However, regulatory obstacles regarding food waste safety (Cheng and Wen, 2022) necessitate strict compliance with toxicity testing and morphological composition regulations. There are critical research gaps concerning the purity of sorted food waste, particularly with regard to contamination by plastic and glass within food waste fractions. More comprehensive theoretical and experimental investigations are required to address these limitations and ensure the safety and quality of compost produced from sorted organic waste. The study's findings contribute to the advancement of waste management technology, providing evidence-based optimization parameters for industrial implementation. The mechanized approach is a significant improvement on manual sorting methods, offering scalable solutions to urban waste processing challenges and supporting sustainable resource recovery practices.

Conclusion

This study concludes that the machine designs developed, which are equipped with rational parameters that take into account the properties of waste and are integrated with an improved technological scheme, have increased the productivity of the waste sorting station by

25–30%. This not only offered consumers affordable recyclable materials but also decreased the number of garbage trucks needed to transport waste to landfills by about 25-30%. By selecting and validating the optimal parameters for the cylindrical screen, the percentage of sorted food waste rose to 97%. First, the possible raw material resource for producing compost for agriculture will increase. Second, due to the increased percentage of food waste, there is no need to develop and implement additional devices to improve the quality of raw materials. Third, separating food and highly liquid waste components (paper, plastic, glass, polyethylene and textiles) at waste transshipment stations will reduce the number of garbage trucks involved by 25–30%. This will save fuel and lubricants and reduce the negative environmental impact of exhaust emissions from specialized vehicles. One of the main advantages of the improved process flow chart is that it is suited to the mixed collection and transportation of waste. Additionally, the equipment in the process flow chart can easily be adapted to changes in waste properties. Using an optimized sorting complex can significantly improve the efficiency of waste processing in Uzbekistan. By extracting elastic fractions of waste, the device reduces waste disposal volumes and environmental pollution while developing a closed-loop economy. Furthermore, implementing such technologies aligns with the national strategy for sustainable waste management, offering a scalable solution for urban centres grappling with mounting waste volumes.

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Data Availability: The data presented in this research are available from the corresponding author upon reasonable request, provided it will be appropriately utilized.

Ethics Statement: The study was conducted in accordance with applicable environmental regulations and ethical standards for scientific research. No experimental interventions were carried out that could pose risks to public health, safety, or the environment. As a result, formal ethical approval or informed consent was not required for this research.

Author's Contribution: T. Khankelov conceived and designed the study, supervised the research, and wrote the original draft. G. Sydykova and M. Irisbekova developed the methodology, performed experiments, and analyzed data. Z. Alimova curated the data and managed resources. K. Shipilova provided methodological guidance and supervised the project. N. Muxamedova contributed to data curation and resource management. All authors reviewed, revised, and approved the final manuscript.

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REFERENCES

Aslanov, N.R., Mukhamadova, N.B., & Mirkhalikov, S.M. (2021). Properties of municipal solid waste and their impact on recycling technology. *Academic Research in Education Sciences,* 2(9), 240–245. https://doi.org/10.24412/2181-1385-2021-9-240-245

Agamuthu, P., & Babel, S. (2023). Waste management developments in the last five decades: Asian perspective. Waste Management & Research: *The Journal for Sustainable Circular Economy,* 41,938. https://doi.org/10.1177/0734242X231199938

Archana, P., Premjith, B., Pillai, M., Sredhar, M., Sreekanth, M., & Sivasubramanian, G. (2025). Cow dung valorization via dual-stream separation: An integrated LCA and techno-economie frame work for agricultural and algae use. *Waste Management Bulletin,* 13, 100248. https://doi.org/10.1016/j.wmb.2025.100248

Arowosegbe, O.B., Ballali, C., Kofi, K.R., Adeshina, M.K., Agbelusi, J., & Adeshina, M.A. (2024). Combating food waste in the agricultural supply chain: A systematic review of supply chain optimization strategies and their sustainability benefits. *World Journal of Advanced Research and Reviews, 24*(1), 122-140. https://doi.org/10.30574/wjarr.2024.24.1.3023

Augambaev, M.A., Abdukarimov, A.K., & Rakhimov, R.R. (1993). *Fundamentals of planning a research experiment. Tashkent: Ukituvchi.*

Baraev, M.A., & Radkevich, M.V. (2020). Ways to solve the problem of household waste accumulation. Universum: Technical Sciences: Electronic Scientific *Journal,* 73, 921.

Cheng, W., & Wen, J. (2022). Now and future: Development and perspectives of using polyphenol nanomaterials in environmental pollution control. *Coordination Chemistry Reviews,* 473, 214825. https://doi.org/10.1016/j.ccr.2022.214825

Cherif, H., Ayari, F., Ouzari, H., Marzorati, M., Brusetti, L., Jedidi, N., Hassen, A., & Boudabous, A. (2009). Effects of municipal solid waste compost, farmyard manure and chemical fertilizers on wheat growth, soil composition and soil bacterial characteristics under Tunisian arid climate. *European Journal of Soil Biology,* 45(2), 138-145. https://doi.org/10.1016/j.ejsobi.2008.11.003

Damara, D.D.N.Z., Meitiniarti, I.V., & Simamora, L. (2023). Efficient solution for food waste in Salatiga City. *IOP Conference Series: Earth and Environmental Science,* 1275(1), 012036. https://doi.org/10.1088/1755-1315/1275/1/012036

Dasgupta, P., Kumar, V., Malik, A., & Kumar, M. (2022). Wastewater Treatment Systems for City-Based Municipal Drains for Achieving Sustainability. *Circular Economy and Sustainability*, 3(1), 585–606. https://doi.org/10.1007/s43615-022-00163-z

Ferdinan, Utomo, S.W.W., Uesilo, T.E.B., & Herdienyah, H. (2021). Changes community behavior in management of household waste in Bekasi city, Indonesia. *IOP Conference Series: Earth and Environmental Science,* 716(1), 012071. https://doi.org/10.1088/1755-1315/716/1/012071

Ganesh, U.L., Rampur, V.V., & Banagar, A.R. (2017). Design and fabrication of organic portable shredder machine. *International Journal of Engineering Research & Technology*, *6*(08), 671.

Guerro, R.O., Villegas, L.G., & Guerrelo, L.A. (1999). Studies on the African production and utilization of vermicompost produced by African Night Crawlers (Eudrilus eugenia) in Philippines. *Dynamic Soil, Dynamic Plant,* 3(1), 45–50.

Hargreaves, J.C., Adl, M.S., & Warman, P.R. (2008). A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems & Environment,* 123(1-3), 1-14. https://doi.org/10.1016/j.agee.2007.07.004

Khankelov, T., Sarmoov, A., & Kadirov, A. (2023). The analytical dependence of the resistance force to digging with a bulldozer blade on the main influencing factors. *E3S Web of Conferences,* 458, 10001. https://doi.org/10.1051/e3sconf/202345810001

Khankelov, T.K., & Mukhamedova, N.B. (2023). Choice of garbage trucks with rational parameters according to the criterion of minimum operation cycle time. *E3S Web of Conferences,* 401, 02053. https://doi.org/10.1051/e3sconf/202340102053

Khankelov, T., Irisbekova, M., Rustamov, K., Abdikadirova, M., & Ochildiev, O. (2024). Bases of the method of physical modeling of the process of crushing of municipal solid waste. *Journal of Applied Engineering Science,* 22(2), 446–457. https://doi.org/10.5937/jaeso-48591

Khankelov, T., Sydykova, G., Radkevich, M., Gapirov, A., Sobirova, D., & Samandar, K. (2025). An integrated approach to selecting the optimal set of machines for sorting and crushing municipal solid waste, substantiation of their key parameters. *Journal of Applied Engineering Science, 23(1).* https://doi.org/10.5937/jaeso-53126

Khankelov, T.K., Rustamov, K.J., Irisbekova, M., & Sabirova, D.K. (2024). Substantiation of the main parameters of a hammer crusher for grinding municipal solid waste. *E3S Web of Conferences, 515, 03019.* https://doi.org/10.1051/e3sconf/202451503019

Korzhakova, A.E., & Molodkina, N.R. (2021). Use of compost from municipal solid waste for reforestation. *Young Scientist*, (20), 133–136.

Lardinois, I., & Klundert, A.V. (1993). Organic waste option for small-scale resource recovery. *Urban Solid Waste Services. Tool/Waste Consultants. Gouda: ISBN 90-70857-33-2.*

Li, Y., Li, Ya, Yu, D., Xu, L., Song, Q. (2025). Reducing food waste behaviors from the viewpoint of university students through the E-TPB model. *Circular Economy,* 43, 100154, https://doi.org/10.1016/j.cec.2025.100154

Manea, E.E., Bumbac, C., Dinu, L.R., Bumbac, M., & Nicolescu, C.M. (2024). Composting as a Sustainable Solution for Organic Solid Waste Management: Current Practices and Potential Improvements. *Sustainability*, *16*(15), 6329. https://doi.org/10.3390/su16156329

Ojukwu, U.P., & Egbuchulam, S.U. (2020). Production and characterization of organic fertilizer from organic waste. *International Journal of Agriculture and Biosciences,* 9(5), 260–262.

Okwor, A.C., Ebenebe, C.I., & Anizoba, M.A. (2012). Biodegradation of domestic organic waste using earthworm (Eudrilus eugenia): a veritable tool for agricultural and environmental sustainability. *Journal of Agriculture and Biosciences,* 1(1), 39–41.

Oumaima, M., Ayadi, M.T., Abid, I.G., & Nassour, A. (2024). Composting and mechanical biological treatment for reducing greenhouse gas emission in Bizerte, Tunisia. *Sustainability,* 16(2), 694. https://doi.org/10.3390/su16020694

Rakhmatullaev, F., Turabdjanov, S., Rakhimova, L., & Kabilov, N. (2021). The process of pyrolysis treatment of solid waste and installation for its implementation. *Universum: Chemistry and Biology,* 5, 11529. https://doi.org/10.32743/UniChem.2021.83.5.11529

Roche, K.B., Bassouka-Miatoukantama, T., Bocko, Y.E., Pando-Bahuon, A., Watha-Ndoudy, N., Nzila, J.D.D., & Loumeto, J.J. (2025). Composting urban biowaste: A potential solution for waste management and soil fertility improvement in Dolisie, Congo. *Sustainability,* 17(2), 560. https://doi.org/10.3390/su17020560

Roland, F., & Frank, W. (2022). Recycling of post-consumer packaging materials into new food packaging applications—critical review of the European approach and future perspectives. *Sustainability,* 14(2), 824. https://doi.org/10.3390/su14020824

Roudneshin, M., & Sosa, A. (2024). Optimising Agricultural Waste Supply Chains for Sustainable Bioenergy Production: A Comprehensive Literature Review. *Energies*, *17*(11), 2542. https://doi.org/10.3390/en17112542

Shen, W., Qiao, H., Tong, X., Xiao, Y., & Han, L. (2025). Assessing the sustainability performances of the supply chain of decentralized urban food waste composting for urban green spaces. *Resources, Conservation & Recycling Advances*, *25*, 200245. https://doi.org/10.1016/j.rcradv.2025.200245

Shipilova, K.B., & Turakulova, M.R. (2022). Volumes of waste accumulation in institutions of the city of Tashkent. *Universum: Electronic Scientific Journal,* 95, 13597.

Soma, D.M., Mathias, P.B., Armel, Z.N., Innocent, K.D., Zacharia, G., & Michel, S.P. (2022). Potential of biogas and organic fertilizers production through anaerobic digestion of slaughterhouse waste in Ouagadougou, Burkina Faso. *International Journal of Agriculture and Biosciences,* 12(1), 27–30. https://doi.org/10.47278/journal.ijab/2022.041

Tahir, Z., Khan, M.I., Ashraf, U., RDN, A.I., & Mubarik, U. (2023). Industrial application of orange peel waste; A review. International Journal of Agriculture and Biosciences, 12(2), 71–76. https://doi.org/10.47278/journal.ijab/2023.046

Weber, J., Kocowicz, A., Bekier, J., Jamroz, E., Tyszka, R., Debicka, M., Parylak, D., & Kordas, L. (2014). The effect of a sandy soil amendment with municipal solid waste (MSW) compost on nitrogen uptake efficiency by plants. *European Journal of Agronomy,* 54, 54-60. https://doi.org/10.1016/j.eja.2013.11.014

Zabolotskikh, V.V., Gomonitskaya, A.O., & Kutmina, S.V. (2016). Technological methods for improving the quality of compost obtained from organic waste. *News of the Samara Scientific Center of the Russian Academy of Sciences,* 18(5), 437–444.

Zavrazhnov, A.I., Mironov,V.V., & Koldin, M.S. (2008). Determination of optimal constructive-secure parameters of composting installation discharge arrangement. Achievements of Science and Technology in the Agro-industrial Complex, 8(2), 36-39.