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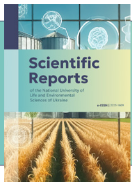

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Determining the effect of different aeration regimes on technological parameters of waste fermentation

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Abstract. The purpose of the study was to determine the optimal frequency of mechanical mixing of the substrate to intensify biothermal processes, stimulate microbiological activity, and increase the efficiency of bioconversion of organic matter. The study was performed under the conditions of an experimental farm using organic waste of plant origin and the biodestructor "Unikal-S". The effect of aeration on the temperature regime and changes in moisture content of the compost mass was analysed during 150 days of fermentation. Different mechanical mixing regimes were used: once every 3, 5, 7, and 10 days. Compost temperature was monitored daily, and moisture content was determined once every 5 days according to applicable standards. The results demonstrate that regular aeration contributed to a more intensive course of biothermal processes in soybean waste and spoiled corn silage. The highest temperature values were recorded in the variants with mechanical mixing once every 3 days. The temperature reached 62°C in soybean waste and 66°C in spoiled corn silage, indicating active development of thermophilic microflora and intensive decomposition of organic matter. More frequent mixing ensured longer maintenance of the thermophilic phase of fermentation and contributed to a more effective decrease in substrate moisture. Aeration once every 3-5 days provided the best technological parameters of fermentation and intensified bioconversion of organic waste. The

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results can be used to improve plant waste composting technologies and increase the efficiency of fermentation processes in agriculture

Keywords: aeration; composting; soybean waste; biodestructor; compost temperature; moisture; bioconversion

Introduction

Rational utilisation of organic waste from agro-industrial production is one of the priority areas of modern biotechnology. Every year, agriculture generates substantial volumes of plant residues, feed waste, and by-products from the processing of plant raw materials. If stored improperly, these materials may become a source of environmental pollution, development of pathogenic microflora, and loss of organic matter. Fermentation and composting are among the most effective methods for processing such waste, since they ensure bioconversion of organic matter into a stabilised substrate suitable for use as organic fertiliser (Sánchez-Monedero *et al*., 2018; Nasir *et al*., 2025).

Particular attention is given to soybean waste and spoiled corn silage, as they accumulate in large quantities on farms in the agricultural sector. Soybean waste contains stems, leaves, pods, and other plant components rich in organic matter, cellulose, and hemicellulose. According to A. Asghar *et al*. (2022), waste from soybean processing is characterised by diverse microbiota and a considerable nutrient content, which makes it a promising substrate for fermentation processes. The researchers also noted the possibility of effective bioconversion of soybean waste with the involvement of microorganisms. The growing interest in the use of soybean processing by-products is confirmed by the review by M. Usman *et al*. (2025), which states that soybean waste is a valuable source of organic matter and can be used to produce bioproducts, organic fertilisers, and composts. Spoiled corn silage is also considered a promising raw material for fermentation because of its high content of organic matter and carbohydrates. When fodder preparation and storage technology is disrupted, the microbial composition changes and feed value decreases, which requires effective methods of utilisation. The paper of L.V. Mitiohlo *et al*. (2023a) indicates that composting spoiled corn silage converts waste into a valuable organic fertiliser and reduces the environmental burden.

D.M. Costa *et al*. (2023) established that the intensity of fermentation processes in plant raw material depends largely on the physicochemical properties of the substrate, its moisture content, degree of grinding, and storage duration. For corn silage, material structure and fermentation conditions are important factors, as they determine microbial activity and the rate of organic matter decomposition. According to M. Atauzzaman & Q.H. Bari (2023), the efficiency of composting organic waste depends largely on temperature, moisture, medium reaction, oxygen availability, and aeration intensity. The researchers established that forced or regular aeration activates aerobic microflora, accelerates biodegradation of organic matter, and supports a stable thermophilic phase of composting. During fermentation of organic waste, the mesophilic, thermophilic, and compost maturation stages follow one another. The thermophilic phase has the greatest importance, as substrate temperature reaches 55-70°C during this period, ensuring intensive decomposition of organic matter and sanitisation of the compost mass. Current research confirms that maintenance of an optimal temperature regime is one of the key factors in obtaining high-quality compost and increasing the efficiency of bioconversion of plant residues.

Biodestructors and microbiological preparations are increasingly used to intensify fermentation processes. L.V. Mitiohlo *et al*. (2023b) established that adding biodestructors during composting of spoiled corn silage prolongs the thermophilic phase, promotes active development of bacteria of the genus Bacillus, and reduces losses of nitrogen and phosphorus. This indicates the prospects of using microbiological preparations to accelerate fermentation and increase the agronomic value of the final product. Despite the large number of scientific publications, optimisation of aeration regimes during fermentation of soybean waste and spoiled corn silage remains insufficiently examined. Identifying the optimal frequency of mechanical mixing of organic matter is particularly relevant since it should maintain high compost temperature, activate microbiological activity, and ensure an optimal decrease in substrate moisture. In this context, the study aimed to determine the effect of different aeration regimes on the technological parameters of fermentation of soybean waste and spoiled corn silage, especially the temperature regime and moisture content during composting. The work also aimed to determine the optimal frequency of mechanical mixing of the substrate to intensify biothermal processes.

Materials and Methods

The effect of aeration regimes on the technological parameters (moisture content and compost temperature) of composting soybean waste and spoiled corn silage was examined in 2025 under the conditions of the experimental farm of the State Enterprise Experimental Farm "Nyva" in Uman District, Cherkasy Oblast. Soybean waste and spoiled corn silage were selected for composting, and four replicates were formed for the control and experimental groups. The mass of each sample was 120 kg. Before composting, the soybean waste and corn silage were mechanically ground to a homogeneous mass with a particle size of 2-5 cm and then thoroughly mixed. Composting was performed separately for each type of organic raw material without mixing them with each other. The initial moisture content of the substrates was 67.2% for soybean waste and 69.5% for spoiled corn silage, which provided favourable conditions for the development of microorganisms and biothermal processes. After substrate preparation, the biodestructor was added to the experimental samples, and mini-heaps were formed from the resulting mass for further composting. The Ukrainian biodestructor "Unikal-S" was added to each organic waste sample at a dose of 60.0 g/t. The preparation is a powdered biopreparation based on a complex of effective microorganisms and enzymes. Its active components are *Bacillus subtilis* and *Bacillus licheniformis*, which are characterised by high destructive activity towards organic matter. Before application, the preparation was activated in water and evenly applied to the organic substrate. Mini-heaps for composting were then formed from the prepared samples. The prepared samples were formed into mini-heaps of the same cylindrical shape, with a volume of about 0.10 m^3 (height – 0.50 m; base diameter – 0.50 m). The mini-heaps were placed on a concrete platform under a canopy, which protected them from direct precipitation and excessive solar radiation. The surface of the heaps was covered with polyethylene film to preserve moisture, stabilise the temperature regime, and minimise heat loss. The mini-heaps were arranged on the platform by randomisation to exclude the possible effect of microclimatic differences between individual areas on the composting process. Throughout the full research period (150 days), environmental parameters were monitored, including air temperature and relative humidity. The average air temperature was 18.5 ± 4.7°C (range 10.0-28.0°C), and relative humidity – 68.0 ± 9.0% (range 50-85%). The monitoring of these indicators was used to account for the effect of external factors on the intensity of biothermal processes and ensured comparability of composting conditions across all experimental variants. In the control, each sample of both soybean waste and spoiled corn silage was mechanically mixed once every 10 days (Table 1).

***Table 1.** Scheme for examining the effect of aeration regimes on fermentation indicators of organic waste, n = 4*

Sample group	Aeration method	Frequency of operation
control	Mechanical mixing	Once every 10 days
experimental I	Mechanical mixing	Once every 3 days
experimental II	Mechanical mixing	Once every 5 days
experimental III	Mechanical mixing	Once every 7 days

Source: compiled by the authors

Compost mass temperature was monitored daily using an electronic probe thermometer that meets the requirements of DSTU OIML R 133:2019 (2019), with a measurement range from -50 to +150°C and an error not exceeding ±0.5°C. Measurements were taken in the central part of each mini-heap at a depth of 20-25 cm from the substrate surface, which corresponded to the zone of the most intensive biothermal processes. Temperature was determined at three points in each heap (in the central part and at two diametrically opposite points) to increase the representativeness of the results, after which the mean value was calculated for each sample. Moisture content in the compost was determined according to ISO 6496:1999 (1999) once every 5 days.

Results and Discussion

The results indicate that the use of the biodestructor in combination with different aeration regimes considerably influenced the temperature regime during fermentation of soybean waste. At the beginning of the experiment, on day 1, the temperature was identical in all groups and was 18°C, indicating equal initial fermentation conditions (Fig. 1).

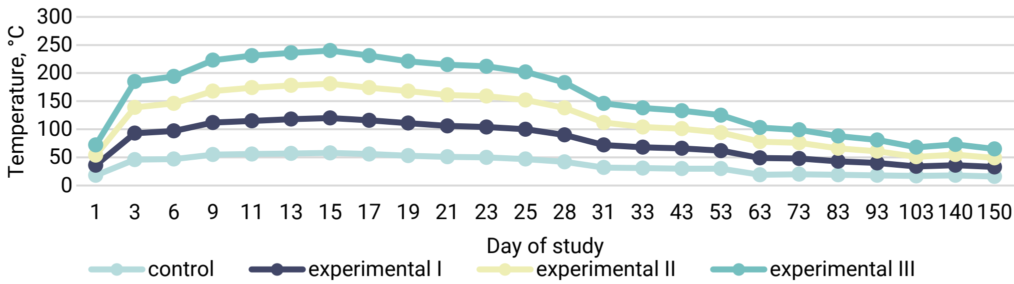

***Figure 1.** Temperature of soybean waste under different aeration regimes*

Source: compiled by the authors

On day 3, a sharp temperature increase to 46-47°C occurred in all variants. This indicates rapid activation of microbiological processes and the beginning of intensive decomposition of organic matter. At this stage, the highest temperature was recorded in experimental group I, where aeration was performed once every 3 days. In the control, experimental group II, and experimental group III, the temperature of soybean waste was 2.1% lower than in experimental group I. From day 6 to day 15, the phase of the most intensive fermentation was observed. In the control group, the temperature increased from 47 to 58°C, whereas the temperature values in the experimental groups were higher. The maximum temperature was recorded in experimental group I on day 15 of composting. The value was 3.4% and 1.6% higher than in the control and experimental group II, respectively. Under aeration once every 7 days, the temperature difference compared with the control was the smallest and was 1.7%. Therefore, more frequent mixing once every 3 days ensured the most intensive heating of the mass, indicating better oxygen access and more active functioning of aerobic or facultative anaerobic microflora.

After day 15, the temperature gradually decreased, indicating a reduction in the intensity of biochemical processes. On day 17, the temperature in the control was 56°C. During this period, the compost temperature was highest under aeration once every 3 days. The differences compared with the control and experimental group II were 7.1% and 3.4%, respectively. On day 21, the temperature decreased to 51°C in the control group, whereas in experimental groups I and II, it remained 7.8% higher. This indicates that regular aeration contributed to longer maintenance of the thermophilic phase of fermentation. From day 23 to day 33, temperature values continued to decrease. In the control group, the temperature decreased from 50 to 31°C, in experimental group I from 54 to 37°C, in experimental group II – from 55 to 36°C, and in experimental group III – from 53 to 34°C. The slowest cooling occurred in experimental group I, confirming the effectiveness of more frequent mixing for maintaining active fermentation. On day 43, the temperature in the control group was 30°C, whereas in the experimental groups it was higher by 6.7-20.0%. At this stage, the highest temperature was recorded in the variant with the most intensive aeration.

Subsequently, from day 53 to day 93, the temperature gradually approached ambient temperature. On day 63, it was 19°C in the control group, whereas in experimental group I it was 30°C, in experimental group II – 29°C, and in experimental group III – 25°C. Even on day 73, the experimental variants maintained higher temperatures than the control value of 20°C. This indicates a longer course of fermentation processes under regular aeration. On day 103, the temperature in all groups equalised and was 17°C, indicating completion of the active fermentation phase. Later, on days 140 and 150, the temperature remained low, at 16-19°C, which corresponded to the final phase of organic matter stabilisation.

Thus, the most effective aeration regime was recorded in experimental group I, where mechanical mixing was performed once every 3 days. In this variant, the highest temperature value, 62°C, and prolonged maintenance of elevated temperature during fermentation were observed. Experimental group II, with mixing once every 5 days, also demonstrated high results close to those of experimental group I. Mixing once every 7 days was less effective, although it still ensured a better temperature regime than the control. The control group, where mixing was performed only once every 10 days, had the lowest temperature values in most observation periods, pointing to a less intensive course of fermentation. Analysis of the results presented in Figure 2 reveals considerable changes in the temperature of spoiled silage depending on fermentation duration and aeration regime. At the beginning of the study, the temperature was the same in all groups at 22°C.

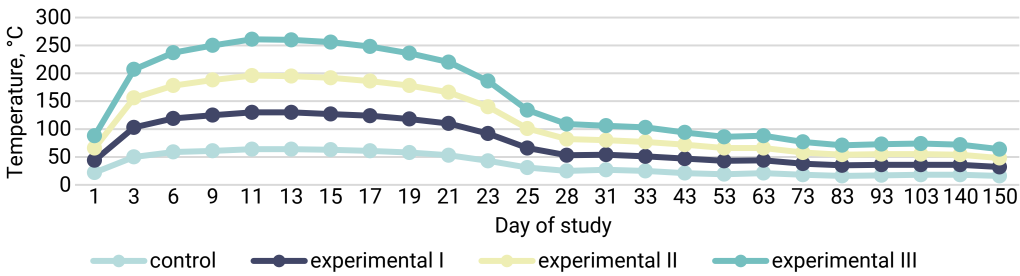

Figure 2. *Temperature of spoiled corn silage under different aeration regimes*

Source: compiled by the authors

On day 3, a sharp temperature increase to 50-53°C was observed in all experimental variants. This temperature rise is explained by the activation of microbiological processes and the intensive decomposition of organic matter in the silage. During the first two weeks, the temperature continued to increase and reached maximum values on days 11-13 of the study. In the control group, the temperature was 64°C. With two mixings per 10 days, the silage temperature in the samples was 1.6% higher than in the control. Similar results were obtained under aeration of waste once every 7 days (experimental group III). Mechanical mixing of spoiled silage once every 3 days increased the temperature by 3.1% compared with the control. Higher temperature values in the experimental variants indicate a more intensive course of biothermal processes under different aeration regimes. Oxygen supply activated aerobic microflora, which accelerated oxidation of organic compounds and was accompanied by the release of a substantial amount of heat.

It is particularly important that the temperature remained within 60-66°C for a rather long period – approximately from day 6 to day 17. This temperature regime is characteristic of the active thermophilic phase of bioconversion of organic raw material. During this period, readily available organic substances are intensively destroyed, the number of pathogenic microorganisms decreases, and partial sanitisation of the substrate occurs. High temperatures were maintained longest in experimental groups I and II, which may indicate optimal aeration conditions in these variants. From day 19, a gradual decrease in temperature was observed in all groups. This is explained by reduced microbial activity due to depletion of readily available nutrients. On day 25, the temperature in the control group decreased to 31°C, whereas in the experimental groups it remained higher by 6.4% and 12.9%. This indicates a longer course of organic matter mineralisation in the aerated variants.

Subsequently, the temperature gradually stabilised and approached ambient temperature. On days 43-63, the temperature in the control group ranged from 19 to 21°C, whereas in the experimental groups it remained 15.7-23.8% higher. During this period, the highest compost temperature remained in the variant in which the substrate was enriched with oxygen most intensively. This indicates continuation of weak microbiological processes in the aerated variants even after completion of the active thermophilic stage. At the end of the experiment, on days 140-150, the temperature in all groups almost equalised and was 16-18°C, indicating completion of the main biological decomposition processes and stabilisation of the substrate. Thus, the results indicate that different aeration regimes promoted more intensive development of biothermal processes in spoiled silage. The most pronounced temperature effect was observed in experimental groups I and II, where the highest temperatures and the longest maintenance of the thermophilic and mesophilic phases were recorded. This corresponds to a more effective course of organic matter bioconversion under optimised aeration conditions.

The main technological indicator, along with temperature, is moisture content in the biomass. The activity of bacterial enzymes is realised in moist waste. At low moisture content, enzymes do not display hydrolytic activity. Therefore, the task was to determine how the frequency of mechanical mixing affects the moisture content in soybean waste. The results prove that the mechanical mixing regime considerably influenced changes in moisture content in soybean waste during fermentation. In all experimental groups, moisture content gradually decreased throughout the research period, which was associated with active microbiological processes, heat release, and evaporation of water from the fermented mass (Table 2). On day 1, the moisture content was the same in all groups at 67.2%. This is due to equal initial conditions for the experiment. Already on day 5 of fermentation, a slight decrease in moisture was recorded in all variants. In the control group, the value was 67.0%. In experimental groups I and II, the moisture content was 0.2% and 0.8% lower, respectively, than in the control group. The greatest moisture decrease at the early stage was recorded in experimental group I, where mechanical mixing was performed once every 3 days. On day 10 of the research, the process of moisture loss intensified. In the control group, moisture content decreased to 65.4%. In the experimental groups, the moisture content in soybean waste was 0.4-2.2% lower than in the control. Compared with day 5 of fermentation, the smallest moisture losses were recorded in the control group and the largest in experimental group I, amounting to 1.6% and 3.0%, respectively. Thus, the lowest moisture value was observed in the variant with the most frequent mixing. This is explained by more intensive oxygen saturation of the substrate, activation of microbiological processes, and increased heat release, which promoted more active evaporation of water.

***Table 2.** Moisture content in soybean waste under different mechanical mixing regimes during fermentation, %, M ± m, n = 4*

Day of study	Sample groups			
	control	experimental I	experimental II	experimental III
1	67.2 ± 1.23	67.2 ± 0.78	67.2 ± 1.33	67.2 ± 1.32
5	67.0 ± 0.23	66.2 ± 1.45	66.8 ± 1.08	67.0 ± 1.05
10	65.4 ± 0.67	63.2 ± 1.43	64.7 ± 0.76	65.0 ± 1.33
20	64.2 ± 1.21	61.2 ± 1.64	63.0 ± 0.86	63.8 ± 1.06
30	61.0 ± 1.11	58.1 ± 1.22	59.4 ± 0.58	60.5 ± 0.87
40	60.7 ± 1.43	57.2 ± 1.42	58.4 ± 0.77	60.0 ± 0.58
50	60.6 ± 1.53	55.8 ± 1.18	58.0 ± 0.86	59.8 ± 0.88
60	60.4 ± 1.25	55.0 ± 0.87	57.2 ± 0.93	59.1 ± 0.94
70	60.1 ± 1.55	54.3 ± 0.86	56.1 ± 1.23	58.0 ± 0.68
80	59.6 ± 0.56	53.3 ± 0.98	55.7 ± 1.04	57.3 ± 0.78
90	58.7 ± 0.64	52.7 ± 0.88	55.3 ± 1.45	56.4 ± 0.67
100	58.4 ± 0.37	52.4 ± 0.76	55.0 ± 1.06	56.0 ± 0.95
110	58.0 ± 0.49	51.3 ± 1.32	54.2 ± 0.88	55.1 ± 0.90
120	56.5 ± 0.76	50.0 ± 1.25	53.2 ± 0.78	54.0 ± 0.76
130	55.9 ± 1.09	49.2 ± 1.06	51.2 ± 0.94	53.3 ± 1.33
140	55.0 ± 1.04	48.2 ± 0.67	49.5 ± 0.75	51.2 ± 1.25
150	54.3 ± 0.77	46.3 ± 0.54	48.1 ± 0.59	50.4 ± 0.99

Source: compiled by the authors

During the first 30 days of fermentation, the moisture content decreased intensively in all groups. On day 20, in the control group, it was 64.2%. During this period, a relationship was established: the more active the aeration, the lower the moisture content in soybean waste. The moisture content in compost from experimental group I was 3.0% lower than in the control. On day 30, the values decreased to 61.0%, 58.1%, 59.4%, and 60.5%, respectively. The most intensive dehydration was observed in experimental group I, whereas the process was slowest in the control variant. From day 40 to day 70 of fermentation, the decrease in moisture continued, although its intensity declined slightly. On day 40, the moisture content in the control group was 60.7%. In experimental groups I, II, and III, this value was 4.8%, 2.3%, and 0.7% lower, respectively. On day 70 of fermentation, the moisture content in waste from the experimental groups was 0.7%, 1.1%, and 1.1% lower, respectively, than the data obtained on day 60 of the experiment.

The results confirm that the most frequent mechanical mixing ensured the most active reduction of moisture in the organic mass. In experimental group I, the difference from the control on day 70 was 5.8%. Experimental group II was also characterised by sufficiently intensive dehydration, whereas in experimental group III, where mixing was performed less frequently, the changes were less pronounced. In the second half of the experiment, from day 80 to day 120, moisture continued to decrease gradually in all variants. On day 80, the value in the control group was 59.6%. In the experimental groups, the values were lower by 2.3-6.3%. On day 100, moisture content was 58.4%, 52.4%, 55.0%, and 56.0%, respectively. On day 120 of the research, the intensity of moisture loss decreased, but the pattern of evaporation associated with aeration frequency remained stable. At the final stage of fermentation, moisture loss continued, although more slowly. The lowest moisture level was recorded on day 150 of fermentation: in the control group, the value was 54.3%. Under aeration once every 3 and 5 days, the moisture content in the compost during this period was 8.0% and 6.2% lower, respectively, than in the control.

Overall, during the whole period, moisture content decreased by 12.9% in the control group, by 21.2% in experimental group I, by 19.1% in experimental group II, and by 16.8% in experimental group III. Thus, moisture losses were highest under the most frequent mechanical mixing. More frequent mixing promoted better aeration of the substrate, more active development of aerobic microflora, and a more intensive course of fermentation processes. Mixing once every 5 days also ensured sufficiently effective dehydration of the mass, whereas mixing once every 7 days was less effective but still exceeded the control variant. Data in Table 3 present a gradual decrease in moisture content in spoiled corn silage throughout the fermentation period, regardless of the mechanical mixing regime. At the beginning of the experiment, moisture content was the same in all groups and was 69.5%, confirming equivalent initial experimental conditions.

Table 3. *Moisture content in spoiled corn silage under different mechanical mixing regimes during fermentation, %, M ± m, n = 4*

Day of study	Sample groups			
	control	experimental I	experimental II	experimental III
1	69.5 ± 1.32	69.5 ± 1.06	69.5 ± 1.06	69.5 ± 1.44
5	69.1 ± 1.11	67.9 ± 1.03	68.8 ± 1.07	69.2 ± 1.53
10	68.4 ± 1.08	66.3 ± 1.05	67.0 ± 1.23	68.0 ± 1.25
20	66.2 ± 1.04	64.3 ± 1.23	65.5 ± 1.52	66.1 ± 1.31
30	65.2 ± 1.05	63.5 ± 1.22	64.3 ± 1.11	64.9 ± 1.07
40	64.2 ± 1.23	61.4 ± 1.15	63.3 ± 1.27	64.0 ± 1.23
50	62.2 ± 1.51	59.2 ± 1.16	60.7 ± 1.53	61.8 ± 1.06
60	60.2 ± 1.17	56.5 ± 0.86	58.3 ± 1.04	59.5 ± 1.17
70	58.5 ± 0.87	55.5 ± 0.94	57.2 ± 1.32	58.0 ± 1.27
80	57.3 ± 0.96	54.7 ± 0.58	55.4 ± 0.96	56.7 ± 0.86
90	57.0 ± 0.59	54.0 ± 0.54	55.0 ± 0.58	56.2 ± 0.85
100	56.8 ± 0.68	53.8 ± 0.88	54.2 ± 0.88	55.5 ± 0.47
110	56.3 ± 0.83	51.4 ± 0.59	53.3 ± 0.57	55.6 ± 0.76
120	56.0 ± 0.96	50.8 ± 0.64	52.7 ± 0.86	55.1 ± 0.94
130	55.6 ± 0.59	49.0 ± 0.73	52.0 ± 0.45	54.4 ± 0. 82
140	55.3 ± 0.55	48.2 ± 0.74	51.5 ± 0.93	54.6 ± 0.76
150	55.1 ± 0.76	47.2 ± 0.93	51.0 ± 0.77	53.2 ± 0.77

Source: compiled by the authors

On days 5-10, a decrease in compost moisture was observed. In the control group, the value on day 10 was 68.4%. The most intensive decrease occurred in experimental group I, where the value was 2.1% lower than in the control. In experimental groups II and III, the moisture content was 1.4% and 0.4% lower than in the control, respectively. This demonstrates that mechanical mixing activated fermentation processes and promoted faster moisture evaporation due to increased aeration and heat release. During days 20-60, the downward trend in moisture content persisted in all groups. The lowest values were consistently recorded in experimental group I. Thus, on day 60, the moisture content in the control group was 60.2%, whereas in the experimental group I, it was only 56.5%, or 3.7% lower. In experimental groups II and III, this value was 1.9% and 0.7% lower than in the control, respectively. The results indicate that more intensive mechanical mixing ensured better contact between the organic mass and air, activated aerobic microflora, and accelerated biodegradation of organic components.

After day 70, the rate of moisture decrease slowed somewhat, which may be associated with a reduction in the intensity of microbiological processes and the transition of fermentation to the stage of organic mass stabilisation. Nevertheless, the difference between the experimental and control groups remained noticeable. On day 100, the moisture content in the control group was 56.8%. Under the most intensive aeration (experimental group I), the moisture content was 3.0% lower than in the control. At the end of the study, on day 150, the lowest moisture content was established in experimental group I, at 47.2%, which was 7.9% lower than in the control, where this value was 55.1%. In experimental groups II and III, it was 51.0% and 53.2%, respectively. Ultimately, mechanical mixing had a considerable effect on moisture loss during fermentation of spoiled corn silage. During the thermophilic phase of fermentation of spoiled corn silage, relative moisture losses in both the control and experimental samples were considerably higher than during the period of temperature decrease to the mesophilic or psychrophilic phase. Reduction of substrate moisture has important technological significance, as it improves the structure of the fermented mass, reduces the risk of anaerobic pathogenic microflora development, and stabilises organic matter. Excessively high moisture can suppress aerobic processes, whereas its gradual decrease creates favourable conditions for effective biothermal fermentation. Thus, the results indicate that mechanical mixing during fermentation of spoiled corn silage contributed to a more intensive decrease in substrate moisture. The greatest losses were recorded under the conditions of mixing once every 3 days.

The obtained results of the experiment demonstrate that aeration regimes majorly influenced the fermentation of soybean waste and spoiled corn silage. The most intensive development of biothermal processes was observed when the organic mass was mechanically mixed once every 3 days. This was accompanied by an increase in compost temperature to 62-66°C and prolonged maintenance of the thermophilic phase. Similar results were presented by C.T. Chang *et al.* (2022), who established that active composting of food waste and soybean curd residue is accompanied by intensive heat release and formation of a stable thermophilic phase, which ensures effective bioconversion of organic matter. Similarly, C. Sundberg (2005) noted that control of aeration and temperature regime is a determining factor in maintaining an active thermophilic phase during composting of organic waste. The study established that more frequent mechanical mixing promoted more intensive oxygen access to the substrate mass, which activated oxidative processes and accelerated bioconversion of organic matter. Similar patterns are described in the work of M. Atauzzaman & Q.H. Bari (2023), where aeration is identified as one of the key factors in maintaining active composting and increasing the temperature of the fermented mass. K.K. Patel *et al.* (2025) also reported that, during vermicomposting of soybean plant residues, intensive development of microbiological processes ensures active decomposition of organic components and transformation of cellulose-containing raw material into a stable organic product. M.P. Raut *et al.* (2008) established that the highest activity of microbial enzyme systems and the most intensive decomposition of organic compounds occur during the thermophilic period.

According to the data of the current study, under aeration once every 3 and 5 days, the temperature of the organic mass remained higher than in the control even in the second half of fermentation. This points to a longer course of microbiological processes and slower depletion of the nutrient substrate. Similar conclusions were reached by Y. Tang *et al.* (2025), who established that the intensity of fermentation processes in corn silage depends largely on microbial activity and fermentation conditions, which determine the quality of the final product. P. Zhou *et al.* (2025) also stated that corn silage and corn plant residues have high bioconversion potential due to the substantial content of organic matter and available carbohydrates. Similar findings were presented by M. Waqas *et al.* (2023) and Z.X. Keng *et al.* (2023), showing that optimal aeration prolongs the active phase of composting, supports intensive development of aerobic microflora, and increases the efficiency of organic matter mineralisation.

Moisture content in the substrate was an important technological indicator of fermentation. In the presented study, increasing the frequency of mechanical mixing increased the intensity of moisture loss. The lowest moisture content in soybean waste and spoiled corn silage was observed in experimental group I, where aeration was performed once every 3 days. This can be explained by increased water evaporation due to active heat release and a more intensive course of aerobic processes. During the thermophilic phase, moisture losses were considerably more intensive than during the mesophilic or psychrophilic phases of fermentation. Similar patterns were highlighted by C.T. Chang *et al.* (2022), who associated active reduction of substrate moisture with high temperature and intensive microbial metabolism during the thermophilic stage of composting. However, excessive moisture reduction can suppress microbial activity; therefore, maintaining an optimal water regime is an important technological task. Parallel conclusions on the effect of moisture on silage fermentation were obtained by K.G. Arriola *et al.* (2011), who found that the physicochemical parameters of the substrate directly affect the intensity of microbiological processes and the quality of the final product.

The use of the biodestructor "Unikal-S" combined with regular aeration promoted the activation of biodegradation of the organic components of the substrate. The results correspond to the conclusions of K.K. Patel *et al.* (2025), who established that using biologically active agents during the processing of soybean plant residues accelerates the destruction of organic matter and humification of the substrate. S. Panda & M.S. Jain (2025), in a systematic review, also emphasised that modern biotechnological methods for processing soybean waste ensure effective utilisation of organic raw material and production of valuable bioconversion products. V.V. Volkogon *et al.* (2019) established that the introduction of cellulolytic microorganisms accelerates decomposition of plant residues and optimises microbiological processes during composting. L.V. Mitiohlo *et al.* (2023b) reported a positive effect of biodestructors on the temperature regime and fermentation intensity of spoiled corn silage. The results on fermentation of spoiled corn silage also align with data from J.M. Wilkinson *et al.* (2015) and G. Santi *et al.* (2015), who noted that corn silage is a biologically active substrate with a high content of organic matter and considerable potential for aerobic and anaerobic bioconversion, provided that optimal technological process parameters are maintained. Thus, the results confirm that optimisation of aeration regimes is an important factor in intensifying the fermentation of organic waste. The most effective conditions were mechanical mixing once every 3 days, which ensured the highest temperature values, a more active course of biothermal processes, and more intensive reduction of substrate moisture.

Conclusions

The conducted study indicated that aeration regimes considerably influenced the technological parameters of fermentation of soybean waste and spoiled corn silage. Mechanical mixing of the organic mass activated biothermal processes, increased compost temperature, and ensured a more intensive reduction of substrate moisture. The most effective aeration regime was mixing once every 3 days, under which the highest temperature values and the longest maintenance of the thermophilic phase of fermentation were observed. Under intensive aeration, the temperature reached 62°C in soybean waste and 66°C in spoiled corn silage. Maintenance of these temperature regimes promoted active microbiological processes, more intensive decomposition of organic matter, and partial sanitisation of the substrate. In the control variants, where mixing was performed once every 10 days, temperature values were lower, indicating a less intensive course of fermentation.

More frequent mechanical mixing positively affected oxygen access to the depth of the organic mass, activated aerobic microflora, and accelerated bioconversion processes. Under aeration once every 3 and 5 days, the experimental groups maintained elevated temperatures for a longer period even after completion of the active thermophilic stage, indicating a prolonged course of microbiological processes. The research established a considerable effect of aeration regimes on changes in the moisture content of the fermented mass. The greatest moisture losses were characteristic of the variants with the most intensive aeration. On day 150 of fermentation, the moisture content in soybean waste under mixing once every 3 days was 8.0% lower than in the control, and in spoiled corn silage it was 7.9% lower. This indicates more active water evaporation due to increased heat release and a more intensive course of aerobic processes.

The use of the biodestructor "Unikal-S" combined with mechanical mixing contributed to the stabilisation of the fermentation process, acceleration of organic matter biodegradation, and improvement of technological composting parameters. The results confirm the feasibility of using aeration once every 3-5 days as an effective technological method during fermentation of soybean waste and spoiled corn silage to intensify biothermal processes and increase the efficiency of bioconversion of organic waste. Further research should determine optimal aeration parameters for different types of organic raw material, analyse the dynamics of microbial communities during fermentation, and evaluate the agronomic efficiency and environmental safety of the resulting product when used as organic fertiliser.

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Conflict of Interest

None.

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Встановлення впливу різних режимів аерації на технологічні показники ферментації відходів

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Анотація. Метою роботи було встановлення оптимальної кратності механічного перемішування субстрату для інтенсифікації біотермічних процесів, активізації мікробіологічної діяльності та підвищення ефективності біоконверсії органічної маси. Дослідження проводили в умовах дослідного господарства із використанням органічних відходів рослинного походження та біодеструктора «Унікал-с». У процесі дослідження вивчали вплив аерації на температурний режим та зміну вологості компостної маси упродовж 150 діб ферментації. Для цього використовували різні режими механічного перемішування: один раз на 3, 5, 7 та 10 діб. Температуру компосту контролювали щодоби, а вміст вологи визначали один раз на 5 діб згідно чинних стандартів. Встановлено, що застосування регулярної аерації сприяло інтенсивнішому перебігу біотермічних процесів у відходах сої та зіпсованому силосі кукурудзи. Найвищі температурні показники були зафіксовані у варіантах із механічним перемішуванням один раз на 3 доби. Температура у відходах сої досягала 62 °С, а у зіпсованому силосі кукурудзи – 66 °С, що свідчило про активний розвиток термофільної мікрофлори та інтенсивне розкладання органічної речовини. Виявлено, що частіше перемішування забезпечувало триваліше утримання термофільної фази ферментації та сприяло ефективнішому зниженню вологості субстрату. Доведено, що аерація один раз на 3-5 діб забезпечувала найкращі технологічні показники ферментації та сприяла інтенсифікації біоконверсії органічних відходів. Отримані результати можуть бути використані для удосконалення технологій компостування рослинних відходів та підвищення ефективності ферментаційних процесів у сільському господарстві

Ключові слова: аерація; компостування; відходи сої; біодеструктор; температура компосту; вологість; біоконверсія