THE SUSTAINABLE RECYCLING OF *BRASSICA OLERACEA* L. WASTE WITH THE USE OF MEAT BONE MEAL AND BIO-STIMULANTS

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Abstract
Economically sustainable bioconversion of vegetable waste into a higher value product for soil improvement can be good practice in reducing the use of mineral fertilizers. The use of MBM (meat and bone meal) and bio-stimulants (BIO) have the potential to optimize the technological parameters of the process by reducing the fluctuations of the indicators. The aim of this work was to determine the effect of different MBM and BIO rates on the parameters of the composting process of cabbage waste (CW) and wheat straw (WS) mixtures in the mesophilic phase. The study assessed the dynamics of temperature and pH changes and the release of CO_2 emissions. During the experiment, 5 mixture variants were created, including a Control, using 5 and 15% MBM and 5 and 15 % MBM+BIO. The results showed that the 15 % MBM+BIO additive rate acted as a buffer system, reducing the fluctuations of pH indicators compared to the Control. During the entire process, the treatments with the 15 % additive rate were characterized by higher temperature values. The highest CO_2 emissions were observed at the 5 and 15% MBM additive rates, while the lowest CO_2 values were determined in the 15% MBM+BIO (0.37%) and 5% MBM+BIO (0.21%) treatments during and at the end of the study, compared to the Control (0.1%). This study showed a positive effect of the 15% additive both with and without BIO, ensuring pH stability, faster temperature rise, and lower CO_2 emissions.
Key words: *composting; cabbage waste; organic additives; mesophilic stage, bioeffectors.*

INTRODUCTION

Population growth encourages more intensive vegetable production, which is why increasingly abundant harvests are obtained in agriculture every year. Considering the sensitivity of vegetables not only to environmental factors, but also to mechanical impact, significant amounts of biodegradable waste (BW) are generated during both harvesting and primary processing operations. The scope of the problem is increased by pests, diseases, improperly adjusted operating parameters of harvesting machines and primary processing equipment, climatic and storage conditions, and inappropriate logistics chains (*Senkienė et al., 2025*). An analysis of waste management practices generated in vegetable farms showed the main waste management methods: burning waste or leaving it on the soil surface, mulching (*Bhatia & Sindhu, 2024; Jusoh et al., 2013*), bioenergy production (*Koul et al., 2022*), incorporation into the soil (*Coulibaly, 2020*), and composting. However, in the context of sustainability, the bioconversion of BW into valuable organic fertilizers using composting technology is highlighted as one of the most effective and environmentally friendly measures.

Composting involves the decomposition of biodegradable heterogeneous organic materials carried out in an oxygen environment by a succession of mesophilic and thermophilic microorganisms (m/o). The optimized initial parameters of the mixtures (C:N ratio 25–30:1; oxygen content ≥ 5%, humidity 40 – 65% (*Azim et al., 2018*) ensure the consistency of the decomposition process in four temperature phases: mesophilic, thermophilic, cooling and maturation (*Meena et al., 2021*). The essential difference is the temperature and the m/o and their microbial activity products that dominate in different ranges. The final stable product, compost, is distinguished by its economic viability and ecological alternative to mineral fertilizers, potentially increases soil porosity (*Siedt et al., 2021*) and reduces its compaction. As a result, soil structure, water infiltration and moisture retention potential are improved (*Koul et al.,* *2022*), which improves soil arability. Compost acts as a soil restoration, erosion control (*Bhattarai et al., 2011*) and a means of inhibiting pathogenic m/o (*Neher et al., 2022*) stimulate the activity of soil microbiota, ensure long-term supply of nutrients to plants and thus contribute to the development of sustainable horticulture.

Various organic and biological additives and their complex combinations are used to improve the efficiency of the composting process of vegetable waste and enrich the nutritional value of compost. Considering the importance of the sustainability aspect and the concept of waste-free production, one of the possible organic additives is meat and bone meals, which is characterized by important nutrients for the soil. Previous scientific studies have shown a positive effect of the MBM additive on the population and activity of microbes participating in the composting process (*Jatana et al., 2020*), which is associated with a longer thermophilic phase, inhibition of pathogenic m/o and faster decomposition of complex cellulosic compounds (*Liu et al., 2022*). BIO can also have a significant effect by contributing to favorable growth conditions ensuring different plant cultures (*Buragienė et al., 2023*). However, there is still a lack of new knowledge on how the complex use of MBM and BIO can affect different technological parameters of the composting process.

The aim of this work is to determine the effect of different MBM and BIO rates on the parameters of the composting process of cabbage waste (CW) and wheat straw (WS) mixtures: temperature, pH and CO_2 emissions in the mesophilic phase.

MATERIALS AND METHODS

A short-term experimental study was conducted in April–June 2025 at the Climate-Friendly Regenerative and Precision Agriculture Research Infrastructure (CLIMAGRO LT) laboratory, Faculty of Agronomy, Academy of Agriculture, Vytautas Magnus University, Lithuania. 15 pcs. 100 l recycled plastic composters were used for the composting process (Fig. 1 and 2).

Fig. 1 Composting equipment (Hozelock EasyMix 2, Hozelock Ltd, United Kingdom*)*

Fig. 2 Measurement points for temperature, pH, and gas concentrations

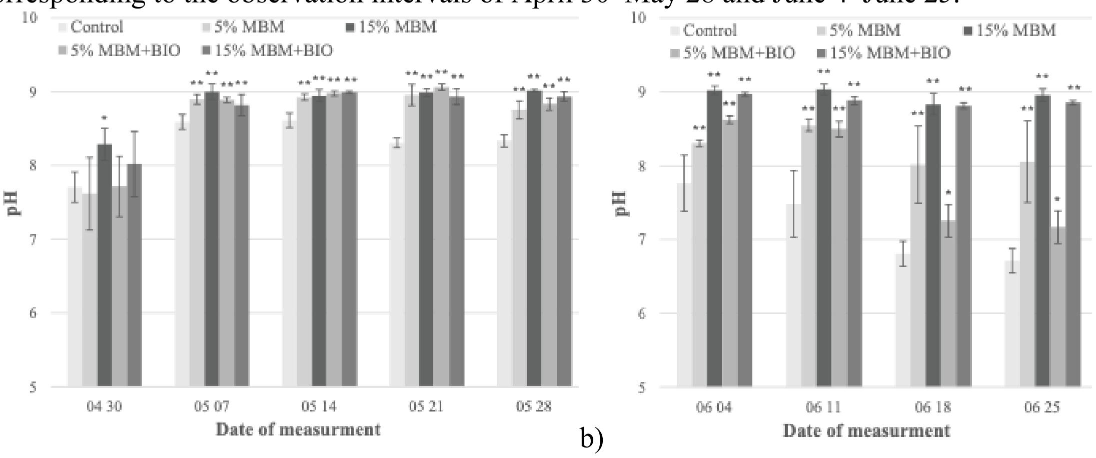
The waste used for the study was collected from UAB "Kvėdarų ūkis" operating in the Kėdainiai district, Lithuania. This waste consisted of outer cabbage leaves and stems. The WS were obtained from the VMU Agricultural academy Testing Station Crop Farm. The supply of MBM, MBM+BIO additives was ensured by UAB "Cignera". Based on the chemical analysis studies performed by the accredited laboratory (Lithuanian Agricultural and Forestry Research Center) provided by the supplier, the elemental composition of MBM was determined: min 8% nitrogen (N); min 14% phosphorus pentoxide (P_2O_5); 14% calcium oxide (CaO); min 1% potassium oxide (K_2O), pH – 6.5.

5 experimental treatments were created, the main base of which was the control treatment (Control: 10 kg CW, 1 kg WS). Other treatments differed in the concentrations of additives used and the use of BIO additive. The percentages of MBM, MBM+BIO were calculated based on the total mass of the mixture and corresponded to 5% – 0.5 kg; 15% – 1.5 kg of granules. The identification of compostable mixture treatments was made: 1 – Control; 2 – 5% MBM; 3 – 15% MBM; 4 – 5% MBM+BIO; 5 – 15% MBM+BIO. 3 replications were assigned to each test treatment; the total sample of test treatments was 15 units. The composters were arranged in a random order in the laboratory. Aeration and mixing of the

compostable mixtures were carried out on weekdays, turning the composter 5 times. During the study, the room temperature fluctuated around 21 °C.
During the experiment, the temperature, pH, and CO_2 gas concentrations of the compostable mixtures were recorded. A hygrometer with a WET sensor (Delta-T HH2, Delta-T Devices Ltd, United Kingdom) was used to measure the temperature. Measurements were performed daily, on weekdays. The pH values of the composted mixtures were determined with a pH meter (GroLine Portable Soil pH Meter – HI98168, Hanna Instruments, USA). The device was calibrated before each measurement using standard buffer solutions. Gas concentrations were determined with a gas analyzer (Screenalyt HONOLD, Honold Umweltmesstechnik, Germany). pH and gas concentrations were measured once a week.
The obtained data were statistically analyzed using the one-factor analysis of variance (ANOVA) method. LSD ($p \leq 0.05$, $p \leq 0.01$) tests were used to determine the significance of differences between the means of the treatments. Gas concentrations were evaluated using the statistical software package – SELEKCIJA (*Raudonius, 2017*).

RESULTS AND DISCUSSION

When evaluating the dynamics of pH changes in the mesophilic phase, a significant influence of the concentration of 15% MBM and both MBM+BIO variants on the alkalinity of the composted mixtures was observed. Throughout the study, the Control variant was characterized by the lowest pH, ranging from slightly alkaline (pH – 7.7 at the beginning of the study) to neutral (pH – 6.7 at the end). The pH of the medium of mixtures with 5 and 15% additive rates tended to increase to slightly alkaline, which is associated with the nitrogen (N) contained in the MBM. Ammonia formed during the N decomposition process increased the pH of the medium, especially in variants with 15% additive rates. Analogous alkalization of composted mixtures at the initial stage was determined in the study by *Tibu et al.* (2019) (pH ranged from 7.14 to 8.29). In the asparagus straw composting study conducted by *Liu et al.* (2022), MBM did not cause sudden pH fluctuations. This explains why the 15% additive rates used in the study were characterized by the greatest stability and the lowest dispersion. At the end of the study, only one variant with the incorporated 5% MBM+BIO additive was characterized by an almost neutral pH (7.17). The dynamic changes in the medium pH of the composted mixtures are presented in Fig. 3a and Fig. 3b, corresponding to the observation intervals of April 30–May 28 and June 4–June 25.



a) b)

Fig. 3a, b Dynamics of pH changes in compostable mixtures. Statistically significant differences between the Control and experimental variants are marked on separate dates. * – $p \leq 0.05$, ** – $p \leq 0.01$.

The results of temperature changes (Fig. 4) showed an exponential increase in temperature already on the second day of the study. This is characteristic of the composting process described in the scientific literature (*Azim et al., 2018*). At that time, the temperature rose from 20.5 (Control) – 21.03 °C (15 % MBM+BIO) to 24.37 (Control) – 26.98 (5 % MBM+BIO), which indicated the onset of an intensive decomposition process. A similar trend in temperature increase was described by *Chinakwe et al.* (2019), indicating a sharp increase in temperature after stacking the composted raw materials. During the entire study, maximum temperature values were recorded on the third and sixth days of the study. In the variants with the BIO additive, the temperature rose faster and reached 27.9 – 29.89 °C. A clear decrease in temperature was observed in all mixtures during the 05 05 period, which may be associated with the use of readily available nutrients during intensive m/o activities or intensive daily mixing (*Franke-Whittle et al., 2014*). After a two-month study period, the total temperature stabilization value achieved by all treatments (23 ºC) was close to the total temperature average of the environment (21.2 ºC). *Jusoh et al.* (2013) found a similar temperature stabilization trend in the later composting stage. During the experiment, none of the mixtures reached thermophilic activity. In the asparagus waste composting study (*Liu et al., 2022*), mixtures treated with 2.5 and 25% MBM rates did not reach the thermophilic phase. The temperature changes of the composted mixtures are presented in Fig. 4.

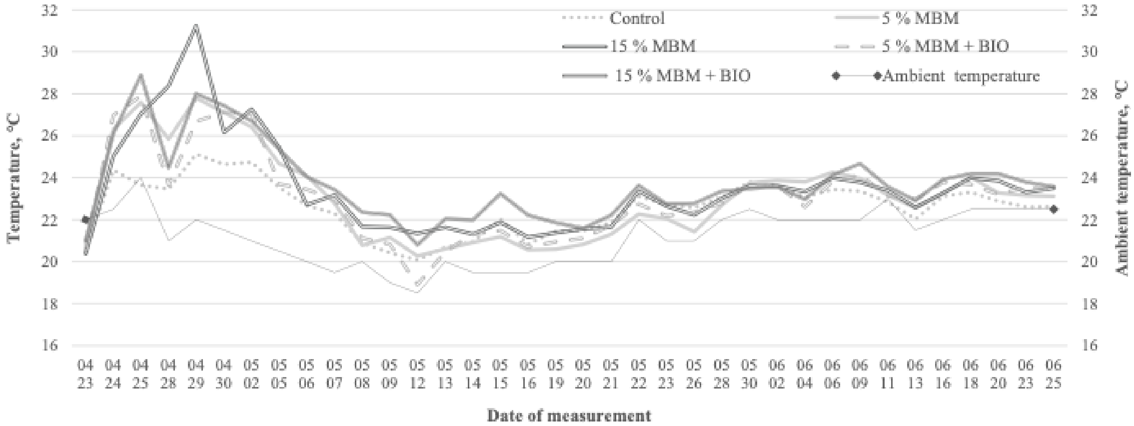


Fig. 4 Changes in the temperature of compost mixtures

During the study, CO_2 emissions changed unevenly (Fig. 5): the highest CO_2 concentration was recorded at the beginning of the study (04.30) with 5% MBM (2.46%), the lowest – in the Control treatment (0.71%). At the beginning of the study, CO_2 increased in all treatments with additives, statistically significant increases were recorded in the period 05.07 in the 15% MBM+BIO ($p < 0.05$) and 5% MBM+BIO ($p < 0.01$) treatments. Contrary results were presented in composting studies by *Karandušovska et al.* (2021), who indicated that they did not record statistically significant differences between the treatments at the beginning of the study. During the study, a significant trend of decreasing CO_2 release was observed in both treatments with a 5% additive rate, a significant increase in concentrations (05.14) was observed in the 15% MBM ($p < 0.01$) treatment. This trend was repeated until 05.21. At the end of May and the beginning of June, no significant differences were detected between the treatments. According to the data of measurements from 06.11 to 06.18, increases in emissions were recorded in all treatments compared to Control. The most significant changes (06.18) were obtained for 15% MBM and 5% MBM+BIO ($p < 0.01$). This trend remained until the end of the study (06.27). During the last measurement, CO_2 emissions ranged from 0.1% (Control) to 0.45% (5% MBM), which indicated a decrease in the intensity of the composting process. The CO_2 emissions of the composted mixtures are presented in Fig. 5.

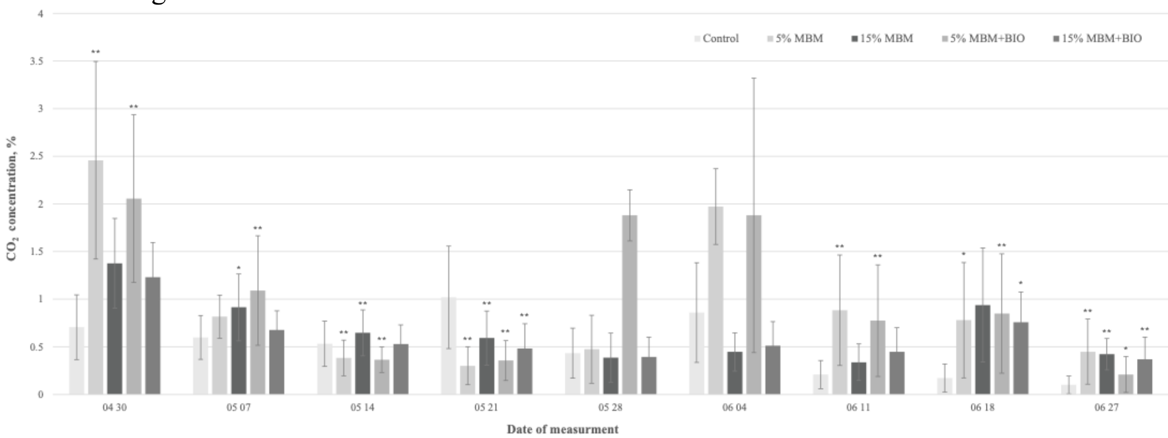


Fig. 5 Dynamics of CO_2 concentration in compostable mixtures. Statistically significant differences between the Control and experimental variants on individual dates: * – $p \leq 0.05$; ** – $p \leq 0.01$.

The results of the one-way analysis of variance (ANOVA) for pH and CO_2 concentrations at different measurement dates are presented in Tab. 1.

Tab. 1 One-factor analysis of variance (ANOVA) statistical evaluation metric pH and CO_2 parameters

Date	Para-meter	SOV				Date	Para-meter	SOV			
		SS	MS	*F*	*P*			SS	MS	*F*	*P*
04	pH	4.7	1.18	2.42	0.06	06	pH	16.3	4.07	45.5	0.001
30	CO_2	17.3	4.33	6.57	0.0	04	CO_2	19.8	4.94	1.92	0.13
05	pH	1.4	0.35	11.6	0.001	06	pH	16.3	4.07	45.5	0.001
07	CO_2	1.37	0.34	5.18	0.01	11	CO_2	19.8	4.94	1.92	0.13
05	pH	1.5	0.38	26.8	0.001	06	pH	49.8	12.5	52.2	0.001
14	CO_2	0.5	0.12	27.1	0.001	18	CO_2	3.31	0.83	3.6	0.02
05	pH	5.7	1.42	67.5	0.001	06	pH	59.9	15.0	65.0	0.001
21	CO_2	2.93	0.73	13.4	0.0	25	CO_2	0.81	0.2	23.9	0.001
05	pH	4.2	1.06	49.9	0.001						
28	CO_2	0.05	0.01	0.64	0.64						

Note: *SS* – sum of square, df – degrees of freedom (df = 4), *MS* – mean squares, *F* – Fishers criterion, *P* – probability level.

CONCLUSIONS

This study showed a significant influence of MBM and MBM+BIO additives on the parameters of the composting process. Different additive rates increased the pH of the mixtures compared to the Control treatment, and 15% MBM+BIO ensured the highest pH stability and the lowest fluctuations in the indicators. Higher additive rates also led to a faster temperature rise at the beginning of the study and maintenance of higher temperature values throughout the process. The lowest CO_2 emissions were determined in mixtures with BIO additives (5% and 15%), compared to the Control. Although MBM had an effect on individual parameters, further studies are necessary to determine the optimal mixture composition and additive rates.

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