Management of food waste containing animal protein in the process of liming and aerobic composting

Zagospodarowanie odpadów spożywczych zawierających białko zwierzęce w procesie wapnowania i kompostowania tlenowego

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Food waste containing animal protein (FW-AP) processing was carried out it two stages: hygienization in the liming process and aerobic composting in real conditions. Pilot compost prisms consisted of 1-1,2 tons of wastes mix contained: (i) sewage sludge, dried to 14,5% of dry weight, (ii) food waste containing animal protein (FW-AP), fragmented to size 12mm, hygienized with calcium oxide CaO; dry matter content, after liming, was equal to 18%; (iii) bulking agents: straw and biowaste such as leaves, grass, waste paper, 66-75% dry weight; (iv) inoculate, 40% of dry weight. In the heaps, the content of limed FW-AP was 20%, 30% and 40%. After about 2 months of composting, the finished compost was obtained. The final product was characterized by the following parameters: moisture 40-52%, pH 7,0-7,4, organic matter 59,4-62,3%, Total Kjeldahl Nitrogen 26,6 – 69,5 g N/kg dry matter by weight., Total phosphorus 17,6 – 63,0 g P/kg d. m.

Presented method is a simple and effective way to convert waste into a product. The contribution of food waste containing animal protein in total compost prism mass on a level up to 40% allows for the rapid processing of large amounts of waste. Final composts meet the requirements given for soil improvers or mineral – organic fertilizers.

Keywords: food waste, food waste containing animal protein, composting, composting of limed food waste, mineral – organic fertilizers

Przetwarzanie odpadów spożywczych zawierających białko zwierzęce (food waste containing animal protein FW-AP) odbywało się w warunkach rzeczywistych w dwóch etapach: higienizacji w procesie wapnowania oraz kompostowaniu tlenowym. Pryzma pilotażowa składała się z 1-1,2 tony mieszanki odpadów zawierającej: (i) osad ściekowy wysuszony do 14,5% suchej masy, (ii) odpady spożywcze zawierające białko zwierzęce (FW-AP), rozdrobnione do wielkości 12mm , higienizowane tlenkiem wapnia CaO; zawartość suchej masy po wapnowaniu wynosiła 18%; (iii) materiał strukturotwórczy: słomę i bioodpady takie jak liście, trawę, makulaturę, 66-75% suchej masy; (iv) zaszczep, 40% suchej masy. W pryzmach zawartość wapnowanych odpadów FW-AP wynosiła 20%, 30% i 40%. Po około 2 miesiącach kompostowania uzyskano gotowy kompost. Produkt końcowy charakteryzował się następującymi parametrami: wilgotność 40-52%, pH 7,0-7,4, materia organiczna 59,4-62,3%, całkowity azot Kjeldahla 26,6 – 69,5 g N/kg suchej masy, Fosfor całkowity 17,6 – 63,0 g P/kg s. m.

Prezentowana metoda jest prostym i skutecznym sposobem przekształcenia odpadów w produkt. Udział odpadów spożywczych zawierających białko zwierzęce w całkowitej masie kompostu na poziomie do 40% pozwala na szybkie przetworzenie dużych ilości odpadów. Komposty końcowe spełniają wymagania stawiane polepszaczom gleby lub nawozom mineralno-organicznym.

Słowa kluczowe: odpady spożywcze, odpady spożywcze zawierające białko zwierzęce, kompostowanie wapnowanych odpadów, nawozy mineralno – organiczne

Introduction

Approximately 1.3 billion tons of food waste (FW) are generated annually, and their production is steadily increasing (Awasthi et al., 2020). In the European Union (EU) alone, approximately 90 million tons of FW is generated annually, most of which (72%) comes from households and food processing plants (Siles-Castellano et al., 2020).

A very common way of dealing with FW is its storage in landfills as part of municipal mixed waste (Mathioudakis et al., 2022), what significantly reduces the capacity of landfills (Wang S. et al., 2018). In addition, due to its susceptibility to putrefaction, FW is a major source of leachate, odors and greenhouse gas emissions from landfills (Zhou et al., 2018).

Food waste and food leftovers can be used as compost or soil improver after

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composting process (Arumugam et al., 2022). Because of a low C/N ratio in food waste it is necessary to mix it with waste with a high C/N ratio (e.g. green waste).

Wang et al. co-composted catering waste with green waste and shredded paper and compared to composted household waste obtained N-rich compost (Wang S. et al., 2018). Other studies show that for best results FW should be composted with at least 40% of bulking agent (Neugebauer et al., 2017).

Co-composting of sewage sludge and food waste eliminates the weaknesses of separate composting of these wastes. It neutralizes contaminants and improves the content of organic matter in sewage sludge, as well remedies the problems of high moisture content and the low pH values of food waste (Chen et al., 2022).

The main problem related to composting of food waste is the fermentation of carbohydrates and fats, which lowers the pH of the composting mass leading to decrease the decomposition efficiency (Wong et al., 2009). The addition of alkaline materials such as lime can mitigate the low pH and help achieve efficient organic degradation. However, it also causes a loss of N in the form of ammonia (Chan et al., 2016; Wang et al., 2016).

According to the EU regulation [CR (EU) No 142/2011] kitchen and food waste containing animal protein (FW-AP) is the material with a low risk (Category 3) and require proper hygienization to eliminate the potential health risks (Seruga et al., 2020). Kitchen waste has to be pasteurized in a minimum temperature of 70 °C within a minimum of 60 min. In addition, waste must be shredded to the size below 12 mm. Besides, the presence of certain pathogens (Salmonella spp., E. coli or Enterococcus spp. and Ascaris spp.) should be monitored (Seruga et al., 2020).

The main disadvantage of pasteurization is its cost. In particular, the heating step usually goes on with steam or heat exchanger and needs large amounts of energy (Arthurson, 2008).

Other methods of hygienization used to hygienize sewage sludge include composting and liming. During composting, decomposable substrates in the sludge are oxidized by the indigenous microorganisms present in the compost. This leads to a significant increase of temperature (up to 60°C or more), but mainly in the center of the heap (Arthurson, 2008). During liming process hydrated lime (calcium hydroxide) is added to liquid sewage sludge at a concentration sufficient to raise the pH to 12.0 for at least 2 h (Arthurson, 2008). High concentrations of alkaline substances can negatively affect microorganisms due to the potential inhibitory effect caused by their high pH (Awasthi et al., 2018). In addition, when lime is added to FW, there is a loss of nitrogen (mentioned above) through NH_3 emissions.

The negative impact of the addition of lime on all biological parameters increases with the increase of the lime dose, although these effects are generally limited to the early stage of the thermophilic phase (Wong et al., 2000). That is why Wong and Fang support the use of lime at a rate of <1.0% (w/w) to co-compost with sewage sludge (Wong et al., 2000). In turn in other studies Awasthi et al. applied 2% dose of lime to co-compost food waste and sawdust (Awasthi et al., 2018). Addition of 3% lime doze with coal fly ash (5-10%) increased the efficiency of decomposition and reduced the FW composting time by 35% (Wong et al., 2009).

Many studies were conducted on a small scale and/or in a laboratory conditions (Huang et al., 2022; Zhou et al., 2018; Wong et al., 2009; Nkansah et al., 2021; Chen et al., 2022; Wang X. et al., 2018; Wang et al., 2016; Awasthi et al., 2018; Chan et al., 2016; Wong et al., 2000).

The aim of the research described in the paper was pilot scale evaluation of possibilities of FW-AP (food waste containing animal protein) management in the processes of liming and composting in real condition with the assumption that final product is safe and useful for agricultural purposes. Such action is in line with the policy of sustainable utilization of biological resources like food waste, especially food waste containing animal protein.

Because composting alone does not ensure enough high higenization temperature, the liming of food waste was applied.

The questions arose cover the aspects of:

- Effect of 3,2-6,5% lime dose on possible disturbance of composting process.
- Proper contribution of limed FW in whole compost mass.
- Nitrogen losses caused by lime dosing (pH rise) and possible decrease of final product fertilization value.

Study materials and methods

Waste processing was carried out it two stages: hygienization in the liming process and aerobic composting. For the tests food waste containing animal protein (FW-AP), classified as Category 3, obtained from collective catering facilities was used. Dry mass of waste was about 17,7%.

Liming

Liming, commonly used for sewage sludge, was applied as a waste hygienization method. Food waste containing animal protein (FW-AP), fragmented to size 12mm, hygienized with calcium oxide CaO – dose 15% in relation to the dry matter content of the waste; dry matter content, after liming, was equal to 16-17%; Liming parameters were in accordance with that one's given for sludge in EPA standards for the use or disposal of sewage sludge. It was assumed that the hygienization process takes place when the pH of the sample is higher than 12 and stays at that level for at least 2 hours. Next, the pH value higher than 11,5 should stay for the next 22 hours.

Composting

The composting process was conducted in real conditions in composting plant belonging to the municipal wastewater treatment plant. Pilot compost heaps consist of 1-1,2 tons of wastes mix (table 1). Composting mix contains: (i) sewage sludge, dried to 14,5% of dry mass, (ii) food waste containing animal protein (FW-AP), fragmented to size 12mm, hygienized with calcium oxide CaO; dry matter content, after liming, was equal to 16-18%; (iii) bulking agents: straw, and biowaste such as leaves, grass/hay, waste paper – content of mixed structure forming material dry mass was 66-75%; (iv) inoculate, which was screen overflow fraction from previous prisms – 40% of dry mass. Used substrates were obtained from a local municipal plant. Pre-digested (open digestion chamber) and dewatered sludge was used.

Table 1. Compost components in heaps: P0, P1, P2, P3
Tabela 1. Składniki kompostu w pryzmach: P0, P1, P2, P3

Compost components	Heap P0		Heap P1		Heap P2		Heap P3	
	Mass [kg]	dry mass [%]	Mass [kg]	dry mass [%]	Mass [kg]	dry mass [%]	Mass [kg]	dry mass [%]
Sewage sludge	1000	14,5%	650	14,5%	550	14,5%	450	14,5%
straw	62	86,7%	50	86,7%	50	86,7%	50	86,7%
leaves	48	44,5%	45,2	44,5%	42,7	44,5%	37	44,5%
grass	11,4	44,5%	10,8	44,5%	10,1	44,5%	12,1	44,5%
waste paper	3	85,5%	3,9	85,5%	5,5	85,5%	3,7	85,5%
bulking agents – in total	124,4		109,9		108,3		102,8	
Hygienized food waste containing animal protein			197,6	17,7%	297,9	17,7%	401	17,7%
inoculate	80	39,40%	50	39,40%	50	39,40%	50	39,40%
In total	1204,4	21,5%	1007,5	21,9%	1006,2	22,2%	1003,8	22,3%

Table 2. Contribution of used components in initial mass of prepared compost heaps P0, P1, P2, P3
Tabela 2. Udział zastosowanych składników w masie początkowej przygotowanych pryzm kompostowych P0, P1, P2, P3

Component	P0	P1	P2	P3
Sewage sludge	83,0%	64,5%	54,7%	44,8%
bulking agents	10,3%	10,9%	10,8%	10,2%
FW-AP	0,0%	19,6%	29,6%	39,9%
Inoculate	6,6%	5,0%	5,0%	5,0%

Four heaps were made. The P0 heap was comparative prism with no addition of FW-AP. In the next heaps, the content of limed food waste FW-AP was P1 – 20%, P2 – 30% and P3 – 40%. The Addition of calcium oxide was equal to 3,2-6,5% of heap dry mass. In tables 1 and 2 the content of individual components in compost heaps is shown.

Used bulking agents, especially straw, are characterized by significant volume of material in relation to their mass. Because of that the assumption that bulking agents contribution will be equal to ca. 10% of initial mass of compost heap and the other components will be treated as "wet" was made. The flipping with a windrow turner machine: every2-3 days in the first, intensive stage of composting (ca. 3 weeks), next three weeks every 4-5 days and, in the final stage of compost maturing, every 1-2 weeks. In each prism (highest ca. 1,2m, width ca. 2,7m and length depends on prism mass) five temperature sensors (continuous temperature monitoring) were placed. Additionally outdoor temperature was measured. Starting form 29th day of composting prisms were sprinkle with water (ca. 20 L per prism). Every week compost from each prism was sampling.

Analytical methods

The following parameters were measured: moisture, pH, organic matter, nitrate nitrogen NO_3^-, ammonia nitrogen NH_4^+, Total Kjeldahl Nitrogen and Total phosphorus.

Total phosphorus: dried compost sample was homogenized and total phosphorus was determined according to the PN-EN ISO 6878 standard. Moisture were measured with moisture analyzer MA 50/1.R (RADWAG – Poland). Content of organic matter was calculated based on loss on ignition measurements. Total Kjeldahl Nitrogen – fresh compost sample and the method after mineralization with selenium (PN-EN 25663) were used. The pH was measured with HQ40d pH-meter equipped with PHC301 electrode (Hach).

For nitrate nitrogen determination Spectroquant photometric nitrate test 1.09713 (Supelco) and Spectroquant Pharo 300 (Merck) spectrophotometer were used. Both nitrate nitrogen and pH were measured in water extracts (10g of compost fresh mass made up to 200 ml with deionized water)

Ammonia nitrogen were measured in diluted (ca. 0.01 M) HCl extract (10g of compost fresh mass made up to 200 ml with diluted in deionized water HCl) with Spectroquant photometric ammonium test 1.00683 (Supelco) and Spectroquant Pharo 300 (Merck) spectrophotometer.

Table 3. Content of macro-(g/·kg d.m.) and microelements (mg/·kg s.m.) in compost components
Tabela 3. Zawartość makro-(g/kg s.m.) i mikroelementów (mg/kg s.m.) w składnikach kompostu

COMPOST COMPONENTS	N	P	K	Mg	Ca	Cd	Cu	Cr	Mn	Ni	Pb	Zn
	g/kg d.m.					mg/kg d.m.						
Hygienized food waste (FW-AP)	22,5	3,2	0,6	2,0	217,3	blq	blq	blq	0,006	0,0003	blq	0,034
Straw	7,2	0,7	1,1	0,7	1,6	blq	blq	blq	0,002	blq	blq	blq
Leaves	6,7	1,7	0,2	2,4	22,6	blq	blq	blq	0,32	0,002	blq	0,027
Hay	5,6	1,7	0,8	0,9	1,8	blq	blq	blq	0,05	blq	blq	0,001
Grass	14,4	3,1	1,2	2,3	8,5	blq	blq	0,0036	0,21	0,002	0,002	0,027
Sewage sludge	52,8	19,6	0,3	4,0	9,7	0,0004	0,21	ND	0,15	0,006	0,009	0,820

blq – below limit of quantification
ND – no data

initial dry mass content of the mixed heaps was 21-22%.

The content of macro – and microelements in a compost components is shown in the table 3.

The main source of nitrogen, phosphorus and magnesium was grass and straw while the main source of calcium was hygienized food waste. The scheme of composting process is shown of figure 1.

Composting was conducted as aerobic process. Aeration was performed by prism

Results and discussion

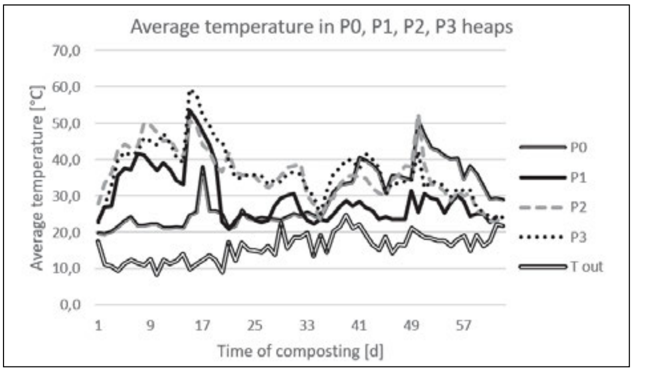
Changes in composting process temperature measured inside the P0 (without food waste), P1, P2 and P3 heaps (Picture 4) are important indicator of composting process progress indicator. On figure 2 changes in outdoor temperature are also shown.

The temperature inside the heaps in the initial period of the compaosting process increased up to 70°C. The addition of food waste (FW-AP) accelerated thermophilic phase.

In the P0 prism the temperature rise above 40°C occurred on day 17. Next temperature rise was noticed only after 40 days. The process slowdown was probably caused by excessive drying of the heap.

In the P1-P3 prisms (with FW-AP addition) temperature rise above 40°C, and even

Fig 2.
Temperature change in compost heaps P0-P3
Rys. 2. Zmiana temperatury w pryzmach kompostowych P0-P3



50°C, inside the prism occurred on days 2-4. In all points of temperature sensor placement (also in prism outer layer) temperature rise above 40°C were recorded on days 3-9 and above 50°C on day 14. Till composting day 56 temperature in whole P2 and P3 prisms stayed ca. 10°C above the outdoor temperature. Only in P1 prism composting

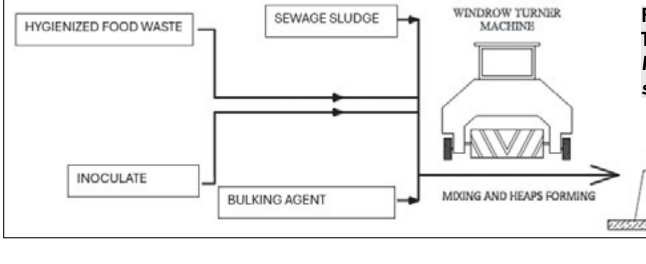


Fig. 1
The composting scheme
Rys. 1 Schemat kompostowania

process took place essentially at ambient temperature after 3 weeks of composting. The 50th day of composting was considered to be the end of the process due to the fact that the temperature stayed 10°C higher than the ambient temperature – the prisms were left to mature.

The initial organic matter content in prisms was equal to 65,9 % (P0 – without FW-AP), 72,7% (P1), 69,1% (P2) and 70,0% (P3). The organic matter content in the compost prisms decreased by 10,5% (P0 – without FW-AP), 14,4% (P1), 14,1% (P2), 12,6% (P3).

On the figure 3 the changes in the content of ammonium nitrogen, nitrate nitrogen and pH in the process of composting are presented.

The compost samples taken from day 0 to day 50 of the process illustrate the changes taking place in the heaps during the composting process.

The compost sample taken on the 190th day illustrates the mature compost parameters.

The initial pH value of compost mixture water extracts in all prisms were on the level of 6,6-7,2 pH. In all of the prisms in the day 8 the significant rise in pH value was noticed – to 8,2 pH in the P0 prism and to 8,6-8,8 in the other prisms. The pH value above 8,0 in the P0 prism stayed on that level till the end of composting (day 50). In the other prisms the pH value deceased to the value close to the initial one after 34 days of composting.

In all prisms similar changes in the content of ammonium nitrogen were observed – the alternating increases and decreases in ammonium nitrogen content in the beginning stage of composting.

The increases and decreases in ammonium nitrogen content can be explained by releasing of unionized ammonia to the gas phase. The process of unionized ammonia releasing to the air is favored by elevated temperature and pH as well as by mixing of the prism.

The content of nitrate nitrogen in samples taken between day 0 and 50 remained constant in all prisms. The decrease in the content of ammonium nitrogen practically to 0 and significant rise in nitrate nitrogen content in mature compost (after day 190) in all prisms were noticed. Similar ammonia nitrogen losses were observed e.g. by Wang (Wang S. et al., 2018). Especially the use of a compost mixture with a low C/N ratio may enhance the release of gaseous ammonium nitrogen. In the case of the tested heaps, the C/N ratio changed from initial 12.5-9.4 to 10.2-8.3 after composting. A comparable C/N ratio was reported by Wang (Wang S. et al., 2018).

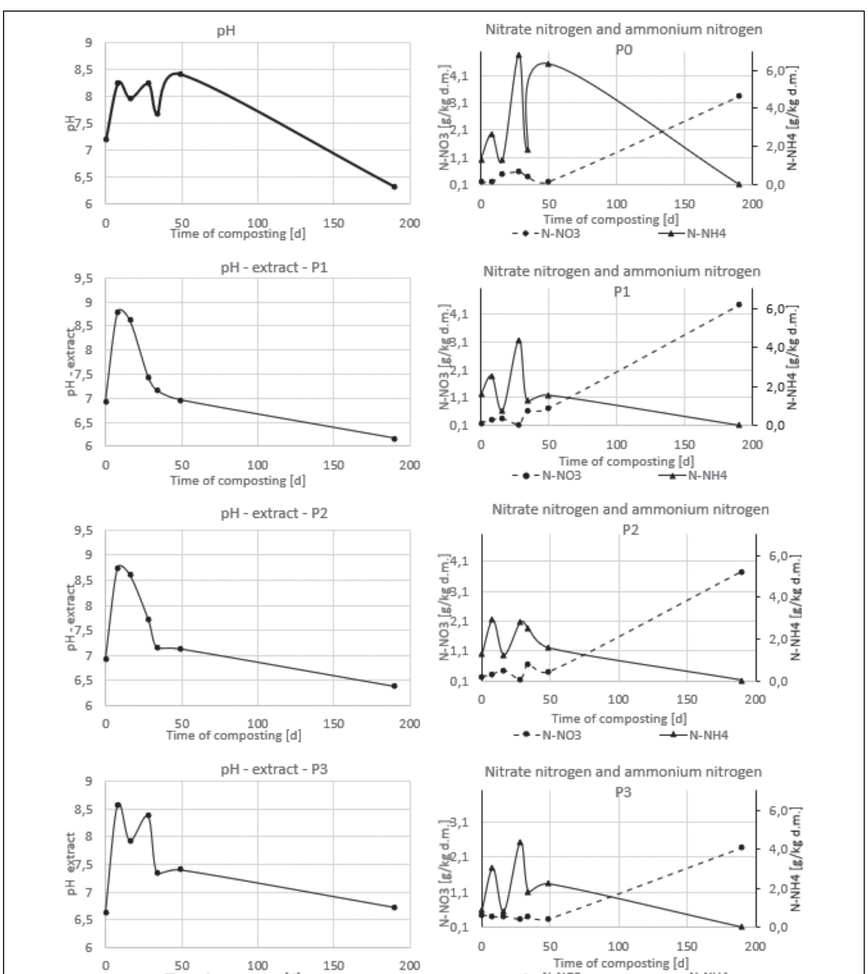


Fig 3.
The changes in the content of ammonium nitrogen, nitrate nitrogen and pH in the process of composting in P0 (without FW-AP), P1 (20% FW-AP), P2 (30% FW-AP) and P3 (40% FW-AP) heaps
Rys. 3. Zmiany zawartości azotu amonowego, azotanu azotanowego oraz pH w procesie kompostowania w P0 (bez FW-AP), P1 (20% FW-AP), P2 (30% FW-AP) i P3 (40% FW-AP)

The initial content of total nitrogen (Total Kjeldahl Nitrogen – TKN) was equal to 36,15 (P0), 31,32 (P1), 33,55 (P2), 33,75 (P3) – values given in grams of nitrogen per kg of compost dry mass (g/kg d.m.). The highest content of nitrogen in P0 prism results from relatively high contribution of sewage sludge, characterized by highest content of nitrogen in relation to the other compost mixture components (table 3). There was no decrease of nitrogen content, after day 50, in P0 prism while in the other prisms decrease of nitrogen content was equal to 14,2% (P1), 20,6% (P2) and 13,2% (P3). The decrease in nitrogen content in P1-P3 prism can be explained by unionized ammonia releasing to the air favorized by elevated pH value caused by lime addition.

The addition of calcium oxide in the amount of 3,2-6,5% of heap dry mass caused no disturbance in composting process.

After about 2 months of composting, the finished compost was obtained. The final product (heap with FW-AP: P1-P3) was characterized by the following parameters: moisture 40-49%, pH 7,0-7,4, organic matter 59,4-62,3%, Total Kjeldahl Nitrogen 26,6 – 29,3 g N/kg dry matter by mass., Total phosphorus 17,6 – 19,1 g P/kg dry matter by mass.

Compost parameters after 50 days of composting process are shown in the table 4.

Despite the observed decrease in the total nitrogen content in heaps containing limed FW-AP, the nitrogen content in mature compost is much higher than the minimum permissible values in organic fertilizers. This means that the added lime does not impair the fertilizing properties of the finished compost (Arumugam et al., 2022).

In the samples collected from the final composts, no bacteria of genus Salmonella and E.coli was found. Also, there were no live parasite eggs of Ascaris sp., Trichuris sp., Toxocara sp.

In turn in other studies Awasthi et al. applied 2% dose of lime to co-compost food waste and sawdust (Awasthi et al., 2018). Addition of 3% lime increased the efficiency of decomposition and reduced the FW composting time by 35% (Wong et al., 2009).

This indicates that the proposed technology based on preliminary liming followed by

Table 4. Compost parameters after 50 days of composting process
Tabela 4. Parametry kompostu po 50 dniach procesu kompostowania

COMPOST HEAP	PO	P1	P2	P3	Limit values for soil improver and/or* organic fertilizers
Parameters					
pH – value	8,4	7	7,1	7,4	
Moisture content %	60,7	48,7	46,6	39,6	
Organic matter content %	58,9	62,3	59,4	61,2	> 30*
Micro – and macro – elements [g/kg dry mass]					
Total nitrogen TKN	36,8	26,9	26,6	29,3	> 3*
Total phosphorus	21,0	19,1	17,6	18,7	> 0,55*
Calcium	20,0	19,3	33,7	38,3	
Potassium	0,6	0,7	0,6	0,7	> 0,7*
Magnesium	5,3	5,5	4,8	5,9	
Metals [mg/kg dry mass]					
Chromium	14,5	24	37	12	< 100
Cadmium	0,3	0,2	0,2	0,3	< 5
Nickel	6,3	10,8	10,4	6,0	< 60
Lead	9,9	15,5	5,5	9,9	< 140
Mercury	blq	blq	blq	0,0007	< 2

blq – below limit of quantification
*) Regulation of the Minister of Agriculture and Rural Development of June 18, 2008 on the implementation of certain provisions of the act on fertilizers and fertilization.

co-composting FW-AP wastes with sewage sludge, bulking agents and inoculate is effective one. The addition of calcium oxide in the amount of 3.2-6.5% of the dry weight of the wastes mixture causes permanent hygienization of the heap waste without interfering with the composting process.

The presented method provide management of catering waste in accordance with polish regulations. Final composts meet the requirements given for soil improvers (all samples) and even mineral – organic fertilizers (most samples). It is a simple and effective way to convert waste into a product.

Conclusions

The method of food waste containing animal protein (third category) FW-AP management in the process of liming and aerobic composting causes decomposition of organic matter and hygienization in accordance with polish regulations.

It is a simple and effective way to convert waste into a product. In the research the contribution of food waste containing animal protein in total compost prism mass was on a level up to 40%, which allows for the rapid processing of large amounts of waste.

Final composts meet the requirements given for soil improvers or mineral – organic fertilizers.

The addition of calcium oxide in the amount of 3,2-6,5% of heap dry mass caused no disturbance in composting process as well as does not impair the fertilizing properties of the finished compost.

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