The impact of distribution and collection systems on the purity of kitchen waste: A comparative analysis of approaches in Slovakia

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Abstract

This study evaluates the impact of different distribution and collection systems on the cleanliness of kitchen waste (KBW) at the consumer stage, focusing on households in three Slovak cities: Žilina, Bratislava, and Partizánske. The analysis highlights differences between individual housing construction (IHC) and collective housing construction (CHC), assessing contamination levels at the point of waste generation and collection. We utilized a methodology based on manual waste sorting and statistical analysis using Friedman's ANOVA to identify significant differences in contamination levels. The study also examines the influence of distributing compostable bags on reducing contamination and compares the effectiveness of door-to-door and drop-off collection systems. Results demonstrate that door-to-door collection significantly improves KBW cleanliness, with the city of Partizánske achieving the lowest contamination rates. Furthermore, a higher distribution of compostable bags correlates with reduced contamination in CHC. These findings emphasize the importance of consumer-stage interventions and systematic analysis methods in waste management to enhance waste purity and support sustainable waste utilization practices.

Keywords: *kitchen bio-waste, waste collection, compostable waste bags, waste management*

Introduction

Waste is generated by every human activity. It is often associated with something unnecessary, dirty, smelly, or dangerous and damaging to the environment. "Waste is a movable item or substance that its holder discards, intends to discard, or is required to discard in accordance with this law or special regulations".[40] According to § 2 para. 14 of Act No. 223/2001 Coll. on Waste, municipal waste is waste from households arising in the municipality during the activities of natural and legal persons.[39]

The European Union sets an ambitious goal to recycle 55 percent of solid municipal waste by 2025, with separate waste collection being a crucial prerequisite for achieving this goal. According to Directive 2008/98/EC, the term "biowaste," as a component of separated collection, includes "biodegradable waste from gardens and parks, food and kitchen waste from households, offices, restaurants, wholesale markets, canteens, catering establishments, and comparable waste from food processing plants." In the EU, from December 31, 2023, at the latest, "biowaste must be separated and recycled at source or collected separately and not mixed with other types of waste".[8] According to calculations by the European Topic Centre for Sustainable Consumption and Production (ETC/SCP), biowaste constituted 37% of municipal waste in Europe from 2008 to 2010.[12]

According to Pepicha (2010), waste and secondary raw materials generated during the cultivation and processing of plants and animals are called biomass. Biomass can be divided into phytomass and zoomass.[22,27] Biomass can be suitable for combustion, biofuel production, or biogas production with subsequent combined heat and power generation[16]. The use of biomass can vary depending on the source, processing method, and the product obtained from it. Many existing technologies produce abundant organic fertilizers, generate energy, or use it as an alternative fuel source from biodegradable waste.[30]

From forestry and agricultural biomass, we can obtain firewood, wood chips, briquettes, or pellets through cutting, drying, pressing, or chipping. Processing can yield heat and electricity. Carbonization can produce charcoal, and gasification can produce syngas. Pyrolysis produces pyrolytic oil or gas. Liquefaction, esterification, and fermentation can produce liquid fuel, biodiesel, or bioethanol, used in transport or for heat and power generation. Processing of biological waste from animal husbandry, food production, green biomass, and biodegradable municipal waste can yield biogas or syngas for heat and power generation.[26]

Another source of biomass is municipal waste. The corresponding biodegradable part of municipal waste is called biomass. It is one of the most universal and widespread sources of energy. Biomass is biodegradable municipal waste, mainly kitchen and restaurant waste and waste from parks and gardens[27]. Waste biomass from wood-processing facilities (such as sawmills, carpentry workshops, etc.) is particularly suitable for energy production. Other suitable biomass sources in rural areas include agricultural crops and their residues (straw, corn stalks, and plant tissues). Every municipality has public spaces that need to be maintained (e.g., parks, playgrounds, cemeteries). A source of dendromass is the spring and autumn pruning of trees in orchards and parks. Not less significant are private lands of residents and their kitchen waste. Approximately 1 billion tons of food waste is produced worldwide annually, posing a major challenge for waste management.[9] Creating suitable conditions for collecting and separating such biomass provides an additional source.[17]

Various processing technologies for the biodegradable part of municipal waste can produce various products.[28] Composting is a natural, controlled, predominantly aerobic biochemical process in which living organisms, particularly microorganisms, convert original organic matter into organic fertilizer (compost)[4]. Home composting means composting biowaste and using compost in gardens belonging to private households. Community composting means composting done by a group of people in a specific location to collectively compost their biowaste generated in that area. The resulting compost is used for the community's own needs. Municipal or industrial composting means composting biowaste from a larger collection area at a central composting facility. The compost can be used for personal needs or sold[6,29]. Various composting methods include pile composting, vermicomposting, or box composting.[28]

Anaerobic digestion is a controlled process of decomposing biodegradable waste and biomass without air access, resulting in biogas and an undecomposed residue called digestate[33]. Biogas is a mixture of gases containing 55 – 75% methane, 23 – 43% carbon dioxide, and approximately 2% hydrogen. Other gases present in trace concentrations include hydrogen sulfide and other sulfur and nitrogen compounds. Digestate is the fermented residue from the process and can be used as an organic fertilizer on agricultural land[18]. Adding digestate to the soil can promote plant growth by providing essential nutrients such as nitrogen (N) and phosphorus (P).[14]

The use of biomass is affected not only by its source and processing but also by its level of contamination. Given the quantity and widespread use of plastics, plastics have become a global biomass pollution source. In recent years, concerns have risen regarding environmental pollution related to microplastics (particles smaller than 5 mm)[3]. These particles are found throughout nature, including in aquatic environments, densely populated areas, and uninhabited places like Antarctica[8]. According to Wang et al.[35], soil may contain 4 to 23 times more microplastics than oceans. In addition to ocean water, microplastics are present in wastewater and sewage sludge.[20,21,25,35] Such pollution can pose serious environmental risks, such as jeopardizing soil quality and affecting plants, animals, and humans. Microplastics are not a single material but a mixture of various plastics and substances (e.g. stabilizers, flame retardants, or environmental toxins and metals adsorbed on their surfaces), which can be harmful upon ingestion, causing abnormal behavior, growth, and reproductive issues[40]. Other studies have shown negative effects of microplastics on soil, affecting animal and microbial activity in the soil. It has also been found that microplastics impact soil's water-holding capacity.[7,37]

Energy processing of biomass or its processing into fertilizers or compost can lead to the transfer of microplastics and other contaminants into the environment. On the other hand, the presence of non-biodegradable components in biomass increases the cost of its processing. Most countries allow certain amounts of impurities like plastics, glass, and metals in fertilizers (0.3% dry weight for each type of impurity and 0.5% dry weight for the total sum[11]. Several studies show that digestate and organic fertilizers from household biowaste fermentation may contain large amounts of microplastic fragments, while fertilizers from agricultural biogas plants and green composts are less contaminated with plastics. Such contamination could result from improper bio-waste sorting by residents and collection by municipalities.[21,31,36] Plastics can enter the soil through plastic mulching or the application of soil supplements containing plastics. Up to 2.38–1,200 mg of plastics per kg have been found in compost so far, while plastic concentrations in sewage sludge range from 1,000 to 24,000 plastic pieces per kg [3].

Braun et al.[41] concluded that compost application should be considered a potential source of plastics for both agricultural and horticultural soils, emphasizing the need for technical solutions to minimize the risks of this contamination while continuing this practice as an important means of ensuring soil health.[41] In industrial composting, manual sorting, mechanical sorting, or air sorting is used to remove plastics from compost.[47] If composting is to expand, it must become profitable and ideally competitive. On the other hand, the time and costs associated with plastic removal currently hinder profitability.[46] Addressing plastic-related issues is one of the milestones of the European Green Deal[45], which identifies the bioplastics industry as one of the potential solutions. Biodegradation depends on the chosen degradation technique and environment, so an optimal biodegradation method must be selected for each biodegradable bioplastic.[44] According to § 81 of the Waste Act (effective from January 1, 2021), municipalities are obligated to separate kitchen waste from households. However, this obligation does not specify a particular method of collection, such as the use of compostable bags. Currently, there is no consensus among stakeholders (i.e., EU member states, manufacturers, waste operators, NGOs) on how waste should be collected and processed. As a result, various approaches to waste management exist, even at local and regional levels, causing confusion and skepticism among consumers.[42] The European standard EN 13432 specifies the requirements and criteria for packaging that is compostable and biodegradable. The standard is used to certify packaging, including compostable bags intended for industrial composting.[43,45]

The aim of this study was to evaluate three different types of kitchen waste (KBW) collection and distribution in the cities of Žilina, Bratislava, and Partizánske. Additionally, we addressed the differences between individual housing construction (IHC) and collective housing construction (CHC). Finally, we assessed KBW contamination in the Bratislava Lamač district a year after KBW sorting was introduced and the impact of distributing compostable (degradable) bags on waste by the municipality.

Material and Methods

The research was conducted in three cities (Bratislava, Partizánske, and Žilina). These cities were selected based on available options, as they are the only ones in Slovakia implementing the observed type of collection and distribution of kitchen waste (KBW) and the only ones that underwent an analysis of sorted waste to the required extent. The analysis of mixed municipal waste (MMW) was based on the legislative guidelines of the Ministry of Environment of the Slovak Republic, which, according to § 105 para. 3 letter a) of Act No. 79/2015 Coll[38]. on Waste and amendments to certain laws, establishes the methodology for analyzing mixed waste in § 1. The analysis of MMW is based on the principles of the legislative guidance of the Ministry of Environment of the Slovak Republic, as defined by § 105 para. 3 letter a) of Act No. 79/2015 Coll[40]. on Waste and amendments to certain laws. Since there is no ministry methodology for kitchen waste (KBW), we used our own methodology based on similar principles. In each selected locality, we analyzed samples of MMW and KBW separately from individual housing construction (IHC) and collective housing construction (CHC). Individual housing construction (IHC) includes single-family houses inhabited by one family, while collective housing construction (CHC) consists of apartment units, each occupied by a separate family, often forming residential complexes. Each of the analyzed cities has its own individually tailored waste collection system (Table 1). For both types of waste, containers were selected from various streets and neighborhoods within the municipal district. In each type of housing, we followed the rule of always taking both containers from one family home collection point, both the MMW and the KBW containers. Containers with non-standard waste or a non-standard quantity of any waste component were excluded when selecting collection containers for sampling. The physical selection of containers was carried out by collection workers. The sample size was designed so that the total weight for MMW (CHC and IHC) ranged between 500 kg and 1 ton. The number of containers for KBW was identical to the number of containers for MMW (applies to both IHC and CHC), as mentioned in the pairs of containers from the same family home collection point. The analysis of samples from each selected municipal district took place at four collection points (MMW from CHC, MMW from IHC, KBW from CHC, and KBW from IHC). For MMW, we sorted it into three components: KBW, garden biowaste, and mixed municipal waste. Each component was placed separately into bags, then weighed, and the weight of each bag was recorded. During the evaluation, the recorded weights of each component were summed. Their sum represented the total weight of the analyzed component of waste from one type of housing. Then their percentage share was determined. KBW was sorted into two basic components (biodegradable waste and non-biodegradable waste) (Figure 1). The European standard EN 13432 specifies the requirements and criteria for packaging that is compostable and biodegradable, intended for industrial composting. In our study, compostable waste bags were categorized under biodegradable waste and were not analyzed further. We followed the same evaluation procedure as for MMW analyses.

Data were statistically processed using the STATISTICA software (StatSoft Inc, 2011). Using the Shapiro-Wilk test, we found that the dataset did not have a normal distribution. We used Friedman's ANOVA to compare the average values of the analyzed data.

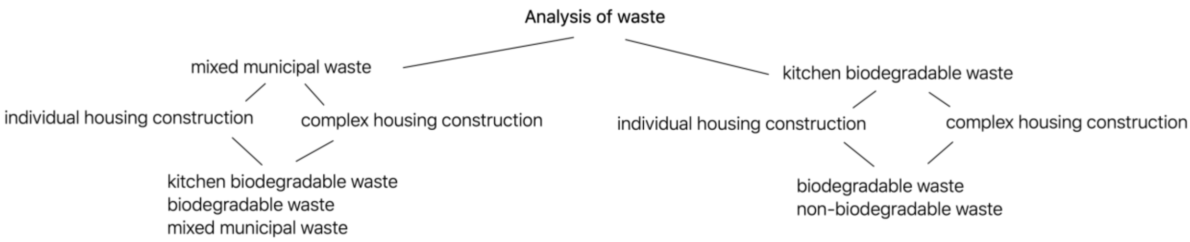

Figure 1: Waste Analysis Scheme (*Figure processed by the authors)*

In the individual cities, several interventions were conducted related to the distribution of bags, an information campaign, and waste collection. Compostable bags for sorted collection were distributed for one year (city of Bratislava), for one month (city of Žilina), and continuously as needed (city of Partizánske). In Bratislava and Žilina, after running out of compostable bags, residents can visit the city office, which will issue them additional bags. In Partizánske, door-to-door collection of kitchen waste (KBW) and distribution of compostable waste bags is done directly to residents' doors as needed. The door-to-door collection system involves residents placing 10-liter waste containers outside their apartment doors, where a city worker collects and empties them. The empty container is left at the resident's door. In individual housing areas, the city provides home composters. In Bratislava and Žilina, there is a drop-off collection system where residents place waste into the nearest container at the collection point designated for sorted kitchen waste (drop-off collection system). The frequency of container collection for sorted waste was twice per week throughout the year, with only once per week in winter in Bratislava (Table 1). Education of residents about the collection system was carried out through door-to-door campaigns (distribution of leaflets, waste bags, waste bins for collecting KBW, individual oral explanation of the collection system), internet campaigns, and distribution of educational materials—leaflets via email and placement in residents' mailboxes. Each city implemented a different type of educational campaign (Table 1). The kitchen waste from the studied cities is processed at the biogas plants of contractual partners. Kitchen waste from Partizánske is transported to the composting facility in Partizánske. Waste from Žilina is processed at the biogas plant in Žiar nad Hronom, while kitchen waste from Bratislava is processed at the composting facility in Horný Jatov (Information provided by JRK Slovensko s.r.o).

Table 1: Basic Data on the Collection and Distribution System in the Monitored Cities (BA- Bratislava, PE- Partizánske, ZA- Žilina)

Town	Number of bags distributed (pcs)	CHC		IHC		Frequency of collection	Information campaign
		collection system	container size (l)	collection system	container size (l)		
BA	150	delivery	240	door to door	20	2x/week- summer 1x/week- winter	door to door, leaflets and internet
PE	as required	door to door	10	home composters		2x/week- all year round	door to door, leaflets and internet
ZA	24	delivery	240 and 1100	delivery	240 and 1100	2x/week- all year round	leaflets and internet

Source: Data provided by JRK Slovensko s.r.o., processed by the authors

In our study, we evaluated three different types of collection and distribution systems for kitchen waste (KBW) in the cities of Žilina, Bratislava, and Partizánske. We also examined the differences between individual housing construction (IHC) and collective housing construction (CHC) in five districts of the city of Bratislava. Lastly, we assessed the contamination of KBW in the Bratislava Lamač district one year after the introduction of KBW sorting and the impact of the distribution of compostable (degradable) bags on waste by the municipality.

Results

IHC Analysis

The analysis of KBW for individual housing construction (IHC) in the city of Partizánske (PE) was not conducted, as KBW collection does not take place in IHC in this city. The city provided residents in IHC with home composters, and KBW is composted by residents in these. In the analysis of KBW from IHC in the monitored cities (ZA and BA), we found that total contamination of KBW with non-degradable components was 0.40% in Bratislava (BA) and 0.58% in Žilina. This difference was not statistically significant. In further analysis, we assessed the share of paper and non-degradable bags; no paper bags were found in KBW in either city. Plastic (non-degradable) bags accounted for 9.57% in Bratislava and 59.17% in Žilina, with the remainder consisting of compostable (degradable) bags. Analysis of the occurrence of non-degradable bags in KBW in Bratislava and Žilina revealed a statistically significant difference in their share ($p \leq 0.001$). The high contamination with plastic (non-degradable) bags in Žilina could have been due to the low distribution of compostable (degradable) bags compared to Bratislava.

CHC Analysis

Basic data on distribution and collection methods in collective housing construction (CHC) and contamination data with non-degradable components in the monitored cities are shown in Table 2. The analyzed data indicate that the drop-off collection system implemented in Bratislava and Žilina negatively impacted the cleanliness of KBW compared to the door-to-door collection system implemented in Partizánske; this difference was statistically significant ($p \leq 0.05$). Based on the analyzed data, we can conclude, as in the IHC analysis, that the more compostable (degradable) bags a city distributes, the lower the contamination of KBW in CHC, and the occurrence of non-degradable bags in this type of waste is significantly lower ($p \leq 0.001$). Furthermore, we demonstrated that the cleanliness of the drop-off collection system is not affected by container size, as this difference was not statistically significant.

Table 2: Comparison of the Purity of Sorted KBW in the Monitored Cities within CHC

Town	Number of bags distributed (pcs) per capita	Collection system	Size of container used (l)	Pollution KBW by non-biodegradable components (%)
Bratislava	150	delivery	240	3.21 %
Partizánske	As required	door to door	10	0.07 %
Žilina	24	delivery	240 and 1100	3.53 %

Source: Data provided by JRK Slovensko s.r.o., processed by the authors

Comparison of KBW Purity in IHC and CHC

In the analysis of five districts (D) in the capital of the Slovak Republic, Bratislava, we found that the average contamination in CHC is 3.21%, while the average contamination in IHC is only 0.40%. In the analysis of KBW contamination in the city of Žilina, we found that contamination in CHC is 3.53% and in IHC 0.58%. These results were confirmed by statistical tests, as statistically significant differences in the purity of KBW from IHC and CHC were demonstrated in both cities ($p \leq 0.001$). No statistically significant differences were found in the comparison between cities.

Based on our findings, we can conclude that there is no statistically significant difference in the purity of KBW in IHC and CHC between the cities of Bratislava and Žilina, even though Bratislava achieves slightly better results. On the other hand, we can state that there is a statistically significant difference in the purity of KBW between IHC and CHC in both cities. The average contamination in IHC is 0.49%, and the average contamination in CHC is 3.37%. When comparing the contamination of KBW from CHC in Partizánske (0.07%) with the contamination in CHC in Bratislava (3.21%) and Žilina (3.53%), a statistically significant difference in favor of Partizánske was demonstrated ($p \leq 0.001$). Based on our findings, we can conclude that the highest purity of KBW in CHC is achieved in the city of Partizánske.

Table 3: Percentage of KBW (non-biodegradable components) pollution in Bratislava, Žilina and Partizánske city districts for IHC and CHC

Town /districts (D)	Priemer (IHC a CHC)	CHC	IHC
Bratislava			
D Lamač	0.87%	1.18%	0.00%
D Petržalka	1.41%	1.48%	0.60%
D Nové Mesto	6.26%	7.02%	0.01%
D Devín	0.87%	-	1.36%
D Podunajské Biskupice	2.94%	3.14%	0.05%
Town average BA	2.47%	3.21%	0.40%
Town Žilina			
Žilina	2.06%	3.53%	0.58%
Town Partizánske			
Partizánske	-	0.07%	-

Source: Data provided by JRK Slovensko s.r.o., processed by the authors

BA- Lamač district Analysis

In further analysis, we focused on the purity of KBW in the Bratislava Lamač district, which we analyzed immediately after the introduction of KBW collection (when residents had access to compostable bags) and one year after the introduction of KBW collection, when residents had used up their compostable bags for KBW and would need to obtain more at the city office. The city of Bratislava distributed compostable (degradable) bags for KBW collection to residents for approximately one calendar year. Afterward, residents could pick up additional bags at the relevant city office. In the analysis of degradable and non-degradable components in KBW in the Bratislava Lamač district, we found an increase in non-degradable components in KBW from 0.41% immediately after the introduction of collection to 1.18% one year after the introduction of KBW collection. This difference proved to be statistically significant ($p \leq 0.05$). On the other hand, we demonstrated a difference between IHC (from 0.47% to 0.00%) and CHC (from 0.98% to 1.18%), also statistically significant ($p \leq 0.05$). We demonstrated an increase in contamination of KBW with non-degradable components one year after the introduction of KBW collection due to the depletion of compostable bags for KBW. Additionally, we demonstrated a statistically significant difference between IHC and CHC in the BA Lamač district ($p \leq 0.05$). The reduction in IHC contamination one year after the introduction of KBW collection, assuming the depletion of compostable bags, may have been influenced by citizens' responsibility and anonymity. KBW collection in IHC is not anonymous, while in CHC, there is high anonymity (it is not possible to identify the resident at the collection container). Since each house has its own container for KBW collection, we assume that residents in IHC behave more responsibly than in CHC. Another factor could be that residents in IHC run out of compostable bags later since they may have home composters that they acquired (Table 4).

Table 4: Analysis of KBW purity in the city of Bratislava-Lamač

Type analysis in district BA- Lamač	Components KBW	Percentage (%)	Date of analysis
1.	Degradable waste	99.59	5.3.2023
	Non-biodegradable waste	0.41	
IHC		0.47	
CHC		0.98	
2.	Degradable waste	98.82	30.11.2023
	Non-biodegradable waste	1.18	
IHC		0.00	
CHC		1.18	

Source: Data provided by JRK Slovensko s.r.o., processed by the authors

Discussion

This extended study is the first in the Slovak Republic to focus on the contamination of kitchen waste (KBW) and the impact of the kitchen waste distribution and collection system on its purity. Based on the analyzed data, we can conclude that the more compostable (degradable) bags the city distributes to residents, the lower the contamination of KBW in CHC. Additionally, the door-to-door waste collection system positively affects the purity of KBW and is statistically significantly better than the drop-off collection system. Similar conclusions have been reached in other studies, showing that cities with door-to-door waste collection sort, on average, 60 kg more dry recyclable materials per resident annually[1].

We further demonstrated that the purity of the drop-off collection system is not affected by the container size but rather by the number of distributed compostable waste bags. Based on our findings, we can state that there is no statistically significant difference in KBW purity between IHC and CHC in Bratislava and Žilina, although Bratislava achieves slightly better results. On the other hand, there is a statistically significant difference in KBW purity between IHC and CHC in both cities.

A similar study has been carried out by researchers in Poland, their study analyses the composition of bio-waste in both urban and rural areas, including differences between areas with single-family houses and apartment blocks. Based on the results, they determined the following composition of bio-waste: food waste accounted for 43.9-56% and garden waste for 27.4-46.3%, with fruit and vegetables making up the majority of food waste. The authors observed the highest level of contamination in waste from residential buildings in urban areas (16.6%). In terms of seasonality, the lowest amount of waste was recorded in winter.[12]

We also demonstrated an increase in KBW contamination with non-degradable components one year after the introduction of KBW collection, likely due to the depletion of compostable bags. A statistically significant difference was found between IHC and CHC in the BA Lamač district. The reduction in IHC contamination one year after the introduction of KBW collection, with the assumption that compostable bags were depleted, could have resulted from the responsibility and anonymity of residents. KBW collection in IHC is not anonymous, whereas KBW collection in CHC is highly anonymous (it is not possible to identify the resident at the collection container). Since each house has its own container for KBW collection, we assume that residents in IHC behave more responsibly than in CHC.

Improving the quality of separated bio-waste was the focus of an Austrian study carried out in ten areas of Styria between 2019 and 2022. The authors found that non-biodegradable plastics (53%) accounted for the highest level of bio-waste contamination, of which plastic bags accounted for the highest proportion. They found higher contamination in winter months compared to summer months. Based on these findings, they implemented various measures and campaigns, with the distribution of paper bags and the threat of increased charges for contaminated waste confirmed as the most effective.[2]

There is evidence that the socio-economic characteristics of the area from which waste is collected can affect the quality of materials, i.e., waste collected from rural areas can differ significantly from waste collected in urban areas, and waste collected from single-family homes may differ from waste collected from complex apartment buildings[19]. The issue of the bio-waste sorting system in Gdynia from the point of view of apartment building residents was investigated by a Polish study after the implementation of the new rules. According to its results, only 15% of respondents correctly classified what belongs to bio-waste and up to 94% of respondents admitted that they throw bio-waste into the mixed waste. They considered the sorting of kitchen bio-waste to be too burdensome. They cited the lack of space for additional bins, the smell of waste and the cost of special bags as other problems associated with the level of sorting. [15] A similar study was also conducted in Spain, where the authors surveyed attitudes towards the willingness to separate bio-waste based on a semi-structured telephone interview. The results showed that approximately 81% of respondents were willing to participate in selective collection of bio-waste. This percentage would increase up to 89% if the municipality provided specific containers and bags for the waste, as the main barrier to participation in the new selective collection system is the need to use specific containers and bags for separating bio-waste.[4]

We did not demonstrate the use of home composters for KBW in IHC in the Lamač district, where KBW collection is in place. We demonstrated more effective KBW collection (in terms of collected waste weight and purity) in IHC than in CHC.

Conclusion

Lastly, we demonstrated highly effective KBW collection (in terms of purity) in CHC in Partizánske. We can conclude that by implementing the same KBW collection system as in Partizánske for CHC and the same KBW collection system as in Bratislava for IHC, a highly efficient KBW collection and distribution system can be achieved. Our research findings are supported by the results of Gwarda and Klopott (2021), who found that in the city of Gdynia, the biofraction collected represents only 9.5% of all collected waste[15]. The most commonly cited reasons for why residents do not sort biowaste were lack of space for another container in the apartment (23%), unpleasant odor (23.8%), and the need to purchase and provide biodegradable waste bags (18.4%). A questionnaire was sent to individuals who failed to meet the obligation to sort biowaste to identify the reasons for non-compliance. Up to 39.6% indicated the absence of free compostable biowaste bags as the reason[15]. Supporting biowaste sorting requires active support from local authorities, both financially and through increasing environmental awareness among residents. Our research findings could be used to support the composition and parameters of waste further and would be suitable for the introduction of waste processing in Slovakia.

Study limitations and future research directions

This study provides valuable insights into the impact of distribution and collection systems on the cleanliness of kitchen waste (KBW); however, some limitations should be acknowledged. Firstly, the study focuses on three cities in Slovakia, which, while diverse in their approaches to KBW collection, may not fully represent all geographic, socioeconomic, or operational differences across the country or internationally. Future research could explore these systems in other regions or countries to validate the findings and assess broader applicability.

Additionally, while the methodology employed manual sorting and statistical analyses to identify contamination levels, the influence of seasonal variations or long-term changes in residents' behavior was not addressed. Further longitudinal studies could provide a more comprehensive understanding of the sustainability and adaptability of different collection systems over time.

Another limitation lies in the assessment of compostable bag distribution. Although a correlation between bag distribution and reduced contamination was observed, a deeper exploration of residents' behavior, such as adherence to sorting guidelines or barriers to participation, would enhance the findings. Future research could incorporate surveys or interviews with residents to gather qualitative data.

Lastly, while the study highlights the advantages of door-to-door collection systems, it does not consider the associated economic or logistical challenges. Comparative cost analyses and environmental impact assessments of different systems would be beneficial in informing policymaking and optimizing waste management strategies.

The study does not describe in detail the use of awareness campaigns in cities due to unavailable information.

By addressing these limitations and expanding on the current research, further studies can build on our findings to enhance the effectiveness and efficiency of KBW management globally.

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Vplyv systémov distribúcie a zberu na čistotu kuchynského bioodpadu: Porovnávacia analýza prístupov na Slovensku

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Souhrn

Táto štúdia hodnotí vplyv rôznych systémov distribúcie a zberu na čistotu kuchynského bioodpadu v spotrebiteľskej fáze, pričom sa zameriava na domácnosti v troch slovenských mestách: Žilina, Bratislava a Partizánske. Analýza poukazuje na rozdiely medzi individuálnou bytovou výstavbou a kolektívnou bytovou výstavbou a hodnotí úroveň kontaminácie v mieste vzniku a zberu odpadu. Použili sme metodiku založenú na manuálnom triedení odpadu a štatistickú analýzu pomocou Friedmanovej ANOVA na identifikáciu významných rozdielov v úrovni kontaminácie. Štúdia tiež skúma vplyv distribúcie kompostovateľných vriec na zníženie kontaminácie a porovnáva efektívnosť systémov zberu „door-to-door“(od dverí k dverám) a „drop-off“ (donáškový). Výsledky ukazujú, že zber „door-to-door“ výrazne zlepšuje čistotu kuchynského bioodpadu, pričom mesto Partizánske dosiahlo najnižšiu mieru kontaminácie. Navyše vyššia distribúcia kompostovateľných vriec koreluje so znížením kontaminácie v kolektívnej bytovej výstavbe. Tieto zistenia zdôrazňujú význam zásahov v spotrebiteľskej fáze a systematických analytických metód v odpadovom hospodárstve na zlepšenie čistoty bioodpadu a podporu udržateľných postupov jeho využitia.

Klíčová slova: *kuchynský bioodpad, zber odpadu, kompostovateľné vrecká na odpad, odpadové hospodárstvo*