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Food Waste – Challenges and Approaches for New Devices

Alžbeta Maxianová[1], Aleksandra Jakimiuk[2*], Magdalena Daria Vaverková[1,2]

[1] Department of Applied and Landscape Ecology, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

[2] Department of Revitalization and Architecture, Institute of Civil Engineering, Warsaw University of Life Sciences - SGGW, Nowoursynowska 159, 02 776 Warsaw, Poland

* Corresponding author's email: aleksandra_jakimiuk@sggw.edu.pl

ABSTRACT

Food waste has recently received attention due to its environmental, economic and social impacts. Final processing of food waste encounters a number of technical challenges, arising from weak physical structure of food waste with weak porosity, high content of water, and low carbon-to-nitrogen relation. This study deals with the research of food waste processing in households by using an automatic device. The main objective of the study was to assess the toxicity of the end-product produced by an automatic device. The research included 10 experiments. The input foundation consisted of common food waste generated in household kitchens. Following its processing, the end-product was tested in a pot experiment for the germination capacity and biomass increase in different concentrations. The end-product was mixed with the reference soil in concentrations 5/95, 30/70, 50/50 (tested/reference substrate). The testing included three different plant species, i.e. *Sinapis alba* L., *Hordeum vulgare* L. and *Cannabis sativa* L. The germination capacity of plants and their increase in biomass were evaluated after 21 days. The increase in biomass was monitored by using the Before-After-Control-Impact method. The plants developed much better without the end-product additive to the soil substrate than with its small addition. The best germination capacity in the case of end-product addition was observed in the concentration ratio 30/70 in all plants. In spite of this, the highest increase in biomass was recorded in the concentration ratio 5/95. This might have caused the occurrence of mould in the pots. The test shows that the end-product made of food waste is toxic to plants; therefore, it is not recommended for direct application as a soil amendment.

Keywords: food waste disposal, waste destructor, end-product, soil amendment, waste circulation

INTRODUCTION

The amount of food waste (FW) is continually increasing and the theme of FW has been currently very topical. As indicated by The Food and Agriculture Organization (FAO), ca. 1.3 trillion tons of food products is wasted every year (FAO, 2013). In spite of various efforts to reduce the FW generation per capita, the quantities of FW continue to increase due to population growth (Salemdeeb et al., 2018). The studies conducted in Europe show that nearly a half of municipal solid waste amount (MSW) consists of FW (Cerda, 2017, Morone, 2019). This amount of waste is a great problem not only for the economy of countries but also for the environment (Kumar, 2018). The economic impact of FW generated in commercial facilities and households represents 680 billion dollars in the developed countries and some 310 billion dollars in the developing countries (FAO, 2013). However, the numbers may further increase. Currently, an increasing interest is seen in the economic and environmental damages caused by FW. Many organizations have set themselves a goal to adopt measures in FW management. In relation with this, the campaigns for preventing FW generation at different stages of the cycle (production, processing, distribution, catering facilities as well as individual households) are launched (Reynolds, 2019). However, as FW is unlikely to be significantly reduced in the short term, greater efforts must be made to reduce its environmental impacts (Salemdeeb, 2018).

The European Parliament has set itself a goal to reduce the amount of FW in individual European Union (EU) countries by 30% (Voběrková, 2020). In addition to economic advantages, there are also environmental factors showing that the generation of FW contributes to the depletion of natural resources. At the moment, the raw materials needed to obtain food represent ca. 25% from the total consumption of fresh water (Hall, 2009). Another problem associated with the origin of food is deforestation and hence increasing amounts of greenhouse gases (GHGs) (Lambin, 2011).

It should be stressed that improper management of FW creates the human health and environment problems. It is, therefore, necessary to mitigate the problems by applying appropriate treatment methods to handle FW (Sam et al., 2016). Until recently, the most common method of FW disposal was landfilling or incineration. However, many countries have proceeded to more sustainable methods in which biological processes are used. These are, for example, composting and anaerobic digestion (AD) (Voběrková, 2020). It was demonstrated that landfilling has a negative impact on the environment. FW is a source of organic substances such as amino acids, fats, vitamins, minerals and other components that are difficult to decompose (Elkhalifa, 2019) and react together during decomposition, thus giving rise to dangerous substances released in the form of leachate and vapours, which can contaminate soil, water and air (Zhou, 2020).

Some authors (Masih-Das, 2018; Shin, 2010) suggest the AD as an optimal technique for FW processing. Apart from stabilisation, another advantage of this form of processing is generation of biofuel and digestate (Kannah, 2020). Nevertheless, this method brings about the costs for waste transport, generation and collection of gas, and its distribution. Moreover, the environmental and economic sustainability will be very much dependent on many factors, including the composition and volume of waste as well as the geographical region where it is generated and treated. Some authors suggest another method – aerobic composting (Pandey, 2016) at which FW can be processed at lower costs. The two processes can have an end-product with parameters similar to those of fertiliser (Zhou, 2020). In certain concentrations, this fertiliser contains the nutrients improving soil and enhancing germination capacity (Pandey, 2016).

Nowadays, metropolitan cities worldwide face the problem of FW disposal due to accelerated industrialization and urbanization (Yao, 2019). Therefore, “Smart Food Waste Processors” systems have recently been developed all over the word to facilitate the FW transformation into the end-product following the principles of circular economy. According to Kucbel (2019), the effective urban composting of FW in individual households as well as in restaurants, schools and other canteens, involves the use of automatic/electric FW processors. The goal of this study was to (i) test the quality of the end-product produced by the “Smart Food Waste device” and (ii) verify the effects of the product on the selected plants. The end-product quality was assessed via the measurement of germination index (GI).

MATERIAL AND METHODS

Device characteristics

The device for FW processing is a small, fully automated instrument sized 450×390×340 mm. Maximum foundation weight is 1.5 kg. The foundation can be of any FW, e.g., vegetables, bread and sweet pastry, fruits, eggs including shells, chicken meat and small bones, coffee grounds, tea, fish and crustaceans, and other kinds of food leftovers. Inappropriate materials are stones, metals, glass, large bones and liquids. The manufacturer does not mention any additive to improve the C/N ratio.

This foundation is processed within an approximately 3-4 hour long cycle, depending on the type of waste. One cycle includes three processes when the waste is crushed, at first into particles smaller than 5 mm. The process of drying then follows, during which the volume of waste is reduced by 90% with using high temperatures. In the third process, the resulting product is cooled down. The device is fully automated and sets the temperature by itself. The correct development of temperature determines how the organic matter will decompose. The FW decomposition results in the release of gases which rank with greenhouse gases (Guo, 2018). However, this device is furnished with carbon filters catching unpleasant gases and bad odours. Thus, the end-product is dried out, stabilised, without bacteria and unpleasant odours, and can be placed in the collecting container for biowaste or used as fertiliser.

Experiment characteristics

The experiment was conducted in 10 repetitions with different intervals and compositions. The foundation texture included mixed vegetables, fruits, egg shells, bread and tea bags. The foundation itself was mainly composed of vegetable and fruit leftovers with other types of wood waste. The comprehensive percentage and weight composition of materials in the foundations is presented in Table 1. Selected materials were placed into the device, which is fully automated, i.e., does not require an operator. Each cycle lasted approximately the same time.

Pot experiment and increase in biomass

Upon the end of the process, the end-product comes to existence in the device, which should have properties as a fertiliser or a soil amendment. This is why the end-product was tested in the interaction with plants, for which a pot experiment was used. The pot experiment was focused on the germination of plant seeds and increase in biomass (Figure 1).

Table 1. Percentage and weight composition of raw materials

Material	%	kg
Total	100.0	0.7500
Vegetables (potato, onion and paprika peels and cuttings)	36 ± 3.5	0.2700
Fruits (apples, bananas, pears)	23 ± 5.5	0.1725
Pastry (old bread, pastry)	22 ± 2.0	0.1650
Animal production waste (egg shells)	11 ± 1.5	0.0825
Citrus peels	5 ± 1.5	0.0375
Other materials (earth, herbs and tea bags)	3 ± 1.0	0.0225

The experiment was conducted to compare the differences in weight and growth of the aboveground parts of higher plants in the control sample and the sample with the testing substrate, functioning on the principle of Before After Control Impact (BACI). BACI is an efficient method using the data from two different samples of which one corresponds to the control and the other one is a tested sample where a certain effect is expected. The data are gathered before the beginning and at the end. These data are then compared and the effect recorded in the tested sample is evaluated and compared with the control sample (Smith, 1993). In the case of our research, the data used were from germination and from biomass weighing.

The test was carried out in the pots in which the end-product (tested sample) was mixed with the reference soil (control sample). Three species of higher plants were used in the experiment (*Hordeum vulgare* L.*,* *Sinapis alba* L.*,* and *Cannabis sativa* L.). The commonly grown *Hordeum vulgare* L. is a versatile plant species capable of adaptation to unfavourable climatic and soil conditions (Elke, 2013). The plant species was chosen for the experiment for its modest growing requirements. By contrast, *Sinapis alba* L. is very sensitive to the environment but characterised by fast germination. Its germination capacity is moderate but the length of roots is high. *Cannabis monoica* L. is characterised by high sensitivity to both germination and the environment. The plant

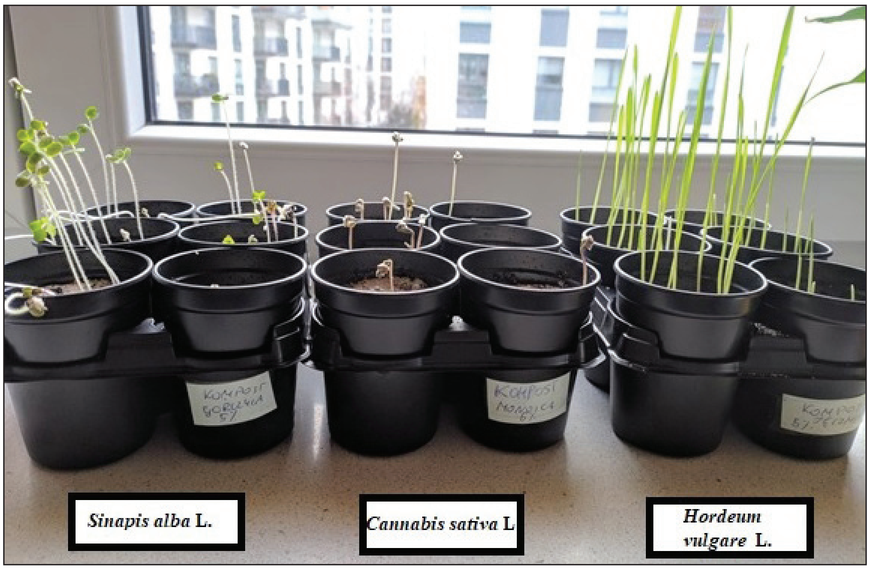

Figure 1. Pot experiment – seed germination test

species was chosen exactly for its high sensitivity and represents demanding plants (Vaverková, 2020). Since each of the chosen plant species has different environmental requirements, the testing had to be conducted with different concentration shares of which some are presented in Table 2.

The pots used in the experiment were 92.5 cm^3 in volume, sized 8×6.8 cm. They were filled with 53 g of mixed substrate on which the seeds of experimental plants were placed, which were then covered with a layer of silica sand to provide for appropriate germination in the dark. The prepared pots were kept under laboratory conditions for 21 days. After 21 days, the results were recorded from the germination of plants, and the *GI* was calculated according to modified formula (1):

$$GI\ (\%) = (A/B) \times 100 \quad (1)$$

where: A – actual number of germinated seeds,
B – number of seeds used in the experiment.

Subsequently, the above-ground part of plants was cut off and weighed on CP224s-0CE analytical scales. The results of biomass weight were compared with the control sample.

RESULTS AND DISCUSSION

Figures 2 and 3 illustrate the weight reduction. The manufacturer indicates that the FW is reduced by up to 90% after the processing. The results of weighing the initial foundation and the end-product showed that such a great weight reduction did not occur in any of the experiments. The average weight reduction was 78.1%. However, in one experiment, the weight reduction was particularly low – ca. 68%, when the initial foundation contained too much of dry material (earth, dry pastry). These results are also corroborated by the research conducted by Kucbel (2019) who casts doubts on the high volume reduction claimed by the manufacturer. Zhou (2020) claims that the initial foundation also determines the course of the process and hence the temperature which is important for the end-product. If the foundation consists of complex organic material, the process may be disturbed and the end-product exhibits worse results as compared with other experiments. However, the manufacturer determines neither the ratio in the

Table 2. Selected plants, share of tested substrate and number of seeds

Concentrations	Selected plant		
	Hordeum vulgare L.	*Sinapis alba* L.	*Cannabis sativa* L.
	Number of seeds	Number of seeds	Number of seeds
50% reference and 50% tested substrate	30	30	30
70% reference and 30% tested substrate	30	30	30
95% reference and 5% tested substrate	30	30	30
100% reference substrate	30	30	30

Figure 2. Comparison of input and output product

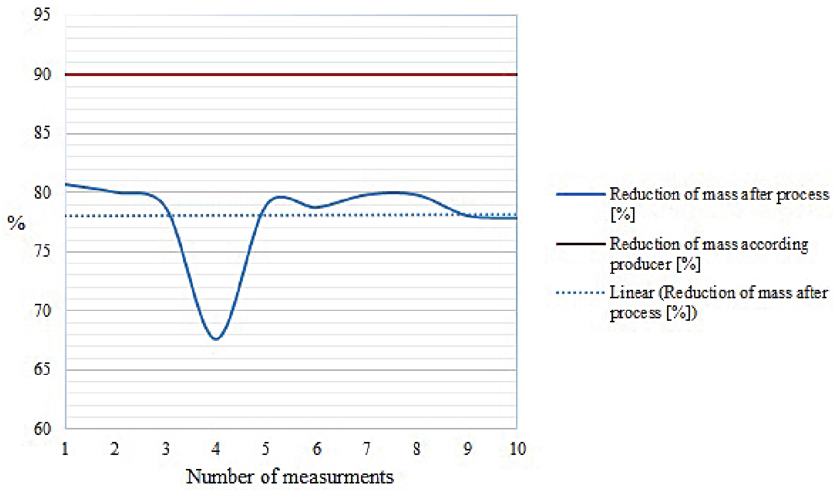

Figure 3. Reduction of mass after the process

initial foundation nor whether it is necessary to apply some additives to the process.

The results of germination from the pot experiments are presented in Figure 4. The graph shows that the highest germinative capacity was recorded in *Hordeum vulgare* L. in all concentration ratios. The plant species corroborated its modest demands for germination and growth. In contrast, the most sensitive plant species of *Cannabis sativa* L. showed low germinative capacity, which indicated the toxicity for plants. The highest germinative capacity was surprisingly observed in the concentration ratio of 30/70 in all above-mentioned plant species.

In this concentration, the germination capacity was even greater than that of the reference sample. Similar results were demonstrated also in the research study conducted by Kauser (2020), in which the highest germination capacity was recorded exactly in the moderate or higher concentration ratios similarly as in this research. It clearly shows that in the correct concentration, the end-product can have a stimulating effect on the plants, similarly as a fertilizer (Sharma, 2017). Although the germination capacity was high and the tested samples showed stimulating effects on the plant growth, nearly all pots exhibited mould at plant roots. The mould occurred there only after several days (Figure 5).

In contrast, the results from the BACI method (Figure 6) showed that the highest increase in biomass was observed in the concentration share of 95/5 in all tested plants. This indicates that although the highest germination capacity was demonstrated in the higher concentration ratio (30/70), the weight increase was considerably higher in the lower concentration ratio. In the case of *Hordeum vulgare* L., the difference amounted to nearly 50%. From this it is clear that the end-product does not have such a significant influence on the germination capacity but has a considerable effect on the growth of the above-ground part of the plant.

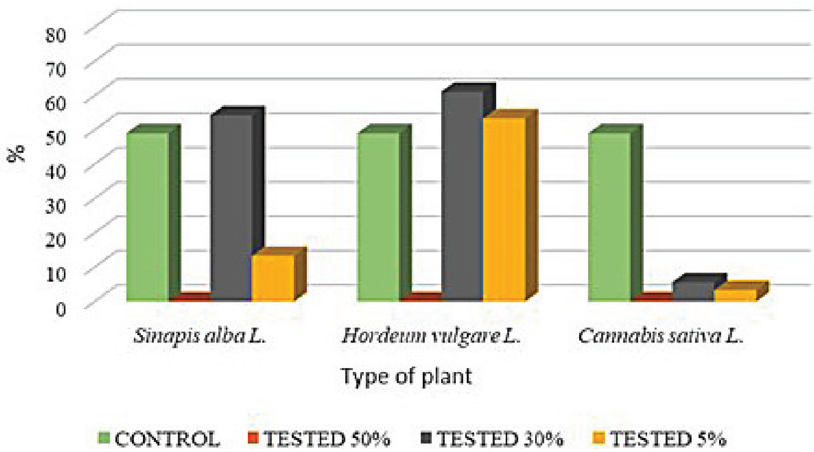

Figure 4. Germination results from a pot experiment

Figure 5. Mould observed in the bottom, profile and top at pot

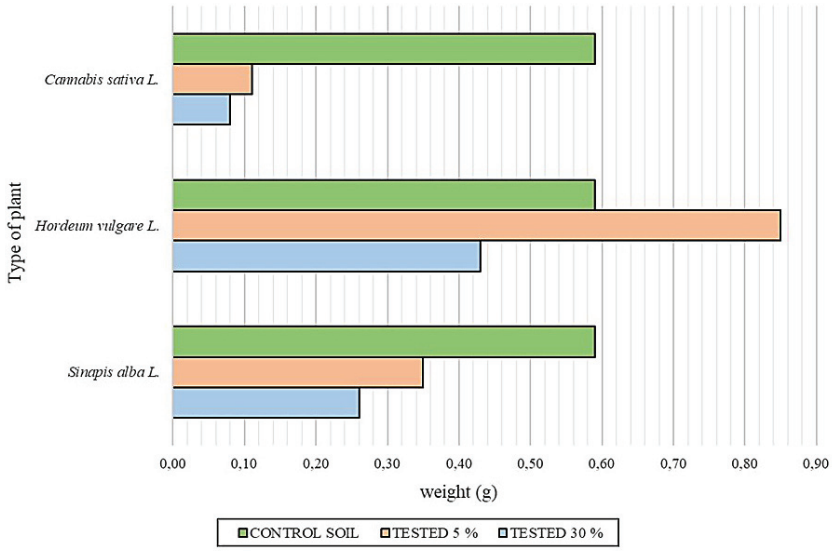

Figure 6. Biomass of selected plants

Apart from the visible mould, these results demonstrate that the end-product is not suited for being applied into the soil in the form of fertilizer. These results are corroborated by the results of similar research studies in which automated devices for FW processing/composting were tested.

According to Maxianová et al. (2019), the end-product produced from the similar automatic FW device does not produce a product that can be used for any other purpose than disposal. The end-product, although meets the standards to a certain extent, requires adding a suitable additive that will neutralize the product. An experiment at Mendel University in Brno (Czech Republic (CR)) confirmed the toxicity of the compost from FW produced from an automatic composter (Maxianová et al., 2019).

Another group of scientists from the Czech Republic studied the quality of compost from the automatic FW processor advertised by the manufacturer as a composter. Their examination also showed that the output product from the FW processor was toxic and did not meet standards. They conducted complex measurements consisting of initial simulation of the compost maturing process and then examined chemical and physical parameters such as temperature, dehydrogenase and protease activity, conductivity and pH, and the phytotoxicity test. The researchers compared the samples containing 100% of the end-product and the samples containing certain additives to improve its quality. The phytotoxicity test showed that the end-product made of FW was toxic to the plants without additives. Its results revealed inhibition, which means that no seeds germinated. With the use of additive in the form of 20% sawdust, the end-product was not toxic (Voběrková et al. 2020). The control soil sample without any additive exhibited and acidic pH with the value of about 4 and the values was markedly lower already after the first day of the experiment (Voběrková et al. 2020).

Although the manufacturer of this device claims that the end-product can be used as fertiliser similarly as compost, these experiments did not demonstrate that the end-product which consisted of 100% FW would meet the conditions for mature compost or fertiliser. The technological process of these automated devices is compared to composting. However, in the case of composting, the process makes use of the activity of microorganisms for several weeks. Despite the intensive research of the composting process in the previous decades, FW composting still encounters a number of technical challenges, e.g., physical structure with poor porosity, high content of water in FW, low C/N ratio in FW (Wang et al., 2016a; Zhou et al., 2018). However, this device functions on a shortened principle and the end-product is created within several hours. During such a short time, only sanitation occurs due to high temperatures. This is why the end-product can be placed into the contained for biowaste collection. This shows that the device can be used only for stabilisation, rather than as a soil amendment. In terms of circular economy, it would be better to use other methods for the processing of FW.

The circular economy principles as well as the waste management hierarchy (DEFRA, 2018) favour AD and composting over incineration and landfilling. Oldfield et al. (2016) undertook a study for Ireland, assessing the environmental impact of FW treatment via AD, composting, incineration and landfilling, in comparison with the waste minimisation. They found that AD had the lowest impacts of the three treatment options for all three environmental indicators, but the difference between AD, composting and incineration was small when compared to waste minimisation, which was the best option. In their research, Slorach et al. (2019) confirmed that FW composting is overall the worst option of FW management. Therefore, although this option complies with the circular economy principles through the recycling of nutrients back to the start of the food supply chain, it is otherwise environmentally unsustainable. The benefits of waste minimisation were discussed by Beretta (2019), who showed that a 38% reduction in FW in Switzerland would lead to lower environmental impact. Therefore, it can be concluded that preventing avoidable FW would achieve far greater benefits, both economic and environmental, and should be favoured over any other treatment option.

CONCLUSIONS

Final food waste processing with "Smart Food Waste Processor" is a very promising method for handling this particular waste type. However, the process is complicated and efficient processing of food waste alone is problematic. The research was focused on the processing of food waste in an electric device owing to which an end-product was expected to be created within several hours, the characteristics of which would resemble compost. The results of the germination test showed that at a certain concentration ratio 30/70 (tested/reference substrate), all tested plants exhibited the highest germination capacity. Even the stimulation of germinating plants was demonstrated; however, the tested samples were infested with mould which altered the growth of biomass. The results of the Before-After-Control-Impact method revealed that the increase in biomass was not so high as in the control sample. The research shows that the end-product of food waste processing is not suitable as soil amendment and its further use is problematic. The study showed the importance of being vigilant when introducing automatic devices that treat bio-waste to the market. The information cards of this type of devices present the consumer with environmentally-friendly solutions, and due to the lack of proven sources about the quality of the resulting product, it is becoming widely accepted. Nevertheless, it is worth noting that the resulting end product meets only the legal requirements and its further use is questioned.

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