J Mater Cycles Waste Manag (2013) 15:431–439
DOI 10.1007/s10163-013-0127-8

SPECIAL FEATURE: ORIGINAL ARTICLE

**The 7th International Conference on Waste Management and Technology (ICWMT) 2012**

# Vermicomposting technology as a tool for nutrient recovery from kitchen bio-waste

**Ales Hanc · Petr Pliva**

Received: 25 October 2012 / Accepted: 12 March 2013 / Published online: 16 April 2013


**Abstract** This study was implemented to investigate the effect of using pre-composted and raw kitchen waste with the addition of woodchips and paper in vermicomposting with regard to temperature, loss of weight, fluctuation of total and available content of nutrients and viability of earthworms. Kitchen bio-waste must be pre-composted for more than 2 weeks to reach a temperature below 25 °C. Vermicomposting increased the total content of N, P, K, Ca and Mg and the availability of P and K. Addition of used paper into kitchen bio-waste proved to be a suitable feed for earthworms. On the basis of the obtained data, a new type of vermireactor for separated pre-composting and subsequent vermicomposting of food waste has been developed.

**Keywords** Vermicomposting · Technology · Kitchen waste · Nutrients · Earthworms

## Introduction

Globally, roughly one-third of the food produced for human consumption is lost or wasted, which amounts to about 1.3 billion tons per year [1].

Unfortunately, landfilling of bio-waste still prevails in many countries of the world. This is despite the fact that the organic fraction of the food or kitchen waste feedstock possesses a range of beneficial microbial substrates including proteins, lipids, sugars, starch, amino sugars, chitin, cellulose, lignin, crude fiber, and other compounds. Levels of these substrates vary in terms of nutrient content, energy content, and availability to microbes. The elements such as N, P, K, Mg, S, Fe, Ca, Mn, Zn, Cu, Co, and Mo are integral to the protoplasmic structure of the microbial cell. These nutrients along with C, H, and O are essential for proper cell synthesis. Nutrients obviously must be present in sufficiently large concentrations in a substrate; however, they must also occur in a form that can be easily assimilated by the microbial cell. Availability is partly a function of the enzymatic production by the microbe, pH and the other factors [2].

Thus, one of the most sustainable methods of handling food waste is composting. The process is defined as a controlled aerobic, biological conversion of organic waste into a stable material. It includes decomposition, transitional, and curing stages. The decomposition phase, also called pre-composting, is characterized by mineralizing the simple, easily assimilable substances such as protein, cellulose, sugars, and lipids. A short period of high temperature accompanies this stage. Composting is practiced with various technological modifications, from simple outdoor piles to sophisticated reaction vessels with controlled temperature, airflow, and humidity. Some popular composting methods are:

A. Open systems

A1. Turned piles are a widely used method for composting municipal solid waste (MSW) due to their simplicity of operation. As the name implies, the feedstock is mixed periodically using a front-end loader or similar equipment.

A2. Turned windrows are elongated compost piles that are turned frequently to maintain aerobic conditions. Forming windrows of the appropriate size helps

A. Hanc (✉)
Czech University of Life Sciences Prague,
Kamycka 129, 165 21 Prague, Czech Republic
e-mail: hanc@af.czu.cz

P. Pliva
Research Institute of Agricultural Engineering,
Drnovska 507, 161 00 Prague, Czech Republic

in maintaining the desired temperature and oxygen levels.

A3. Static piles using air blowing or suction can also be used. This approach is effective when space is limited and the composting process must be completed relatively rapidly. In this method, a series of perforated pipes is situated within or below a pile (or windrow). Air can be supplied via a negative pressure (suction) system or a positive pressure (blower) system. Fans or blowers force air through the pipes, which is then drawn through the feedstock materials. The air movement through the pipes maintains aeration within the pile, thus eliminating the need for turning.

B. Closed systems

B1. Rotating drums rely on a tumbling action to mix continuously feedstock materials.

B2. Tanks are available as horizontal or vertical types. These tanks are long vessels in which aeration is accomplished through the use of external pumps that force air through the perforated bottom of the tanks.

All systems are designed and operated to establish optimum conditions for composting. These conditions directly influence the growth and metabolism of the microorganisms that are responsible for the process [2, 3].

Composting using earthworms is known as vermicomposting and it is considered by some authors as the most advanced composting technique. The process involves the bio-oxidation and stabilization of organic material by the joint action of earthworms and microorganisms. Although it is the microorganisms that biochemically degrade the organic matter, earthworms are the crucial drivers of the process as they aerate, condition, and fragment the substrate, thereby drastically increasing the microbial activity [4].

There are several techniques in vermicomposting:

- Small-scale domestic systems typically consist of a suitable container, bedding, earthworms, and proper environmental conditions [5].
- Low technology vermicomposting systems are known as windrow and batch systems. The windrow system requires a large area of land and is relatively labor-intensive. Since this is usually an outdoor process, there is evidence that a large proportion of the essential plant nutrients, which are in a relatively soluble form, are either washed out of the organic matter or can volatilize from it during this long processing period. Batch vermicomposting can be done in any size of container [6].
- Medium- and high-technology vermicomposting systems are represented by manually operated or fully automated continuous-flow vermicomposting reactors. Unlike capital expenditure, their labor and running costs are extremely low, and the earthworm populations in reactors reach equilibrium and can usually be run trouble-free without adding or removing earthworms for a number of years [7].

Vermicomposting as a completely environmentally friendly technology is a viable method of diverting the organic portion of waste streams, avoiding the costs of disposal and converting it to a value-added vermicompost [8]. This product is nutrient rich but also contains high quality humus, plant growth hormones, enzymes, and substances which are able to protect plants against pests and diseases. Many cropping areas in the world are deficient in organic matter and nutrients. Farmers need to use a sustainable alternative which is both economical and also productive while also maintaining soil health and fertility. By adding the vermicompost to soil, money that would have been spent on chemical fertilizers and pesticides may be saved [9].

Composting and vermicomposting techniques have their inherent advantages and disadvantages. Combining vermicomposting with pre-composting would seem to be useful in at least these respects: (1) the initial thermophilic stage of composting should result in effective pathogen control which vermicomposting alone may not achieve, (2) the addition of vermicomposting enhances the stabilization of bio-waste and improves the product quality compared to composting alone, and (3) inoculation of the material resulting from the thermophilic phase of composting with earthworms reduces the expense and duration of the treatment process [10–12].

Most of kitchen waste produced from households and restaurants are high in moisture content. Therefore composting and vermicomposting of kitchen waste without any bulking agent is very difficult in practice. The mixture in our study consisted of kitchen waste, cow dung and soil in the ratio 6:3:1 (on dry weight basis) and was processed by earthworms (*Eisenia foetida*) for 100 days [13]. Three types of feed materials were used for the vermicomposting: (1) kitchen waste + cow dung in 70:30 ratio, (2) cow dung + coffee grounds in 30:70 ratio, and (3) kitchen waste + cow dung + coffee grounds in 35:30:35 ratio [14]. Food industry waste was vermicomposted in the mixture with cow dung, biogas plant slurry and poultry droppings in different rates for 15 weeks [15]. In our study we also focused on the addition of woodchips and paper into the kitchen waste. Woodchips are commonly used as a bulking agent in large-scale composting technology, especially for enhancing the aeration process. High amounts of used paper (e.g. napkins or doilies) can be found in catering facilities and kitchens. The advantage of this material is a high absorption capacity for water, and a non-toxic and biodegradable nature [16].

Keeping in mind the above facts, we assumed that pre-composted kitchen waste with the addition of paper should be very suitable material for vermicomposting.

This study was implemented to investigate the effect of pre-composted and raw kitchen waste with the addition of woodchips and paper on vermicomposting with regard to: (1) temperature; (2) loss of weight; (3) fluctuation of total and available content of nutrients; and (4) viability of earthworms.

Businesses and institutions are increasingly interested in adopting sustainability practices while at the same time cutting costs. The results achieved in this study helped us to design an effective vermireactor for kitchen and food waste that could be adopted widely throughout industries and communities.

## Methodology

### Collection of bio-waste

The waste used in this experiment was kitchen bio-waste collected in households living in urban settlements. A detailed description of the composition and properties of this kitchen bio-waste is shown in our previous study [17]. The composition in terms of weighted and volumetric fraction is shown in Table 1.

Woodchips (<3 cm) and old paper [coated paper (50 % by volume), newsprint (40 % by volume), and cardboard (10 % by volume)] were used as bulking agents to improve structure, enhance aeration, and absorb excess liquids.

### Treatment of bio-waste by pre-composting

Before vermicomposting, part of the kitchen bio-waste with woodchips and with old paper were pre-composted in laboratory reactors of 70 L capacity, with perforated stokers enhanced by 40 mm thick foam insulation to reduce heat loss. The reactors were kept in a room at 25 °C for 14 days. An active aeration device was used to push air through the composted materials from the bottom. The mixtures were batch-wise aerated for 5 min every half hour with 4 L air/min$^{-1}$. On the basis of our previous experiences, we found that this aeration level was usually sufficient to achieve the optimal parameters of the composting process. Very low aeration levels are insufficient for effective composting, yet on the other hand, increased aeration merely increases cooling of composted material [18].

**Table 1** Composition of used kitchen bio-waste

| Components | Wet weight (%) | Wet volume (%) |
|---|---|---|
| Grass | 13.5 | 14.1 |
| Plants | 16.1 | 34.3 |
| Wood | 2.2 | 6.9 |
| Citrus fruit | 14.6 | 7.9 |
| Non-citrus fruit and vegetables | 32.5 | 18.0 |
| Bread | 1.6 | 1.0 |
| Bedding | 3.8 | 2.0 |
| Soil | 8.7 | 4.8 |
| Paper | 3.3 | 5.7 |
| Non-classifiable | 2.5 | 2.1 |
| Improper | 1.2 | 3.2 |

### Vermicomposting

For vermicomposting, a specially adapted laboratory with controlled conditions (temperature 22 °C, relative humidity 80 %, ventilation for 15 min every 12 h) was used.

The composition of feeds (in volume portion) in different vermicomposting units is given below:

Vermicomposting treatment I: pre-composted kitchen waste 75 % + woodchips 25 %
Vermicomposting treatment II: pre-composted kitchen waste 50 % + paper 50 %
Vermicomposting treatment III: raw kitchen waste 75 % + woodchips 25 %
Vermicomposting treatment IV: raw kitchen waste 50 % + paper 50 %

Thirteen liters of aerobically pre-composted material or raw material was manually mixed with 3 L of substrate containing 600 earthworms of the genus *Eisenia.* The mixture was placed into a plastic bowl with a perforated bottom, equipped with irrigation and temperature measurement tools. The bowl measured 40 × 40 × 18 cm. The covered bowls were put into a metal rack. Each treatment was carried out in triplication. Before sampling, the eventual leachate captured in a stainless bowl was returned to the vermicomposted material to achieve a closed loop. A sample of 200 g from every bowl was collected every month for 5 months. The earthworms were then sorted out and the resulting samples were dried at laboratory temperature and ground.

### Analytical methods

Measurements of pH were taken from samples mixed with deionized water (1:10 w/v dry basis) by WTW pH 340 i (WTW, Germany). Total nitrogen content was determined by the Kjeldahl method. Contents of N-$NH_4^+$ and N-$NO_3^-$ in 1:10 (w/v) 0.01 mol $L^{-1}$ $CaCl_2$ extracts were measured colorimetrically using the SKALAR SAN$^{PLUS}$ SYSTEM®. Total element contents in the digested soil were obtained by pressurized wet-ashing ($HNO_3$ + HCl + HF) with microwave heating using an Ethos 1 (MLS GmbH, Germany). The available content of elements in the material was ascertained in 1:20 (w/v) 0.11 mol $L^{-1}$ $CH_3COOH$. Concentrations of elements were determined using inductively coupled plasma optical emission spectrometry (ICP-OES, VARIAN VistaPro, Varian, Australia) with axial plasma configuration.

## Results

### Treatment of feedstock by pre-composting

Figure 1 illustrates that the maximum temperature of 60 °C was recorded in both pre-composted mixtures after 3 days. From the sixth day, there was a gradual decrease in temperature, until 44 °C was finally reached after 2 weeks of the process. Mixtures of kitchen waste with woodchips reached slightly higher temperatures compared to kitchen waste with paper. This was caused by the better structure of the woodchips versus paper in terms of facilitating airflow.

Higher losses of total fresh mass were recorded in the mixture of kitchen waste with paper (decrease by 10 %) than with woodchips (decrease by 6 %) after 2 weeks of pre-composting (Fig. 2).

### Vermicomposting

#### *Differences in temperature and weight loss of pre-composted and raw bio-waste*

At the beginning of vermicomposting, the temperature of the pre-composted materials slightly decreased. Conversely, the temperature of non-pre-composted materials sharply increased in 2 days, but then a gradual decrease was recorded (Fig. 3).

A clearly higher relative weight loss was found with the raw kitchen waste (58 % on average of both treatments) than in the pre-composted waste (38 % on average of both treatments), as shown in Fig. 4. The addition of paper into kitchen waste caused faster and substantial loss of weight during vermicomposting. The highest loss of weight occured in the mixture of raw kitchen waste with paper (loss by 71 %).

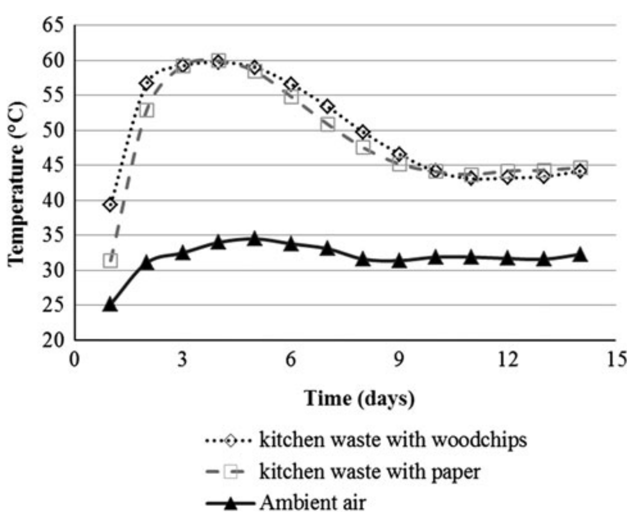


**Fig. 1** Course of temperature (°C) during pre-composting of bio-waste used in vermicomposting treatment I and II

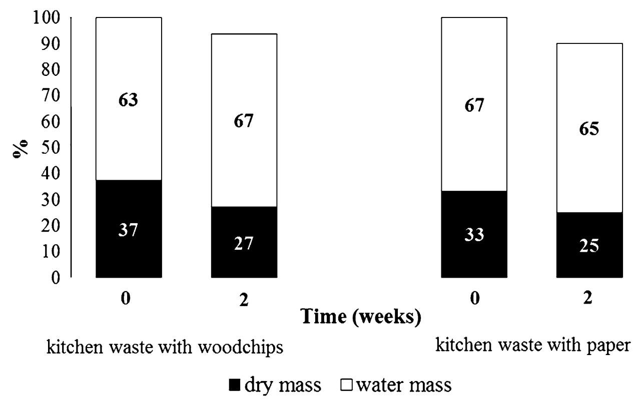


**Fig. 2** The relative weight of total fresh mass in % during pre-composting of kitchen waste with woodchips and of kitchen waste with paper

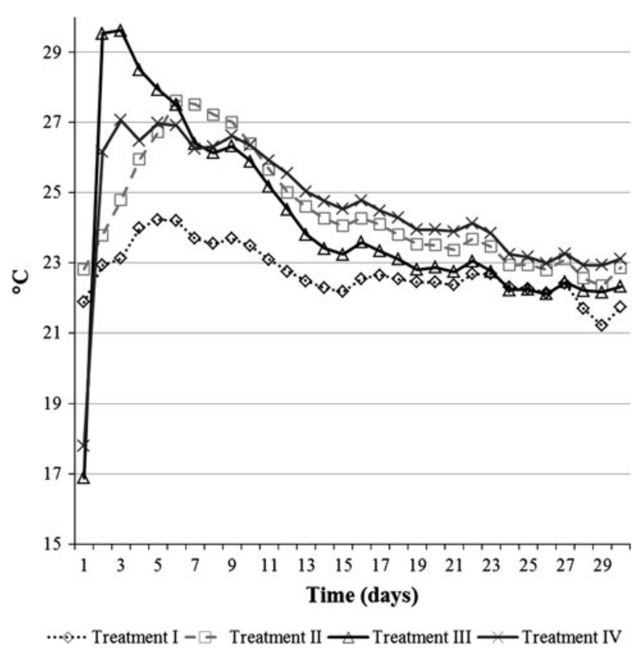


**Fig. 3** Course of temperature (°C) during vermicomposting of pre-composted and raw materials

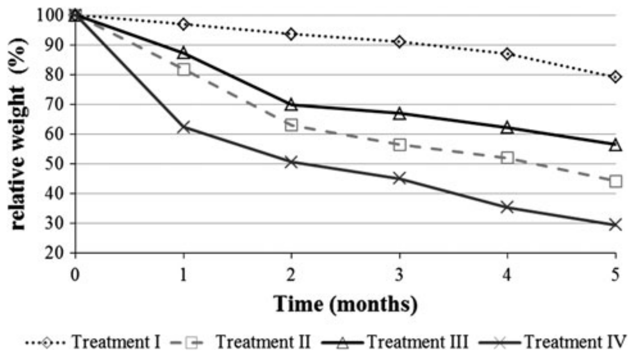


**Fig. 4** Course of relative weight during vermicomposting of pre-composted and raw materials

*Total and available contents of nutrients*

Pre-composted bio-waste showed higher total content of N than feedstock (Fig. 5). The addition of paper caused a decrease of total N in the initial mixture but increased this content in the final vermicompost. A higher percentage of N-$NH_4^+$ from total N content was found in the non-pre-composted materials (1.3 % at the beginning and 0.5 % at the end of vermicomposting) than in the pre-composted ones (0.8 % at the beginning and 0.3 % at the end of the process). The content of N-$NH_4^+$ decreased during vermicomposting on average in all treatments by 48 % (Fig. 6). The addition of paper had a more positive effect on the N-$NH_4^+$ content in the final vermicompost compared to the woodchips mixture irrespective of pre-processing. The content of N-$NH_4^+$ was inversely proportional to pH which fluctuated during the vermicomposting process, as illustrated in Fig. 7. The correlation coefficient *R* was the following for treatment I, II, III and IV: −0.81, −0.80, −0.74 and −0.44, respectively. Unlike N-$NH_4^+$, the content of N-$NO_3^-$ (Fig. 8) increased during vermicomposting. The recorded increase was on average 240, 334, 320, 558, and 1,837 % after 1, 2, 3, 4, and 5 months compared to the beginning of the vermicomposting, respectively. The N-$NO_3^-$ content made up 7 % of total nitrogen at the end of vermicomposting.

The total content of macroelements such as P, K, Ca, and Mg increased in the vermicompost at the end of the process, as shown in Figs. 9, 10, 11 and 12. The highest increase was found in the case of Ca and Mg. Higher growth was recorded in vermicompost originating from the kitchen bio-waste with the addition of paper rather than woodchips. For Ca, the increase was 1.9- and 1.3-fold, and in the case of Mg it was even higher (2.8- and 2.1-fold).

We observed different behaviors between the available contents of P and K, and Ca and Mg (Table 2). Despite considerable fluctuations in the available content of P and K during vermicomposting, the contents were often higher at the end than at the beginning. Available P and K content

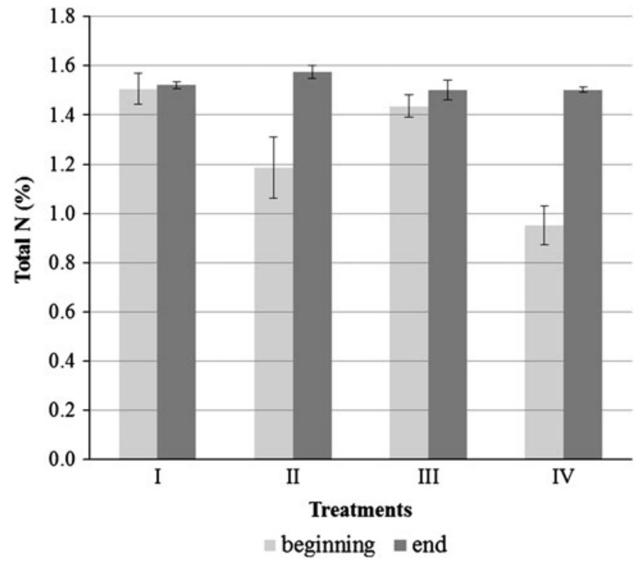


**Fig. 5** Total content of N (mg/kg) at the beginning and at the end of vermicomposting

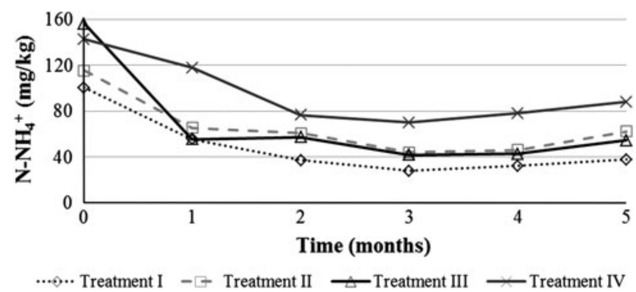


**Fig. 6** Fluctuation of N-$NH_4^+$ (mg/kg) during vermicomposting

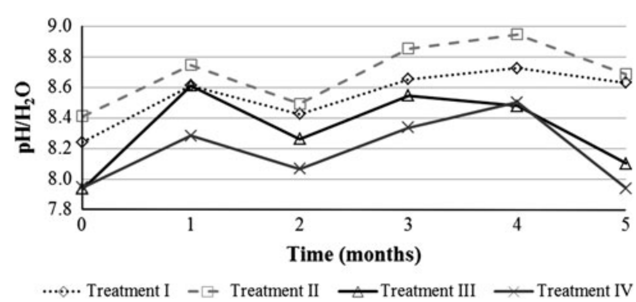


**Fig. 7** Fluctuation of pH during vermicomposting

constituted approximately 50 and 5 % from total contents, respectively. Higher available P contents were found in the material with woodchips than with paper. Pre-composting of feedstock positively affected the available K content in the final vermicompost. The content of available Ca and Mg decreased at the end of vermicomposting. The decrease of Ca was more significant (by 72 %) than the decrease of Mg (by 37 %).

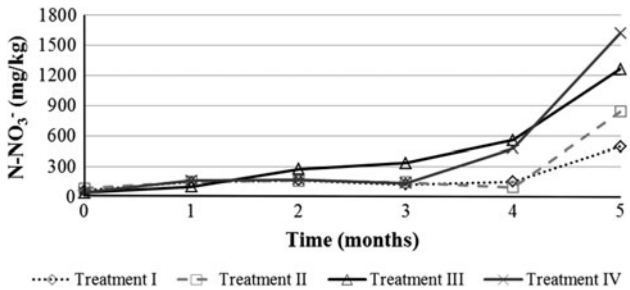


**Fig. 8** Fluctuation of N-$NO_3^-$ (mg/kg) during vermicomposting

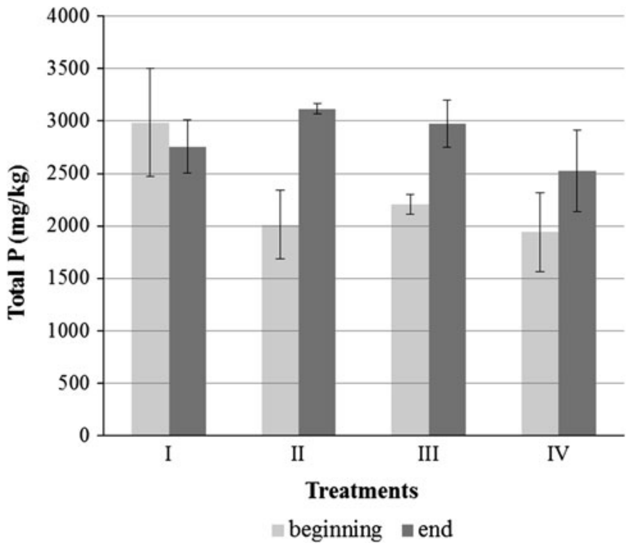


**Fig. 9** Total content of P (mg/kg) at the beginning and at the end of vermicomposting

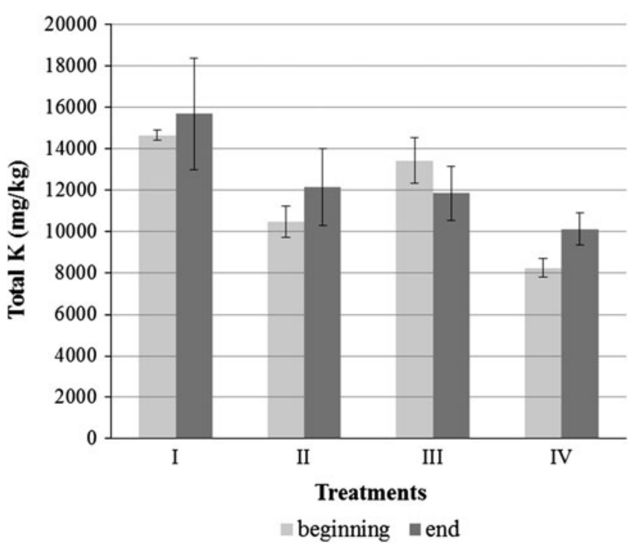


**Fig. 10** Total content of K (mg/kg) at the beginning and at the end of vermicomposting

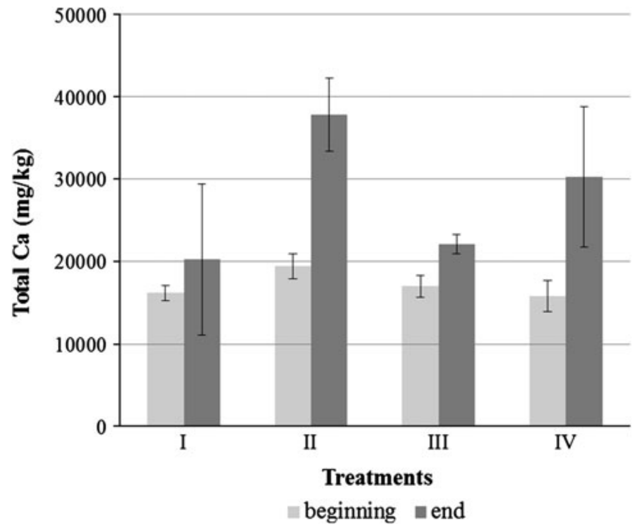


**Fig. 11** Total content of Ca (mg/kg) at the beginning and at the end of vermicomposting

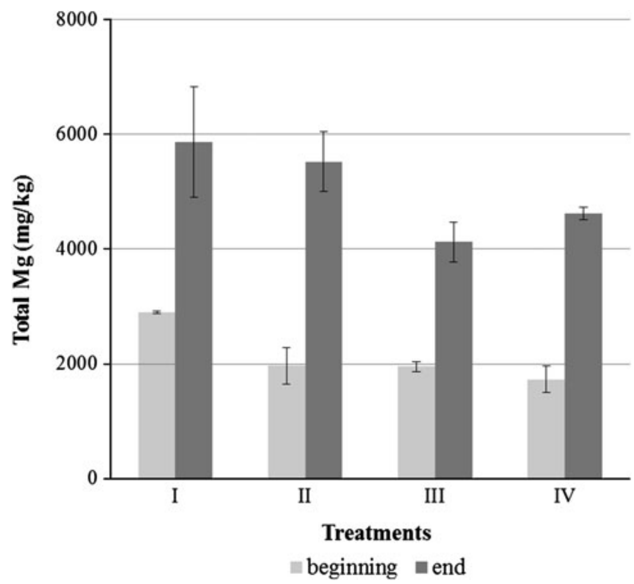


**Fig. 12** Total content of Mg (mg/kg) at the beginning and at the end of vermicomposting

### *Viability of earthworms*

The weight of earthworms relative to one kilogram of material was used to assess changes in biomass of earthworms during 5 months of vermicomposting (Fig. 13). An upward trend was observed in the second half of the process. In treatment II, the earthworm biomass increased up to 11-fold. In the case of treatments III and IV, biomass increased 7-fold. The smallest increase was observed in treatment I, where the value was only 1.3-fold.

**Table 2** Available content of phosphorus, potassium, calcium and magnesium (in mg/kg) in initial feed mixtures and vermicomposts (mean ± SD, $n = 3$)

| Element | Treatment | Initial mixture | Vermicompost |
|---|---|---|---|
| P | I | 1,814 ± 326 | 2,220 ± 77 |
| | II | 917 ± 373 | 1,077 ± 74 |
| | III | 1,381 ± 84 | 2,143 ± 135 |
| | IV | 730 ± 283 | 915 ± 204 |
| K | I | 1,307 ± 144 | 2,179 ± 370 |
| | II | 1,104 ± 275 | 1,495 ± 122 |
| | III | 1,295 ± 648 | 2,259 ± 1103 |
| | IV | 740 ± 340 | 1,011 ± 374 |
| Ca | I | 20,226 ± 2238 | 7,341 ± 853 |
| | II | 30,287 ± 2983 | 8,417 ± 936 |
| | III | 24,374 ± 1986 | 8,236 ± 942 |
| | IV | 24,970 ± 2022 | 3,141 ± 425 |
| Mg | I | 2,154 ± 256 | 1,090 ± 158 |
| | II | 1,874 ± 223 | 1,187 ± 189 |
| | III | 1,698 ± 195 | 1,177 ± 205 |
| | IV | 1,179 ± 153 | 778 ± 112 |

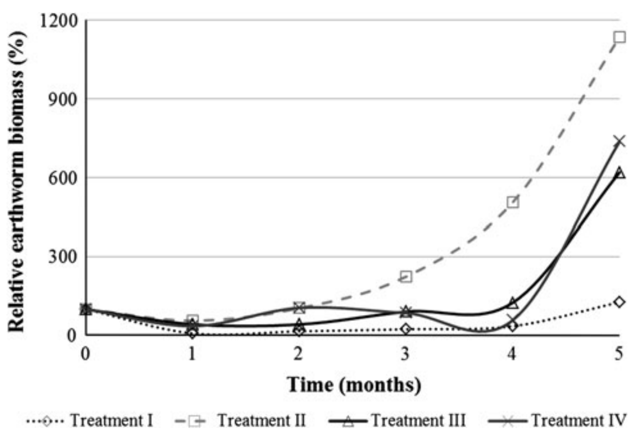


**Fig. 13** Changes of relative earthworm biomass in 1 kg of material during vermicomposting

## Discussion

The unfavorable effect of high temperatures on earthworms is not entirely a direct effect because these warm temperatures also promote chemical and microbial activities in the substrate, and the increased microbial activity tends to consume the available oxygen, with negative effects on the survival of earthworms [19]. Given that the optimum temperature for the proper development of earthworms should not exceed 25 °C, kitchen bio-waste should be pre-composted for more than 2 weeks. For pre-composted material, it is assumed that the temperature will no longer increase during vermicomposting and that this important condition for successful vermicomposting will have already been met. So, the properly pre-composted material could be put into an aerated vermireactor in a large volume at once without danger of heating. In a study investigating the influence of temperature on pathogen content in kitchen waste it was found that the optimum period to obtain pathogen safety was 9 days of pre-composting, followed by 2.5 months of vermicomposting. This result showed that if pre-composting process did not reach a high enough temperature, it was possible not only that pathogens may be insufficiently inactivated, but also that they would even proliferate [20].

Pre-composted kitchen waste with the addition of woodchips and paper had a higher content of total N by 15 %, P by 20 %, K by 18 %, Ca by 18 % and Mg by 31 % on average, compared with the same raw feedstock mixtures. Similarly, total N, P, K increased by 12, 66 and 40 %, respectively, in source-segregated household waste after 14 days of pre-composting [21]. In vermicomposting, earthworms mineralize the organic matter, converting a part of it into worm biomass and respiratory products, while the rest is egested as nutrient rich vermicompost. The appropriate feed composition for the earthworms could optimize the value of the vermicompost [16]. Lower amounts of mineral nitrogen in treatment I and II could be explained by the volatilization of ammonia during the pre-composting. It is speculated that the higher content of N-$NH_4^+$ in the last months of vermicomposting could be caused by the release of nitrogen from deceased bodies of earthworms and a decrease of pH values. As shown in Fig. 8, the majority of N-$NH_4^+$ was nitrified in N-$NO_3^-$, which is apparently more available for plants. Earthworms also have a great impact on nitrogen transformations, by enhancing nitrogen mineralization, so that mineral nitrogen may be retained in the nitrate form [22]. Lower contents of N-$NO_3^-$ in pre-composted materials than in raw materials at the end of vermicomposting could be partially explained by higher pH levels in the first mentioned materials.

Higher total contents of macroelements in final vermicompost compared to feedstock was affected by changes of weight and material volume during the process. In addition, part of the element amounts had to be accumulated in earthworms. The uptake of elements by earthworms and their accumulation in the worms' tissues is affected by earthworm density and quality of feed [23]. At the end of the study, the earthworms were sorted out from the analyzed sample. Thus the change of earthworm biomass affected the total and available content of elements during vermicomposting and in the final vermicompost. This is consistent with the results of vermicomposting experiments with various types of feedstock [24]. The quantity and quality of the nutrients in vermicomposts can be also explained by the accelerated mineralization of organic matter, increased microbial activity, breakdown of polysaccharides, and higher rates of humification achieved during vermicomposting [25]. The amount of Ca in used paper contributed to the high content of this element in the final vermicompost. On average in all the treatments, the final vermicompost had a lower weight and volume by 20–70 %, and by 55–80 %, respectively, compared to feedstock. Larger amounts of mineral nutrients in vermicomposts compared to commercial plant growth medium were reported. The wastes they investigated were separated cattle solids, separated pig solids, cattle solids on straw, pig solids on straw, duck solids on straw, and chicken solids on shavings. Vermicomposts from these materials contained mineral contents (% dry weight) ranging from 2.2 to 3.0 N, 0.4 to 2.9 P, 1.7 to 2.5 K, and 1.2 to 9.5 Ca, whereas the commercial plant growth medium had only 1.80 N, 0.21 P, 0.48 K, and 0.94 Ca [26].

In our experiment, the higher available contents of P and K were found in the final product compared to feedstock. On average of treatments, available P and K content increased by 30 and 53 %, respectively. In the experiment with the mixture of domestic bio-waste and cow dung in a 2:1 ratio, the available P and K content was also higher in vermicompost as compared to the initial feed mixture. This vermicompost prepared by earthworms, genus *Perionyx*, showed more available P and K by 106 and 85 %, respectively, after 150 days of vermicomposting [27]. Similarly, vermicomposting of coffee pulp increased the availability of nutrients such as P and Mg [28]. Mineralization of organic P is faster in treatments with earthworms than without them. Earthworms help to release P from organic forms, and thereby increase its amount in available fractions [29]. The release of P is partly due to the presence of phosphatases in the earthworm stomach and subsequently to activity of microorganisms present in the vermicasts [30]. Significant decrease of available Ca during vermicomposting is in agreement with another study, where 11.5 % loss in the amount of exchangeable Ca in sewage sludge with earthworms was found [31]. It is suggested that the earthworm converts a proportion of Ca from bound to free forms, which can be assimilated through the columnar epithelial layer of their gut as a physiological supplement [32]. The 80 % loss of available Ca in vermicompost from the kitchen waste with paper can be explained by increases of earthworm biomass and food availability. In other studies, most vermicomposts contained an adequate amount of macronutrients, micronutrients, and the trace elements of various kinds, but amounts inevitably depended on the type of the parent earthworm feedstock [33, 34].

The growth and reproduction of earthworms is affected by many factors: pH, conductivity, presence of hazardous substances, temperature, the ratio C:N, and last but not least, the type of vermicomposted material). During the first month, the earthworm biomass was reduced by 44–92 %. Changing environmental conditions could result in stress of earthworms and lead to their death [35]. Before vermicomposting, it is necessary to cool the pre-composted material and let the earthworms crawl there themselves. This knowledge will be used in the construction of a new type of vermireactor. The highest earthworm biomass was found during vermicomposting of the kitchen bio-waste with paper. Paper seems to be a very suitable feed for earthworms because they are able to produce cellulase enzymes for its decomposition [36]. It is worth noting that earthworms in the substrates liked to form clusters of individuals and this could cause fluctuations in the measured values.

## Conclusion

Kitchen bio-waste must be pre-composted for more than 2 weeks to reach temperatures below 25 °C. Vermicomposting increased the total content of N, P, K, Ca and Mg and the availability of P and K. The addition of used paper into kitchen bio-waste proved to be a suitable feed for earthworms. Resulting data showed that pre-composting of kitchen bio-waste is effective before vermicomposting. A new type of vermireactor for separated pre-composting and subsequent vermicomposting is needed. Therefore, the authors of the paper designed, and are currently developing and testing a special two-modular vermireactor for food waste.

**Acknowledgments** Financial support for these investigations was provided by NAZV project No. QI91C199 of the Ministry of Agriculture of the Czech Republic. The authors would like to thank Emilie Brown for revision of the English text.

## References

1. Gustavsson J, Cederberg C, Sonesson U, van Otterdijk R, Meybeck A (2011) Global food losses and food waste. Study conducted for the International Congress SAVE FOOD! at Interpack 2011 Düsseldorf, Germany: Extent, Causes and Prevention. FAO, Rome
2. Pichtel J (2005) Composting MSW. In: Waste management practices. Taylor & Francis Group, LLC, UK, pp 213–246
3. Diaz LF, Savage GM, Eggerth LL, Golueke CG (1993) Composting and recycling of municipal solid waste. Lewis Publishers, Boca Raton
4. Domínguez J, Edwards CA, Subler S (1997) A comparison of vermicomposting and composting. BioCycle 38:57–59
5. Appelhof M (1997) Worms eat my garbage. Flower Press, USA. ISBN:0942256107
6. Edwards CA (2011) Low-technology vermicomposting systems. In: Edwards CA, Arancon N, Sherman R (eds) Vermiculture technology. CRC Press, Boca Raton, pp 79–90
7. Edwards CA (2011) Medium- and high-technology vermicomposting systems. In: Edwards CA, Arancon N, Sherman R (eds) Vermiculture technology. CRC Press, Boca Raton, pp 91–102

8. Sherman RL (2011) Vermicomposting for businesses and institutions. In: Edwards CA, Arancon N, Sherman R (eds) Vermiculture technology. CRC Press, Boca Raton, pp 391–408
9. Sinha RK, Agarwal S, Chauhan K, Valani D (2010) The wonders of earthworms & its vermicompost in farm production: Charles Darwin's friends of farmers, with potential to replace destructive chemical fertilizers from agriculture. Agric Sci 1:76–94
10. Frederickson J, Butt KR, Morris RM, Daniel C (1997) Combining vermiculture with traditional green waste composting systems. Soil Biol Biochem 29:725–730
11. Ndegwa PM, Thompson SA (2001) Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. Bioresour Technol 76:107–112
12. Tognetti C, Laos F, Mayyarino MJ, Hernández MT (2005) Composting vs. vermicomposting: a comparison of end product quality. Compost Sci Util 13:6–13
13. Garg P, Gusta A, Satya S (2006) Vermicomposting of different types of waste using *Eisenia foetida*: a comparative study. Bioresour Technol 97:391–395
14. Adi AJ, Noor ZM (2009) Waste recycling: utilization of coffee grounds and kitchen waste in vermicomposting. Bioresour Technol 100:1027–1030
15. Garg VK, Suchar S, Yadav A (2012) Management of food industry waste employing vermicomposting technology. Bioresour Technol 126:437–443
16. Gupta R, Garg VK (2009) Vermiremediation and nutrient recovery of non-recyclable paper waste employing *Eisenia fetida*. J Hazard Mater 162:430–439
17. Hanc A, Novak P, Dvorak M, Habart J, Svehla P (2011) Composition and parameters of household bio-waste in four seasons. Waste Manag 31:1450–1460
18. Hanc A, Szakova J, Svehla P (2012) Effect of composting on the mobility of arsenic, chromium and nickel contained in kitchen and garden waste. Bioresour Technol 126:444–452
19. Dominguez J, Edwards CA (2011) Biology and ecology of earthworm species used for vermicomposting. In: Edwards CA, Arancon N, Sherman R (eds) Vermiculture technology. CRC Press, Boca Raton, pp 27–40
20. Nair J, Sekiozoic V, Anda M (2006) Effect of pre-composting on vermicomposting of kitchen waste. Bioresour Technol 97:2091–2095
21. Frederickson J, Howell G, Hobson AM (2007) Effect of pre-composting and vermicomposting on compost characteristics. Eur J Soil Biol 43:S320–S326
22. Atiyeh RM, Dominguez J, Subler S, Edwards CA (2000) Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei* Bouche) and the effects on seedling growth. Pedobiologia 44:709–724
23. Ndegwa PM, Thompson SA, Das KC (2000) Effect of stocking density and feeding rate on vermicomposting of biosolids. Bioresour Technol 71:5–12
24. Nath G, Singh K, Singh DK (2009) Chemical analysis of vermicomposts/vermiwash of different combinations of animal, agro and kitchen wastes. Aust J Basic Appl Sci 3:3671–3676
25. Albanell E, Plaixats J, Cabrero T (1998) Chemical changes during vermicomposting (*Eisenia fetida*) of sheep manure mixed with cotton industrial wastes. Biol Fertil Soils 6:266–269
26. Edwards CA (1988) Breakdown of animal, vegetable and industrial organic wastes by earthworms. In: Edwards CA, Neuhauser EF (eds) Earthworms in waste and environmental management. SPB Academic Publishing, The Hague, pp 21–31. ISBN:90-5103-017-7
27. Suthar S, Singh S (2008) Vermicomposting of domestic waste by using two epigeic earthworms (*Perionyx excavatus* and *Perionyx sansibaricus*). Int J Environ Sci Technol 5:99–106
28. Orozco SH, Cegarra J, Trujillo LM, Roig A (1996) Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: effects on C and N contents and the availability of nutrients. Biol Fertil Soils 22:162–166
29. Ghosh M, Chattopadhyay GN, Baral K (1999) Transformation of phosphorus during vermicomposting. Bioresour Technol 69:149–154
30. Lee KE (1992) Some trends and opportunities in earthworm research. Soil Biol Biochem 24:1765–1771
31. Hartenstein R, Hartenstein F (1981) Chemical changes affected in activated sludge by the earthworm *Eisenia foetida*. J Environ Qual 10:377–382
32. Suthar S (2008) Bioremediation of aerobically treated distillery sludge mixed with cow dung by using epigeic earthworm *Eisenia fetida*. Environmentalist 28:76–84
33. Werner M, Cuevas R (1996) Vermiculture in Cuba. BioCycle 37:61–62
34. Businelli M, Perucci P, Patumi M, Giusquiani PL (1984) Chemical composition and enzymatic activity of some worm casts. Plant Soil 80:417–422
35. Suthar S (2010) Recycling of agro-industrial sludge through vermitechnology. Ecol Eng 36:1028–1036
36. Ueda M, Goto T, Nakazawa M, Miyatake K, Sakaguchi M, Inouye K (2010) A novel cold-adapted cellulase complex from *Eisenia foetida*: characterization of a multienzyme complex with carboxymethylcellulase, β-glucosidase, β-1,3 glucanase, and β-xylosidase. Comp Biochem Physiol Part B 157:26–32