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Home Composting of Food Wastes Using Rotary Drum Reactor as an Alternative Treatment Option for Organic Household Wastes

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ABSTRACT

In this research, the application of home composting system as an alternative approach for household organic waste management was investigated. A rotary drum home composter made of galvanized steel was designed and used for the composting process. It consists of two chambers of about 170 L each, and is equipped with sufficient holes to ensure aerobic conditions as well as valves for leachate drainage. Different parameters, including using waste to bulking agent ratio, co-composting using animal manure and introducing charcoal with the feedstock were investigated. The designed reactor proved its efficiency for composting purposes, according to the obtained results regarding the degradation of the organic waste with ease operation and monitoring. The highest reduction volume (85%) in the composted materials was in treatment of 1:0.5 waste to bulking agent, whereas co-composting using animal manure better enhanced the organic matter degradation, as the highest decrease in the C/N ratio (about 62%) was observed in this treatment. No significant effect of the charcoal war recorded regarding the degradation process, but was clear in reducing odors.

Keywords: waste management, food wastes, home composting, rotary drum composter.

INTRODUCTION

Due to its crucial role in providing protection to human health and environment, waste management has become a global environmental priority and an important part of the urban infrastructure design. This important issue is also highly related to various aspects of human life [ISWA, 2002]. The generated wastes normally consisted of different categories, where the organic fraction represents a major part of these wastes [Jeon et al. 2020]. Landfilling is still considered the most commonly used practice for final disposal of municipals waste, including organic fraction mainly in developing countries [Elkhalifa et al., 2019]. However, in developed countries like EU member states, the Landfill Directive (1999/31/EC) and Waste Framework Directive (2008/98/EC), force these states to use more sustainable and environmentally friendly technologies to recycle organic fraction rather than send it to a landfill [Bruni et al., 2020; Wei et al., 2017]. Composting, which is an aerobic process used for biodegradation of organic materials under controlled conditions, is still categorized among the most preferred urban waste management practices [Sayara et al., 2020a]. The process produces a final end product that can be used as organic fertilizer and improve the soil properties. Furthermore, it is well-known as an environmentally-friendly and cost effective process compared to other technologies, when it is performed under controlled and optimal conditions [Iqbal et al., 2020; Sayara et al., 2020b]. Traditionally, centralized composting plants are used for treatment of organic fraction of municipal solid wastes. However, and due to different consideration, centralized plants are not feasible in many areas, or are not the most applicable and cost-effective ones [Manu et al., 2019; Vázquez and Soto, 2017]. Accordingly, different approaches that focus on using decentralized systems are being nowadays employed to deal with municipal organic wastes. Home composting and community composting are among these approaches. Actually, these options would serve to reduce the collection and transporting costs for local communities, as organic waste are separated and treated at source [Bruni et al., 2020; De Kraker et al., 2019]. In this regard, Martínez-Blanco et al. (2010) concluded that home composting is an interesting alternative to central composting, especially in the areas with low density population. Moreover, this option is normally preferred and applicable in small and rural communities that have independent yards in their houses [Comesaña et al., 2017].

In Palestine, more than 50% of the generated municipal wastes are organic (mainly food and vegetable waste) and the majority are finally disposed in landfills, while this fraction could be recycled through composting and thus contribute to solving the solid wastes problems, simultaneously producing a valuable product for agricultural application [Sayara et al., 2020a]. Consequently, the current research which forms part of decentralized composting systems in small town (DECOST) project, addresses the application of home composting for composting household organic wastes as a sustainable approach for waste treatment. In this regard, a rotary drum home composter as a prototype reactor was designed by Palestine Technical University and used for conducting the composting process; thus, validation of the designed composter was set as an objective. Furthermore, and as the composting process is affected by different variable including C/N ratio, moisture content, temperature among others, the combination of different feedstock's and optimization of bulking agent ratio was investigated by studying the composting process performance under different bulking agent to waste ratio, the additions of animal manure and charcoal to the waste were also studied.

MATERIALS AND METHODS

Composting reactor

The experiment was carried out using a coated galvanized steel rotary drum composter (Figure 1), since this type of composter has been considered as a suitable decentralized option for composting of food and household wastes [Rich et al., 2018]. The designed reactor consists of two chambers of about 170 L per chamber with internally mixing paddles, easy rotation handles for mixing, and firmly closed doors specifically to be rodent proof. For leachate drainage, two adjacent holes with valves were also made underneath the drum. Aeration of composted materials was accomplished by natural aeration, where both sides of the reactor were supplied by a sufficient number of holes that assure proper air circulation inside reactor chambers and maintain aerobic conditions. Additionally, turning of the composting materials during the experiment contributes in mixing and aerating the mixture.

Figure 1. The used rotary drum compost (reactor)

Composting materials and operation

As a main feedstock, source segregated food wastes mainly composed of vegetables and fruits were obtained from locally vegetable market and restaurants, whereas animal manure which was introduced in one treatment as a co-substrate and inoculant was obtained from an animal farm. Additionally, charcoal was also employed in one treatment. All composted materials were mixed with wood chips that were used as bulking agent to improver aeration and structural support [Awasthi et al., 2015; Rish et al., 2018]. Moreover, the used bulking agent helps in reducing the high moisture content of the used feedstock. Table 1 shows the initial characteristics of the used materials that were shredded manually to obtain a particle size of 1–2 cm and mixed with the bulking agent and other co-substrates according to the experiment design which was as following:

- Treatment 1 (R1A): food waste and bulking agent were mixed at a ratio of 1:1 (V/V);
- Treatment 2 (R1B): food waste and bulking agent were mixed at a ratio of 1: 0.5(V/V);
- Treatment 3 (R2A): food waste and animal manure (90% food waste and 10% animal manure) and bulking agent were mixed at a ratio of 1:1 (V/V);
- Treatment 4 (R2B): food waste and charcoal (90% food waste and 10% charcoal) and bulking agent were mixed at a ratio of 1:0.5 (V/V).

In all treatments, the introduced materials were mixed by turning the reactor in attempt to have a well-structured and homogenous mixture for the composting process and initial readings of different controlling parameters were recoded. The reactors were fed with additional materials by the end of the first and second week, considering the same mixing ration in the first step. Table 2 shows the volume of the introduced materials during the composting process, whereas Table 3 shows the initial characteristics of the composting mixtures.

The performance of the composting process in the reactors was followed by taking measurements for different process controlling parameters. In this regard, the temperature within the mixture was measured daily, whereas representative samples were taken weekly for the determination of pH, organic matter (OM), electrical conductivity (EC), moisture content (MC). However, the content of N, P, K and total organic carbon (TOC) were determined only at the beginning and by the end of the process. The reactors were turned at least twice a week during the first three weeks and then once a week until the end of the experiment. By the end of the experiment (about 7 weeks), the content of reactors was removed and final characteristics of the produced compost was determined.

Table 1. Characteristics of the initial raw materials used in the experiment

Parameter	Manure	Food waste
Moisture content (MC %)	43	88
Organic matter (OM %)	68	91.5
Total organic carbon (TOC %)	37.7	50.8
Total Nitrogen (%)	20	0.71
Carbon to nitrogen ratio (C/N)	21	67
pH	9.5	5.1
Electrical conductivity (EC ms/cm)	14.3	3.1
Total Phosphorus (ppm)	1050	1280
Total Potassium (ppm)	3400	1200

Table 2. The volume of the introduced materials during the composting process

	Bulking agent (L)	Food waste (L)	Animal manure (L)	Charcoal (L)
Initial feed (day 0)				
R1A	51	51	-	-
R1B	34	68		
R2A	34	61.5	6.5	-
R2B	34	61.5	-	6.5
Second feed (day 7)				
R1A	25.5	25.5	-	-
R1B	17	34	-	-
R2A	17	30.5	3.5	
R2B	17	30.5	-	3.5
Third feed (day 14)				
R1a	25.5	25.5	-	-
R1b	25.5	56	-	-
R2a	17	31.5	3.5	
R2b	17	31.5	-	3.5

Table 3. The initial physical and chemical characteristics of composting mixtures

Parameter	R1A	R1B	R2A	R2B
MC (%)	80	81	83	82
OM (%)	88.2	89.9	85.6	86.6
TOC (%)	49	50	47.5	48.1
TN (%)	1	1.1	1.5	0.9
C/N ratio	49	45	31.5	53
pH	6.8	6.0	6.9	6.1
EC(ms/cm)	3.7	3.5	11.2	6.2
Total P (ppm)	794	660	977	973
Total K (ppm)	2200	2000	2500	1600

Analytical method and measurements

As indicated before, different controlling parameters were followed during the composting process in order to determine the efficiency of the studied variables on the process performance. Since temperature is regarded as an important parameter for monitoring and controlling composting process, it was measured daily using a portable-digital thermometer (Thermocouple). Furthermore, at least two representative homogenised samples were analysed based on standard testing methods and the presented results are the mean values of these samples. Moisture content (MC) was determined by drying the samples in a forced-air oven (stove) at 105 °C for 18–24h, whereas the samples were ignited (combustion) in a muffle furnace for 2.5 hours at 550 °C for organic matter determination and total organic carbon (TOC) was calculated from volatile solids content. The pH and EC were determined using pH and EC meters, where the slurry of tested material and distilled water were blended at a ratio of 1:2 (v/v), then samples were shaken for 30 minutes at room temperature and the pH and EC were measured. The potassium content was measured using a flame photometer and an extract of (1:10) was prepared and shaken for 30 minutes; then, a filtered sample was used for K determination. The phosphorous content was measured using a spectrophotometer; a crushed sample of 2.5 g was added to 50 ml of $NaHCO_3$ and stirred using a shaker for 30 minutes; then, the sample was filtered and 5 ml were mixed with 5 ml of vitamin C, 0.5 ml of H_2SO_4 and distilled water until a total volume of 100 ml was obtained. After that, a representative amount was introduced to the spectrophotometer. Finally, the total nitrogen (TN) was analyzed using the Kjeldahl method.

RESULTS AND DISCUSSION

In order to validate the performance of the designed reactor through the DECOST project, the feedstock was pre-treated and mixed with bulking agent, and the treatments were run in parallel to evaluate the process performance under the different studied conditions. Generally, the process performance and the final results showed that the used reactor is suitable for home application. Actually, mixing the feedstock inside the reactor, aeration, leachate drainage was easy to perform and ensures a smooth maturation of the composted materials if there is a well controlling and monitoring from users. These observations coincide with the results obtained by Sudharsan and Kalamdhad, (2013) for such type of reactors.

Temperature

In a normal composting process, temperature evolution is recognized as an indicator of the process performance, as it is well correlated with organic matter biodegradation. Figure 2 shows the temperature profile of different treatments. In all treatments, a similar trend was observed and an increase in temperature was recorded due to the

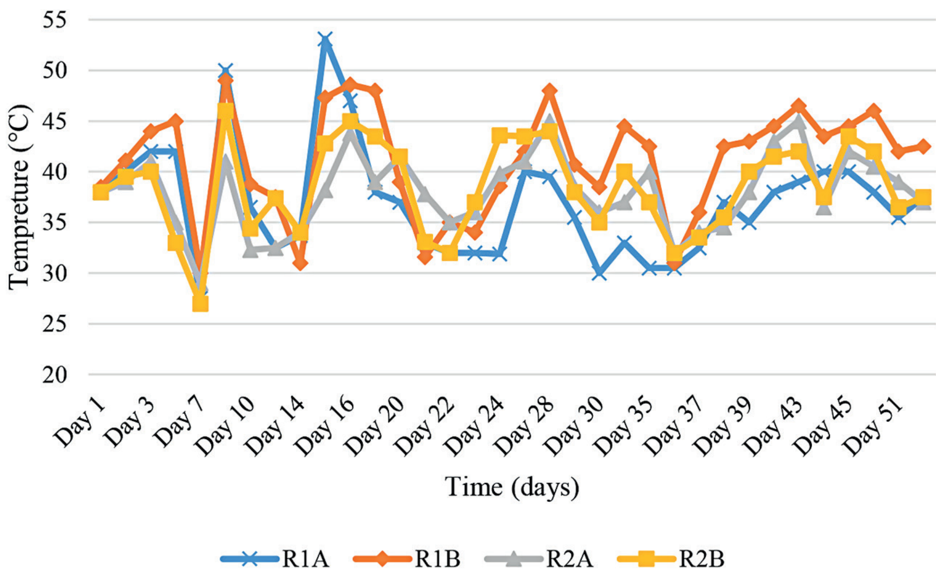

Figure 2. Temperature profile during the composting period

microbial activity and the availability of easily biodegradable organic matter, which was clear as no initial lag period was observed [Kulikowska and Gusiatin, 2015; Singh and Kalamdhad, 2013]. Additionally, the temperature increase was clearly noticed directly after the addition of new feedstock (day 7 and 14). However, some differences among the treatments was observed, where the highest temperature was found in treatment 2 (R1B) with low bulking agent (0.5) followed by treatment 1 (R1A). This could be attributed to the abundance of more organic matter that supports the microbial activity compared to other treatments which had the same ratio of waste and bulking agent, thereby, in treatments 2 and 3 that received less feedstock the temperature was slightly lower.

As noted in the experiment, initial moisture content and bulking agent ratio had an effect on the temperature evolution. Actually, the moisture content in all treatments was slightly high compared with the recommended values (40–60%) which resulted in preventing temperature rise [Sudharsan et al., 2015], whereas the waste to bulking agent ratio of 1:1 in treatment 1, 3, 4 contributed in increasing convection that ultimately lead to an inability to maintain the heat and reducing the microbial activity as a consequence [Jolanun and Towprayoon, 2010]. The temperature increase was also noticed directly after turning the reactors but lasted for short periods, which is normal in such type of reactors as they have low heat retention properties of the composting materials [Singh and Kalamdhad, 2013] because the layer for decomposing material is too thin to retain a significant amount of heat and the heat is quickly transferred out from the mixture.

pH, EC and MC

The initial pH values were in the range of 6.7, 6, 6.9 and 6 in treatment 1, 2, 3 and 4 respectively. However, and as the experiment proceeded forward, these values began to increase and a similar trend was observed in all treatments, such that these treatments moved toward alkaline conditions, and maintained these conditions till the end of the experiment; a slight difference was recorded among the different treatments, as shown in Figure 3. This change in the pH value toward alkaline conditions is caused by the mineralization of the acids that are normally formed at the beginning of the process due to the breakdown of the materials which is rewarded as a good indicator for the microbial activity during the composting process [Rugerie et al., 2008; Sudharsan Varma et al., 2015; Sayara et al., 2021]. Additionally, and due to the biodegradation of the organic matter, a slight increase in the EC was noticed in all treatments (data not shown). This slight increase is usually attributed to the release of free ions as a result of the organic matter degradation [Karanja et al., 2019]. The variation in both pH and EC was in alignment with the change in other monitored parameters which all confirm a good microbial activity and biodegradation of the organic matter.

The moisture content also was found to decrease in all treatments (Figure 4). The temperature increase due to the microbial activity enhances the losses of moisture within the composted mixture. On the other hand, the used feedstock was characterized by high moisture content, which resulted in producing a considerable amount of

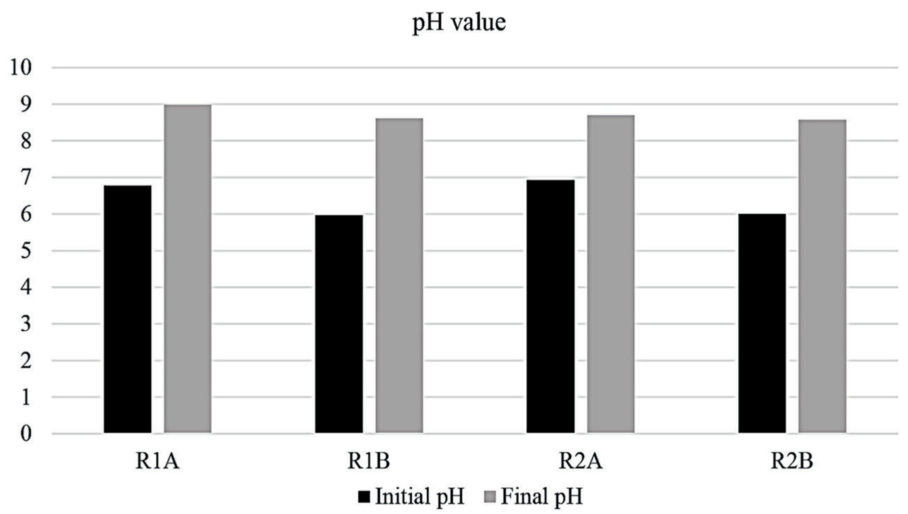

Figure 3. Initial and final pH values of the composted materials

leachate, which additionally contributes to decreasing the moisture content. This leachate is produced due the hydrolysis of the organic matter from the microbial activity. Importantly, the used composter affected the moisture content change over the experiment time. Indeed, the closed drum resulted in confining the vapor which ultimately condensed within the mixture, so the reduction in moisture content was slow mainly during the active phase [Troy et al., 2012], and water found its way through leaching. Accordingly, to avoid or reduce these conditions, users might leave the reactor doors open for certain time during active decomposition phase (especially in hot weather) to facilitate the release of the generated vapor and reduce this effect.

Organic matter degradation

Throughout the process and in alignment with the temperature evolution as well as the changes in other parameters, a reduction in the organic matter as a result of the microbial activity was observed in all treatments. Usually, a diversity of microbial communities including mesophilic bacteria, spore-forming bacteria, fungi and actinomycetes are found in composting mixture and finally degrade the organic matter into stable humic components [Bhatia et al., 2013]. Figure 5 demonstrates the obtained volume reduction in the composted materials as a result of the microbial activity by the end of process. In treatment 2 (R1B), the highest reduction (85%) was obtained, but the other

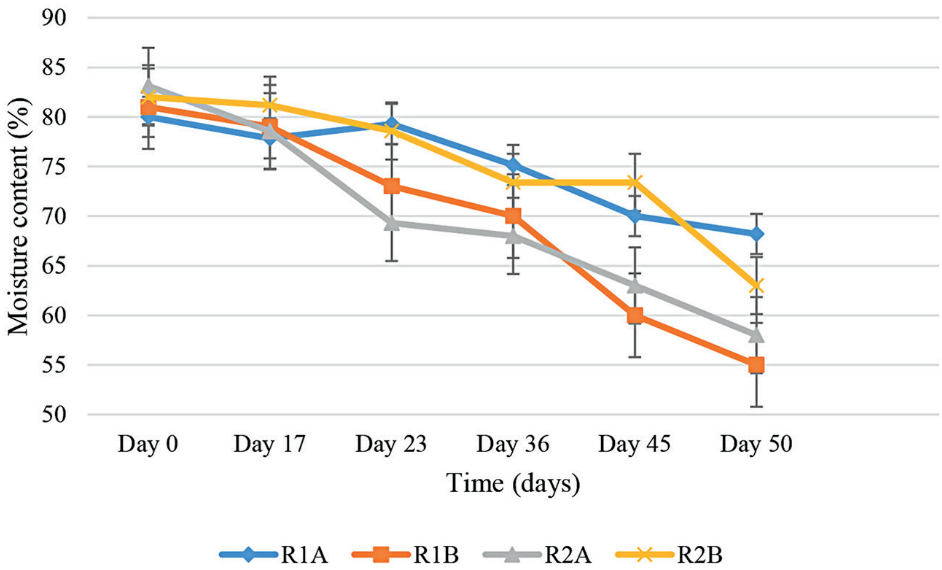

Figure 4. Moisture content variation during the composting period

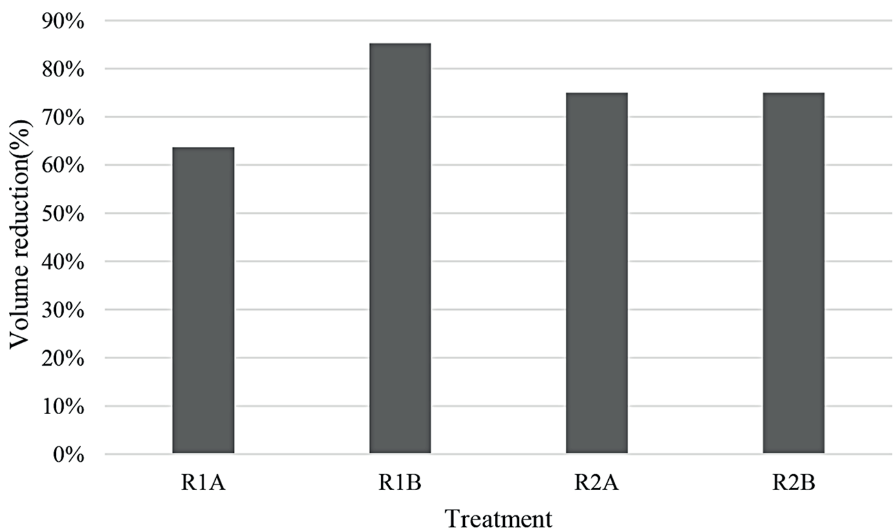

Figure 5. Percentage of volume reduction during composting period

treatments achieved a considerable reduction also, which was about 65% as least percentage in treatment 1 (R1A). These values are in general considered important regarding waste management.

This reduction in the volume matches the recorded reduction in the TOC and TN concentrations as these two elements are considered crucial for microbial growth and activity, since microbial communities utilize carbon as a source of energy and results in the emission of CO_2 as consequence, while the nitrogen is used by the microbial communities for building cell structures, but vitalization of ammonia, especially under high temperatures, might also occur [Sayara et al., 2021]. By the end of the treatments, and due to the fact that the used feedstock is characterized as an easily degradable organic matter, almost a complete degradation of this feedstock was observed, and the remaining material consisted of the bulking agent which complicated the obtaining a representative sample for final end product characterization. These observations match the results obtained by [Sudharsan Varma et al., 2015] where a complete degradation of the composted materials was achieved and more TOC was found. The final compost was full of partially degraded leaves. As illustrated in Figure 6, the decreases in both TOC and TN contents has been reflected on the C/N ratio which also tends to decrease [Mouginot et al., 2014; Rich et al. 2018]. The highest reduction (62%) was noticed in treatment R2A, which could be attributed to the high content of nitrogen in animal manure feedstock added to this treatment (2%-TN) compared to food wastes which had about 0.74%. Moreover, manure normally contains a wide range of microbial communities which facilitates the decomposition of the organic matter. Treatment R1B also achieved a considerable reduction (52.5%) compared to other treatments, which most probably due to the abundance of more organic matter that supports the microbial activity, as discussed previously. The results of this treatment (R1B) revealed also that the mixing ratio of waste to bulking agent of 1:0.5 is more efficient. Actually, this ratio gives the opportunity to treat more waste, which ultimately provides more nutrients to support the microbial activity and results in generating and maintaining more heat (Figure 2) that enhance the development of various microbial communities, meanwhile providing the required aerobic conditions. In contrast, high bulking agent in the rest of treatments could adversely affect the process as high convection enhances heat loss [Jolanun and Towprayoon, 2010]. It is worth mentioning that few odors were found during the experiment, which could be due to the high carbon content of the composted mixtures that is normally used by microorganisms at elevated temperature as well as reduces the NH_3 emissions and other odors under similar conditions [Li et al., 2013]. Moreover, in treatment 4 (R2B) which contained charcoal, no significant impact on the degradation was noticed, but the odor was minimal, compared to other treatments which confirm the role of charcoal in reducing the emissions from the composting process [Sayara et al., 2021]. Thus, since home composters are usually used in the home yards, it is recommended to add some charcoal to the reactor to avoid or reduce any odors resulting from the composter.

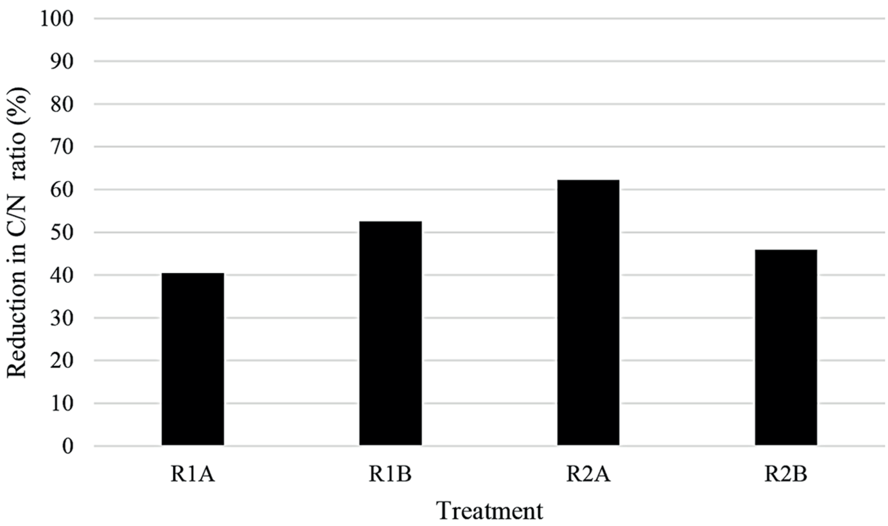

Figure 6. Percentage of reduction in C/N ratio

CONCLUSIONS

On the basis of the obtained results, the designed rotary drum home composter was found to be appropriate for composting process, and could be used effectively in decentralized plan for composting of household organic waste. Furthermore, the waste to bulking ratio of 1:0.5 was found to achieve better results regarding waste reduction volume, which is seen as a positive feature as more waste could be treated. However, for more degradation of the organic matter, co-composting with animal manure gives better results, as observed in this study. The addition of charcoal showed no significant effect on the degradation of the organic matter, but was effective in reducing the odors caused by the process. The obtained results are considered as preliminary results and more studies are still needed to clarify the effect of different parameters and amendments on the process and its final product using this reactor.

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