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Evaluation of the effect of cocopeat in continuous thermophilic composting (CTC) of kitchen waste, a preliminary study of the process rate and the quality of compost

Nadeena Chandramali, Kokila Ranasinghe*

Department of Chemical Sciences, South Eastern University of Sri Lanka, Sri Lanka.

Abstract

The influence of cocopeat, when coupled with continuous thermophilic compositing (CTC), in the degradation of kitchen waste was examined by preparing four different sample types. The key sample type, MW_{50}, contained fresh kitchen waste mixed with cocopeat in a 3:1 ratio (mixed waste or MW) and was kept at 50 ^{o}C. The other three sample types served as controls and consisted of fresh kitchen waste kept at room temperature (KW_{30}), at 50 ^{o}C (KW_{50}), and MW kept at room temperature (MW_{30}). The composting process and the quality of the resultant compost were assessed by monitoring standard parameters such as temperature (T), pH, moisture content (MC), total organic matter (TOM), C/N ratio, and germination index (GI) over a period of 43 days. The obtained results indicated that the addition of cocopeat complements and enhances the continuous thermophilic composting (CTC) of KW by improving the rate of the process and the physicochemical properties of the final compost. Compared to MW_{30} and KW_{50}, in which the CTC condition and the addition of cocopeat were practiced individually, the MW_{50} exhibited a rapid decrease in TOM content indicating that the rate of degradation is faster in the latter. Further, relatively higher GI and lower C/N ratio values were observed for the resultant compost of MW_{50} compared to that of the controls indicating that the quality of the final product is significantly improved by the applied combination of conditions. Thus, the proposed valorization method showcases a potency to be used in mass production of compost upon further investigation to confirm that the results are reproducible for much larger samples.

Keywords: Accelerated composting, biodegradation, cocopeat, CTC, kitchen waste, valorization.

INTRODUCTION

Effective and efficient waste management is important in reducing the negative environmental impact caused by urbanization, industrialization, and population growth. Like most other developing countries, less attention is paid to waste treatment in Sri Lanka, while the focus is mainly on waste collection [1]. The disconnected transition from solid waste collection to its meaningful valorization is due to many reasons such as lack of technical knowledge of modern waste management methods, inadequate financial capital, weak regulatory system, lack of public awareness, and lack of political initiatives [2-4].

Currently, the municipal solid waste (MSW) generation of Sri Lanka is roughly 0.3 kg/person/day [5] and it is been forecasted to increase up to 1.0 kg/person/day by 2025 [4, 6]. The Sri Lankan government has implemented a national policy on waste management in 2019 [7]. Local authorities such as municipal councils, urban councils, and village councils are legally responsible to properly collect and dispose of MSW. However, only 27 % of the generated MSW is being collected and around 85 % of the collected MSW is disposed via open dumping, an inefficient

Corresponding Author: ranasinghek@seu.ac.lk

waste disposal method [5, 8]. Thus, it is a national need to design sustainable and economical waste management solutions targeted for MSW as a whole or for at least selected constituents of MSW. Biowaste, the short-term biodegradable organic fraction that consists of kitchen and garden waste, manure, sewage sludge, agricultural waste, etc., is a major constituent of MSW. In 2012, the average organic fraction of MSW produced in Sri Lanka was 1301.5 tons per day [3], and is rising as a result of population growth. Currently, all most all the municipalities of Sri Lanka practice the collection of kitchen waste separately at the household level but mainly end up in a neglected composting yard [9, 10]. Balangoda and Weligama municipalities operate successful composting facilities in which kitchen waste is used as one of the main ingredients [3]. But many municipalities have no further steps taken to utilize KW in producing value-added product/s, other than filing up separately in the dumping location [8]. This practice leads to many environmental and socio-economic issues such as bad odors, health hazards, occupying dump yard space for longer periods, attracting wild animals, and greenhouse gas emission [11]. Thus, it is important to introduce accelerated and sustainable solutions targeting the separately collected organic portion of MSW in Sri Lanka.

On a separate note, excessive synthetic fertilizer usage in Sri Lanka's crop production system has resulted in many environmental and health problems. Many allegations indicate that agricultural chemicals could be the cause of high cancer and chronic kidney disease incidents reported in Sri Lanka [12, 13]. In general, today's agriculture largely depends on the use of many agrochemicals such as chemical fertilizers, pesticides, and weedicides, and unfortunately, Sri Lanka uses relatively higher amounts of chemical fertilizers compared to other countries [14]. Furthermore, the direct cost of importing synthetic fertilizers and the virtual cost of recovering from environmental harm caused by fertilizer mismanagement, have become a burden to the country [15]. Thus, it is a timely need to promote the production and utilization of organic fertilizers among the public and authorities.

The current study is focused on simultaneously addressing the two national problems mentioned above by developing one sustainable solution, composted kitchen waste. The conversion of biodegradable waste into compost, an organic fertilizer, has been practicing worldwide for decades now [16, 17]. Application of compost as an agricultural soil supplement improves soil structure through better soil aggregation, enhanced soil porosity, water holding capacity, cation exchange capacity, and biological activity, etc [18]. Though it sounds like an excellent solution, the production and application of composting have two major problems, longer processing time and nutrient status dependency on the method of composting and on the composition of the initial substrates used. Over the years many solutions have been proposed addressing these issues [16, 19-21]. One simple yet efficient method to accelerate the composting process is Continuous Thermophilic Composting (CTC) in which the waste is incubated in moderately high temperatures synthetically creating the thermophilic composting phase during the entire process. According to literature, CTC can reduce the composting cycle of KW to 14 days while a regular cycle can be last up to 60 days [20]. However, one drawback of artificially accelerated composting processes is the lowered quality or maturity of the resultant product [22]. Thus, identification of optimized procedures and economically feasible additives to produce high quality compost within a shorter period of time is still a timely topic in organic waste management.

Cocopeat is a byproduct of the process of fiber extraction from coconut husk and is abundantly available in Sri Lanka for low cost [1]. Due to high cellulose and lignin content, cocopeat itself is not useful as a soil amendment, however it has many benefits when used as a bulking agent with other composting substrates: Cocopeat increases the porosity of the substrate thereby promotes the aeration, while its high water-holding capacity supports to maintain optimal moisture content [23]. Cumulatively, the addition of cocopeat promotes microbial growth and accelerates the aerobic digestion of substrates. Further, the higher cation exchange capacity and high carbon content of cocopeat improve the maturity of the resultant compost [23, 24]. Many local and region-specific research have been conducted about the horticultural and agricultural applications of cocopeat [23-26]. However, to our knowledge, no studies are reported about the effect of cocopeat in composting under CTC conditions. The current study proves that the integrated thermophilic composting process with cocopeat as an additive valorizes KW into high-quality compost via a rapid and economically feasible route.

Methodology

1. Collection of materials and design of composting pots

Kitchen waste (KW) was collected from the canteen of FAS, South Eastern University of Sri Lanka, Sammanthurai. The major components of KW were cooked rice and vegetables, noodles, bread, raw fruit and vegetable peelings, tea and coffee grounds, and eggshells. The KW substrates were initially shredded to lengths of 1–2 cm. Compost inoculants were obtained from a facility owned by the urban council in Ampara. Cocopeat was obtained from a commercial cocopeat production site in Embilipitiya. Composting was carried out in aluminum pots. Each pot was suitably modified for air circulation by drilling 10 mm holes on the pots in three layers. The pots were kept on shallow containers to facilitate leach collection from the bottom.

2. Mixed waste (MW) and sample preparation

Mixed waste (MW) was prepared by mixing inoculated kitchen waste (KW) with cocopeat in a 1:3 ratio. Four types of samples (Table 1; KW_{30}, KW_{50}, MW_{30}, MW_{50}) with two different compositions and with the intension to keep at two different temperature conditions were designed: The sample labeled as MW_{50} contained MW and kept at 50 ^oC and the other three sample types served as controls and consisted of KW kept at room temperature (KW_{30}), at 50 ^oC (KW_{50}), and MW kept at room temperature (MW_{30}). Each sample type was duplicated. All the samples were subjected to composting for 43 days. During composting, KW_{30} and MW_{30} sample types were kept out in open space to allow natural aeration. The other two sample types, KW_{50} and MW_{50}, were placed in an incubator at 50 ^oC. Initial moisture content (MC) of each sample was adjusted to be within the range of 60-70 % and an adequate volume of water was added weekly, when necessary to maintain MC within the range. The compost samples were manually turned in every 24 h to facilitate aeration. Testing samples (~10 g wet weight) were collected once a week from the middle of each drum immediately after manual turning.

Table 1. Composition and provided temperature conditions of each waste sample type.

Sample Type[a]	Composition (per 1 kg)		Temperature (^0C)
	KW	Cocopeat	
KW_{30}	1	-	RT[b]
MW_{30}	0.75	0.25	RT
KW_{50}	1	-	50 ^0C
MW_{50}	0.75	0.25	50 ^0C

[a]Each sample type is duplicated. [b]Room temperature.

3. Monitoring composting process

The temperature of the samples was measured at the middle portions of each sample pot after the manual turning using a QUALI-TECH chemical mercury thermometer. The pH of the samples was measured using a water extract of compost [27]; a 1:6 (w/v) mixture of compost and deionized water was allowed to equilibrate for 30 minutes with occasional stirring and the resultant solution was filtered through a Whatman No. 40 filter paper, which was then used for direct measurement using a pH meter (model E520, Metrohm Herisau, Switzerland). The MC values of the samples were determined as a percentage weight loss upon drying at 105ºC in an oven (BTI 29, Bio-Technics, India) for 24 hours [28, 29]. The oven-dried samples were ground into powdered form and used to analyze total organic matter (TOM) by 'loss on ignition' method: Approximately 1 g of dried powdered sample was kept in a muffle furnace at 550 °C temperature for 4 h and the samples were allowed to cool up to room temperature before weighing [30, 31].

4. Evaluation of compost maturity

Approximately 3 mg of oven-dried and ground samples (initial and the samples collected on 43rd day) were fed to CHNS analyzer (Perkin Elmer 2400 Series II CHNS/O Analyzer) to obtain carbon and nitrogen contents, which were then used to determine C/N ratios [31]. Evolution of the maturity of the compost samples over the testing period was monitored by determining seed germination index (GI) for the samples collected on 8th, 22nd, 36th, and 42nd day by following a method reported in the literature [27]: A 5 mL aliquot of 1:10 aqueous compost extract was poured into 15 mL Petri-dish containing a Whatman No.42 filter paper. Ten seeds of *Zea mays* were placed on the filter paper and covered petri-dishes were incubated in the dark at 25-28 ºC for 4 days. A control sample was prepared by moistening the filter paper with 5 mL distilled water. After 4 days, the percentage of germination was calculated using the following formula.

$$\text{Germination index (\%)} = \frac{\text{Seed germination (\%)} \times \text{Root length of treatment} \times 100\%}{\text{Seed germination (\%)} \times \text{Root length of control}}$$

Results and discussion

The composting process of each sample type was monitored weekly by measuring temperature, pH, MC, and TOM, while the compost quality was monitored biweekly by determining GI. The C/N ratios were measured only for the initial and final products. Analyses were performed in duplicates and the mean values are showcased in the figures. The KW_{30} sample type was considered as the main control because the given sample conditions were similar to an open dump (no bulking agent added and kept in open aeration at RT). The initial values of pH, MC, TOM, and C/N parameters of KW_{30} were 7.7, 64.4 %, 85.3 %, and 48.0, respectively and are similar to those reported in the literature [27, 31].

1. Changes in physicochemical parameters during composting

1.1. Temperature

Temperature is one of the most significant factors influencing microbial growth and composting development, with 50 ºC serving as the differentiation point between the thermophilic and mesophilic phases in the composting process as well as between the mesophilic and thermophile bacteria [20]. Several successful CTC studies are reported in which thermophilic conditions (50 – 60 ˚C) are externally provided throughout the process to increase the rate of aerobic digestion of biowastes such as kitchen waste and animal manure [20, 32-34]. In this study, KW_{30} and MW_{30} samples were held at room temperature, while KW_{50} and MW_{50} samples were kept in an incubator at 50 ^{o}C. No additional temperature control measures were taken and all the sample types were allowed for further natural temperature changes. As shown in Figure 1, KW_{30} and MW_{30} reached the maximum temperatures of 36 and 35 ^{o}C, respectively (~13 % increment compared to 1st day) during the fourth week. In contrast, KW_{50} and MW_{50} showed a similar amount of increase by the first week and attained the maximum temperatures of 60 and 59 ^{o}C, respectively, during the fourth week (~20 % increment compared to 1st day).

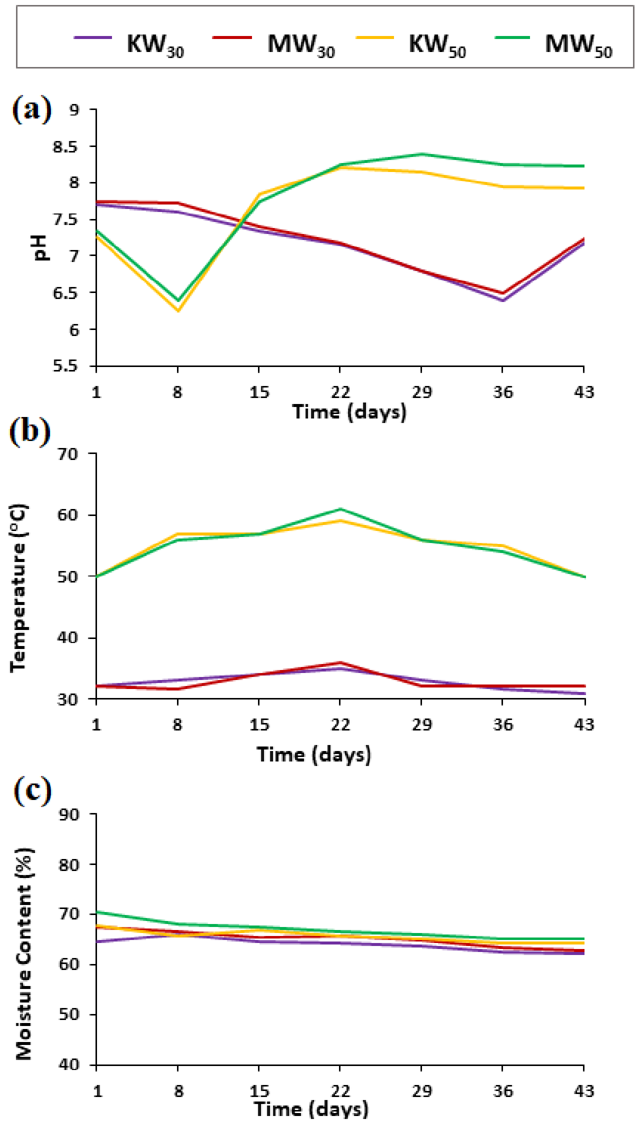

Figure 1. Weekly changes of (a). pH, (b). temperature (˚C) and (c). MC (%) in the four sample types. Average values of the duplicates of each sample type are shown.

The thermophilic stage of a composting process consists high levels of microbial activity that causes significant changes in physicochemical properties of the material and specifically allows the decomposition of tough components such as hemicelluloses, cellulose, and lignin. During this high microbial activity, the temperature of the composting substances can be raised up to 60 ^{o}C. Purposely elevated temperature in KW_{50} and MW_{50} facilitates the early initiation of the thermophilic stage as demonstrated by the quicker increase of temperature up to 60 ^{o}C indicating the high thermophilic microbial activity compared to the samples kept at room temperature. This observation clearly showcases that the provision of the thermophilic conditions from the beginning of composting has accelerated the composting process.

1.2. pH

The acceptable pH range tolerable for microorganisms (bacteria, fungi, and actinomycetes) is generally considered to be 6.5–8.5 [35]. As shown in Figure 1, the studied samples were within the said pH range at all times. In general, during initial stage of composting, the pH decreases gradually upon decomposition of sugars and fats due to the formation of carbon dioxide gas and high quantities of organic acids such as lactic, acetic, and butyric acid [36]. Then the pH continues to increase and keep increasing (mostly during the thermophilic phase) due to the formation of free ammonia (NH_3) during protein degradation and the further decomposition of organic acids [20, 27, 31, 34]. Accordingly, all four sample types exhibited a gradual decrease in pH until it reaches ~ 6, followed by a continuous increase up to ~8. However, the pH decline occurred only in the first week for the two sample types with CTC condition (KW_{50} and MW_{50}), while for the other two types (KW_{30} and MW_{30}), it lasted for five weeks before the pH started to increase again, indicating that the composting process in the latter was slower than the former types. Furthermore, for the pair of sample types, KW and MW (with and without cocopeat, respectively), kept at a given temperature, the pH changes are almost identical, which indicates that the effect of cocopeat in the initial decomposition stages of KW is minimal.

1.3. Moisture content (MC)

Moisture present within a composting substrate directly affects the oxygen uptake rate and thus the microbial activity and the time taken for compost maturation [37]. High MC promotes anaerobic digestion over composting, while low MC extends the composting duration or stops the degradation completely. The optimal water content range for organic matter biodegradation is considered to be 60–70% [38]. The range of MC in this study was maintained to be 60-70% by adding water to the samples if needed (Figure 1). The main factor of moisture loss during composting is the natural rising of compost temperature [39]. Especially, the high temperature condition provided in the CTC technique requires the frequent monitoring and adjusting of MC in the samples. However, the addition of a fibrous material as a bulking agent could be useful in stabilizing the moisture content of the substrates as they can absorb part of the leachate when MC is high and release when MC is low [40-42]. In fact, we have observed that the addition of cocopeat partly solved the problem of moisture loss, thus MW_{30} and MW_{50} required less moisture adjusting, especially compared to KW_{50}, in which there are no bulking agents added.

1.4. Total organic matter (TOM)

The initial TOM content of all the sample types (~85 %) was similar and was comparable to reported values for KW in literature [31, 34]. Among the four sample types, KW_{30} and MW_{30}, which were kept at RT, exhibited similar and relatively low rates of TOM degradation, whereas CTC samples (KW_{50} and MW_{50}) showed significantly higher rates (Figure 2) indicating that the microbial activity of the latter types is higher than the former sample types. A drastic drop of TOM can be observed for all the samples during the first week of composting, which can be attributed to the decomposition of simple sugars and other easily digestible components. Within the analyzed period (~6 weeks), TOM of KW_{30} and MW_{30} decreased to ~55% and that of KW_{50} to 50.47%. The highest drop of TOM is for $MW_{50,}$ which showed 43% as the final TOM. As expected, the results corroborated the fact that CTC facilitates an accelerated composting route in both KW and MW.

This observation can be attributed to the higher activity of the prominent thermophilic microbes (like *Actinomyces* sp., *Bacillus* sp., *Clostridium thermocellum*, *Geobacillus* sp., and *Thermus thermophilus*), who decompose the complex organic molecules; fats, proteins, and carbohydrates [34].

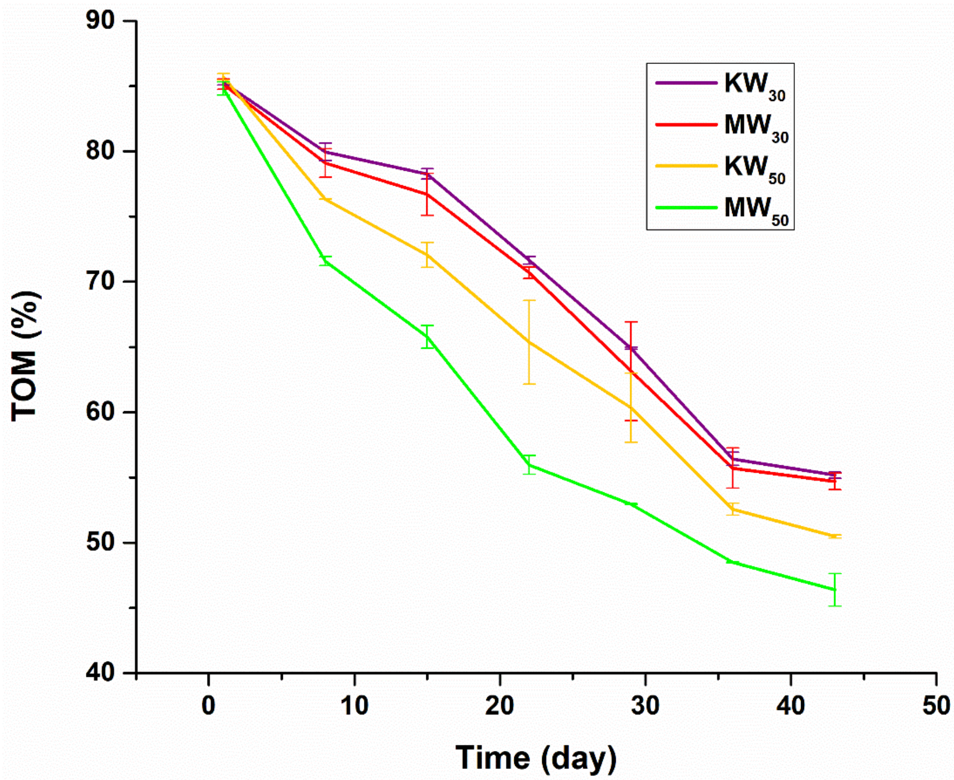

Figure 2. Weekly changes of TOM (%) in the four sample types. Standard deviations of the duplicates of each sample type are shown as error bars.

The addition of cocopeat could be expected to increase the initial TOM of MW compared to KW, however the observations imply that the added amount of cocopeat (25% by weight) might not be enough to showcase a significant difference in initial TOM content. However, based on the observations, when combined with CTC condition, the added amount of cocopeat is adequate to significantly enhance the microbial growth as reflected by the faster degradation in MW_{50}. Corroborating the increased microbial activity in MW_{50}, an intense fungal growth has been visually observed for the MW_{50} samples compared to other types, especially during the middle stages (2 – 4 weeks) of the process (Figure 3). Thus, the overall TOM results indicate that all the samples underwent gradual degradation, while the MW_{50} sample type exhibited the fastest rate out of the four types.

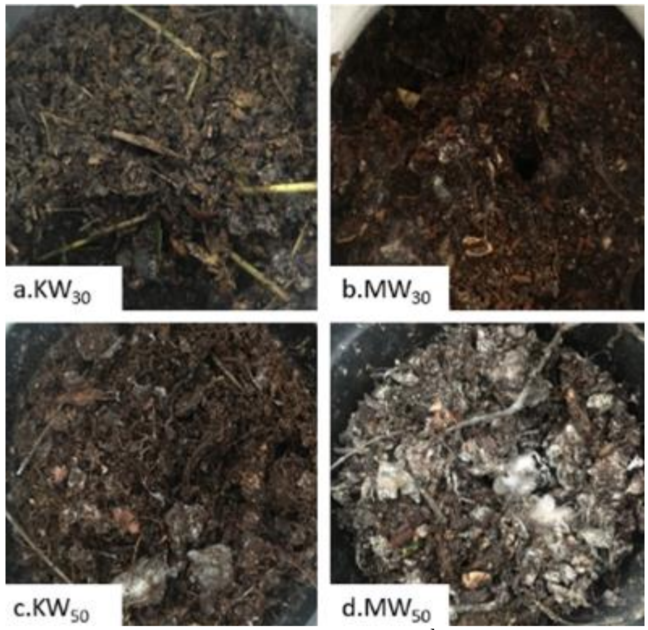

Figure 3. The physical appearance of the samples on 22nd day of the composting process.

2. Maturity evaluation

The GI values of the samples were determined every other week (on 8th, 22nd, 36th, and 42nd) to monitor the compost maturation. In order to further confirm the maturity of the final product, the C/N ratios were calculated for the samples collected on the 43rd day. The average C/N values obtained for the final products were 12.8, 16.6, 10.6, and 8.9, for KW_{30}, MW_{30}, KW_{50}, and MW_{50}, respectively (Table 2), which are significantly lower values than the C/N ratio of the initial samples (~48.0). Further, the C/N ratios of all the final samples were well below the standard permissible value expected for mature compost [31]. However, having the lowest value of all, the MW_{50} sample shows the highest maturity within the given time frame. It could be anticipated that MW_{50} had reached the permissible C/N value sooner than the other samples. The relatively high C/N ratio in MW_{30} compared to the analogous KW sample (KW_{30}) could be due to the high C content contributed from the added cocopeat, a rich source of cellulose and lignin.

Table 2. The CHN analysis data for samples collected on 43rd day.

Sample type	KW_{30}		MW_{30}		KW_{50}		MW_{50}	
Sample No.	1	2	1	2	1	2	1	2[a]
C (%)	13.59	14.01	20.87	17.48	15.32	14.06	12.70	-
N (%)	1.02	1.14	1.28	1.04	1.39	1.38	1.42	-
H (%)	1.85	2.11	2.66	1.98	2.11	1.56	1.83	-
C/N	13.3	12.3	16.3	16.8	11.0	10.2	8.9	-

[a]Analysis was not conducted due to sample damage during transportation.

As shown in Figure 4, GI values in all of the samples were very low during the early phase of composting due to high quantities of volatile fatty acids and NH_4^+ salts produced, which are toxic to seed germination [43]. Over time, GI of all the sample types increased gradually, but MW_{50} always exhibited distinctly higher GI values with respect to the other samples. In general, a compost sample is considered to be matured when the GI value is higher than 90% [20]. Accordingly, MW_{50} exhibits adequate maturity after 36 days and more than 100% GI value for the samples collected on 42nd day (Avg. 104.15%, Figure 4). This result indicated that by the end of the analyzed period, the phytotoxins present within the compost produced via the MW_{50} route is minimal to none. In contrast, none of the other three sample types attained 90% of GI within the analyzed time period, indicating that either the composting process is not completed or the resultant compost has relatively lower quality in those samples. The progression of the GI graphs clearly indicates that at any given point, the highest maturity out of the four sample types is shown by MW_{50}.

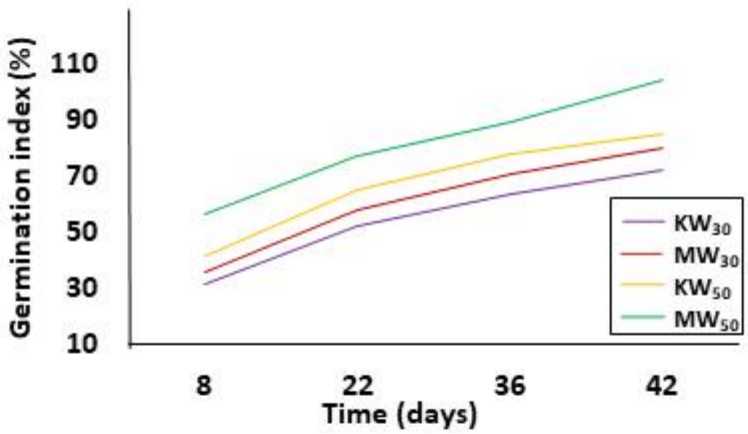

Figure 4. Biweekly changes of GI% in the four sample types. Germinated seeds of a MW_{50} sample collected on the 42nd day are also shown.

Conclusion

The present investigation combined continuous thermophilic composting (CTC) with the addition of a locally available cheap bulking agent, cocopeat, in order to produce high-quality compost from kitchen waste through a shorter composting cycle. Based on the high TOM reduction rates compared to the control sample types, the proposed route requires shorter period of time to produce compost. More importantly, the GI values clearly showcase significantly higher maturity in the compost produced through the proposed method compared to the controls. This study concludes that cocopeat has influenced the key parameters such as aeration and porosity of composting mixture, thereby facilitated a higher microbial activity under manipulated thermophilic condition. Thus, the proposed route is recommended to apply for larger MSW quantities in order to determine its practical applicability on industrial scale.

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