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Evaluation of Heavy Metals Content in Simulated Solid Waste Food Compost

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ABSTRACT

Composting is one of the solid waste management (SWM) methods where the organic component decomposed biologically under controlled conditions. In this study, a 0.166 m^3 bioreactor tank was designed to compose 59.2Kg of simulated common municipal solid food waste having a bulk density, organic matter, organic carbon, pH, nitrogen content, C/N and nitrification index (NH_4-N/ NO_3-N) of 536.62 kg/m^3, 62.34%, 34.76%, 6.53, 1.86%, 23 and 0.34 respectively. The bioreactor operated aerobically for 30 days, and anaerobically for 70 days, until the end of the composting process. Results proved that the composting process could reduce the mass of the waste by 69%. Nitrogen content, C/N, nitrification index, NPK, and germination index (GI) were found to be 1.52%, 14.54, 0.31, 1.52%, 1.53%,0.85 % and 85.5% indicating that the obtained compost is stable and mature according to the standards. Twelve heavy metals of Zinc (Zn), Cupper (Cu), Molybdenum (Mo), Zirconium (Zr), Strontium (Sr), Rubidium (Rb), Manganese (Mn), Scandium (Sc), Iron (Fe), Titanium (Ti), Calcium (Ca) and Potassium (K) were detected by using Niton (XRF) device. Results of Cu and Zn were within the limits of the standards, while the rest were considered acceptable as standards did not restrict them.

Keywords: municipal solid waste (MSW), organic waste, compost, heavy metals, germination test.

تقييم محتوى المعادن الثقيلة في السماد العضوي للنفايات الصلبة

زينب زامل الساعدي
مهندس أقدم
وزارة الصحة والبيئة

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الخلاصة

أن التسميد هو أحد طرق إدارة المخلفات الصلبة (MSW) اذ يتم التحلل البايولوجي للمادة العضوية في ظروف مسيطر عليها .في هذه الدراسة تم اعداد خزان بحجم (0.166) م^3 كمفاعل بايولوجي لغرض التحلل العضوي لما يقارب من(59.2) كغم من خلطة شائعة مشابهة لمخلفات الطعام البلدية وبكثافة ظاهرية ومحتوى الرطوبة والمواد العضوية والكربون العضوي والرقم الهيدروجيني ومحتوى النيتروجين ومؤشر (الكاربون /النتروجين) (C / N) ومعامل النترجة (NH4-N / NO3-N)) كانت (536.6) كغم / م ^{3} و(62.34٪) و(34.76٪) و(6.53) و(1.86٪) و(23) و (0.34) على التعاقب .كان المفاعل البايولوجي يعمل بشكل هوائي لمدة 30 يومًا ، وبشكل لاهوائي لمدة 70 يومًا ، حتى نهاية عملية التسميد. أثبتت النتائج

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أن عملية التسميد يمكن أن تقلل كتلة النفايات بنسبة 69٪ وكان محتوى النيتروجين و C / N ومؤشر النترتة و NPK ومعامل الإستنبات 1.52 ٪ و 14.54 و 0.31 و 1.52 %و 1.53 % و 0.85 ٪ و 85.5 ٪ على التوالي مشيرا إلى أن السماد الذي تم تحقيقه مستقر وناضج وفقا للمعايير. تم فحص اثنا عشر نوعاً من المعادن الثقلية لكل من الزنك (Zn) والنحاس (Cu) والموليبدنوم(Mo) والزركونيوم (Zr) والسترونتيوم (Sr) والروبيديوم(Rb) والمنغنيز(Mn) والسكانديوم (Sc) والحديد (Fe) والتيتانيوم(Ti) والكالسيوم (Ca) والبوتاسيوم (K) باستخدام جهازفحص المعادن الثقيلة (Niton XRF) وكانت نتائج Cu و Zn ضمن حدود المعايير اما بقية نتائج المعادن فتعد مقبولة لأنها غير مقيدة بالمعايير.

الكلمات الرئيسية : إدارة المخلفات الصلبة (MSW) ، النفايات العضوية ، السماد ، المعادن الثقيلة ، أختبار الإنبات.

1. INTRODUCTION

As the interest in municipal solid waste (MSW) composting increases, the concerns of the extent to which low concentrations of heavy metals and metalloids (metal-like elements) present in MSW compost also increases, **Basta and McGowen, 2004**. Heavy metals and metalloids may adversely affect plant growth, soil organisms, water quality, animal and human health, **Obiora, et al., 2016**. Many metals and metalloids are present in minute ("trace") amounts in soil and water. Those trace elements occur naturally are silt of rocks weathering, **Achiba, et al., 2010,** while metals appear in MSW stream from a variety of sources. Batteries, consumer electronics, ceramics, light bulbs, house dust, and paint chips, lead foils such as beverage bottle closures, used motor oil containers, plastics, inks containers, and glass all can introduce metal contaminants into solid wastes stream, **Veeken, and Hamelers, 2002.**

Composts made from organic material in solid waste will inevitably contain these elements, although in low concentrations where most contaminants have been removed. Many of these trace elements (e.g., boron, zinc, copper, and nickel) are essential for plant growth but in small amounts, **Cooperband, 2000.** However, in higher amounts they may adversely affect plant growth. Other trace elements (e.g., arsenic, cadmium, lead, and mercury) are of concern primarily because of their potential to harm soil organisms and animals and humans who may eat contaminated plants, **De Guardia, et al., 2010.**

Previous work of **Petruzzelli, et al., 1989,** determined the speciation of Cu, Zn, Ni, Cr, Pb, Cd, in compost from solid urban wastes. **Veeken and Hamelers, 2002,** had found that application of composts to soil systems may lead to the accumulation of heavy metals in soils, and therefore legal criteria were laid down in a decree to guarantee the safe use of composts. **Hseu, 2004** suggested that the production and application of compost potentially contaminate the environment with heavy metals.

Thus, this study aims to evaluate the influence of the composting process on the concentration and distribution of heavy metals that would be detected throughout samples of food waste compost.

2. MATERIALS AND METHODS

2.1 Bioreactor Design

The bioreactor tank was designed to contain 59.2 Kg of different simulated food waste, having a C/N of 23. The food waste occupies 75% of total tank´s volume. The tank was 130 cm in height, 45 cm in diameter and had a 0.2 cm wall thickness. A perforated plate was located about 5cm above the tank bottom to support waste heap, air circulating and to drain leachate. **Fig. 1** shows the tank configuration and raw materials used in the compositing process.

The tank was made of carbon steel. Walls were painted from the inside with epoxy to avoid corrosion. Two openings (slots) were installed at the top of the vessel, one for gas release and the

other for introducing specialized sensors of temperature and moisture; the slot was tightly fitted to ensure the anaerobic phase stage that will be conducted later.
An opening for leachate collection was made at the bottom of the tank, 5 cm below the perforated plate. Day 1 was defined as Jan. 20/ 2018 and ended after100 days on April 29/ 2018. Samples were taken from the piles in days 0, 7, 21, 30, 44, 72, 86 and 100 for chemical analysis. The bioreactor operated aerobically from day 1 to 30, and anaerobically from day 31 to 100 to ensure the most extended period composting for waste at different aeration conditions.

Figure 1. Raw materials used in the compositing process.

2.2 Raw Materials

Biodegradable organic food waste was segregated at house level as feed material, shredded manually into pieces of about 0.5 cm length except for rice, it was steamed. Simulated food waste mixture containing carrots, potatoes, meat, leaves, steamed rice, garden soil, and animal manure were used to control compost's characteristics. Those raw materials and masses were selected to ensure that the value of carbon and nitrogen ratio (C/N) within the ideal range (20-25) suggested by **Tchobanoglous, et al., 1993**, and when calculation the initial value of C/N was found to be (23) as shown in **Table 1.**

Table 1. Mass of raw materials used in the composting process and the calculation of C/N.

Item (Kg)	MSW(Kg)	Dry wt. kg	N %*	N dry wt.	C/N*	C	C/N total
Potato	9.35	1.77	1.5	0.0265	25	0.663	23
Carrot	7.70	2.541	1.52	0.0386	34	1.313	
Meat	1.00	0.33	7	0.0231	2	0.046	

Cooked rice	**8.50**	**3.315**	**1.55**	**0.0513**	**27**	**1.387**	
Soil	**10.40**	**1.976**	**3.7**	**0.0731**	**20**	**1.462**	
Leaves	**2.50**	**0.8**	**0.75**	**0.006**	**60**	**0.36**	
Animal manure	**14.75**	**4.425**	**3.75**	**0.1659**	**22**	**3.65**	
$\sum=$	**59.20**	**15.157**		**0.3845**		**8.881**	

*** Tchobanoglous et al., 1993**

2.3. Analytical Procedure (Characterization of the Compost)

2.3.1 pH

The pH of the compost was determined according to **ASAE,2004:** Raw samples were mixed with deionized water at a weight ratio of 1:10. The mixture was shaken for 1 hr. And then allowed to settle under quiescent conditions; pH of the clear supernatant was measured with a pH meter prob.

2.3.2 Determination of organic matter (O.M. %) and carbon (C %)

Organic matter was determined using combustion method **ASAE, 2004:**

- Two grams of samples were weighed and dried in an air oven at 105°C for 24hr until dryness of the samples.
- The dried samples were weighed to determine the dry weight (R).
- Each dried sample was burned in the furnace at 550°C.
- Samples were left in a desiccator at least for five minutes to prevent moisturizing. Each sample was weighed, and ash weight (S) was recorded.
- The contents of organic matter were measured using the percentage formula:

$$organic\ matter\% = (R - S)/R \times 100 \quad (1)$$

Carbon percentages were calculated according to the following equation, **De Guardia, et al., 2010:**

$$carbon\% = (organic\ matter\ \%)\ /\ 1.76 \quad (2)$$

2.3.3 Determination of N-NH_4, N-NO_3, total nitrogen

The content of nitrogen as ammonium and as nitrate was determined by using Multi Direct photometer for multi-parameter analyses (water test equipment, Lovibond, Germany).

2.3.4 Potassium and heavy metals concentrations

The concentrations of potassium (K) and heavy metals in dried samples were determined using Thermo Scientific 900 Heavy Metals Analyzer Niton (XRF), (Germany). Data were introduced in (ppm)units directly.

2.3.5 Germination test

To evaluate the final product of compost as a plant growing media, the Germination Index (GI%) was measured. The germination percentages concerning the control and root lengths were determined according to **Bertran, et al., 2004,** where the test was performed for 48 hr. At 25°C in the dark with 20 radish seeds placed on a 9 cm filter paper (Whatman No. 1) soaked with 4 ml of compost extract and placed in a Petri dish, **Bertran, et al., 2004.** The germination test was repeated with deionized water as a control, and with extract of commercial compost (beat moss).

The following equations were used to calculate the relative seed germination, relative root growth, and germination index (GI %), according to **Tiquia, et al., 1996, Zucconi, et al., 1997,** and **Marek, et al., 2003:**

$$\text{Relative seed germination (\%)} = \frac{\text{Number of seeds germinated in compost extract}}{\text{Number of seeds germinated in control}} \text{ x } 100 \qquad (3)$$

$$\text{Relative root growth(\%)} = \frac{\text{Mean root length in compost extract}}{\sqrt{\text{Mean root length in control}}} \text{ x } 100 \qquad (4)$$

$$\text{GI (\%)} = \frac{\text{(Relative seed germination)x(Relative root growth)}}{100} \qquad (5)$$

3. RESULTS AND DISCUSSION

3.1 Mass loss

The starting weight of 59.2 kg raw material had turned to be 18.53 Kg as a total remaining mass after the 100th days of composting indicating a successful reduction in mass quantities**.**

3.2 pH

During the first weeks of composting the intense microbial activity and organic matter degradation led to the release of ammonia and a sharp pH increase. The increase in pH might be due to the release of ammonia by protein decomposition, **Moldes, et al., 2007.** As the composting process proceeds a decrease in pH because of the activity of acid-forming bacteria that break down complex carbonaceous material to organic acids which occurred due to the conversion of NH^{4+} to nitrous and nitric acids. Ammonia is oxidized to nitrates by the action of nitrobacteria and trapped air that lowers high pH and reduces odors and favoring a balanced microbial population **Huang, et al., 2011**. However, initial pH was (6.53), and the final was (7.03) as shown in **Fig. 2.**

During the experiment, no putrefactive odors were generated, indicating the prevalence of satisfactory aerobic conditions. The pH of the mature compost indicates good quality compost that is within the suggested range of (6.0–8.5) **TMECC, 2002**. This finding was closely related to **Chyad, 2014 and Obiora, et al., 2016.**

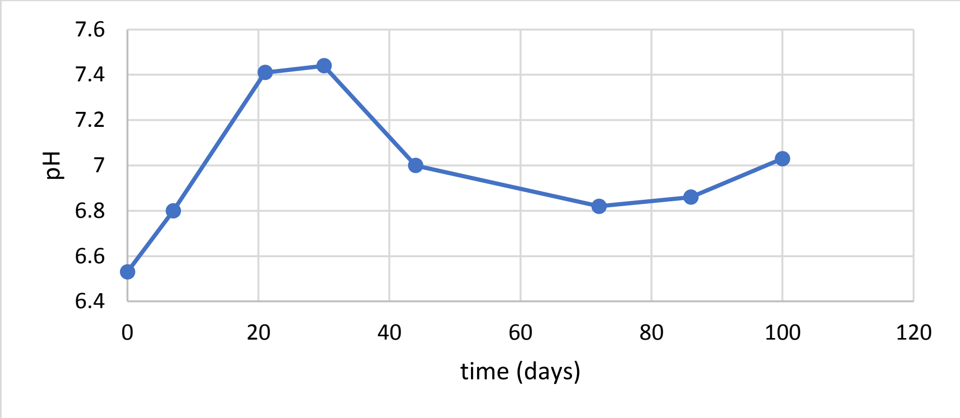


Figure 2. pH variations vs. time.

3.3 Organic Matter (O.M%) and Organic Carbon (O.C%)

Although there is no absolute level of O.M that is ideal in terms of compost quality; quantities of (O.M%) must be viewed concerning the age of the compost and its intended use. It is useful for purposes of composting to report the initial and the final (OM%), as it gives an idea of the extent of decomposition**, Jimenez and Garcia, 1991.**

The process which took place in the composting bioreactor resulted in low (OM%) content of the substrate. It dropped from (62.34%) as the initial value to (39.88%) at the end of the composting process of the 100 days as shown in **Fig.3.**

Organic Carbon (O.C %) was found to be (34.76%) of feedstock in the initial stage of the composting process and dropped to (22.15%) at the end of the composting process. The content of carbon was decreased in the compost pile as it transformed into carbon dioxide and water, **Chazirakis, et al., 2011.**

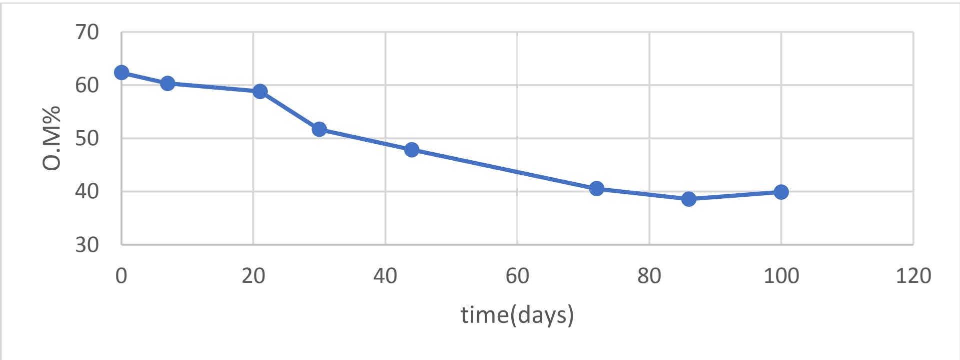


Figure 3. Organic matter vs. time

3.4 Nitrogen Content (N%) and C/N

Nitrogen content was measured at the initial and final composting process; the initial value measured was (1.86%) and had turned to be (1.52%) as shown in **Table 2**. During composting, nitrogen was metabolized mainly to ammonia while the non-soluble complexes of nitrogen decompose to soluble nitrogen form that is readily available for metabolic activities, **Eklind and Kirchmann, 2000**. (O.M%), (O.C%), (N%) and C/N as initial and final values of feedstock are

given in **Table 2.** An important note in the matter of nutrition is a supply of available carbon to serve as an energy source, and nitrogen as building blocks of protoplasm, **Obiora, et al., 2016.**
Energy requirement being high, more carbon than nitrogen is needed; however; there is a limit over carbon over nitrogen beyond which organic activity diminishes, **Guo, et al., 2012.** The initial feedstock had a C/N ratio of 23, i.e., for every 23 parts of cellulose consumed by fungi and bacteria, one part of the nitrogen is changed from an inorganic nitrogen form into microbial protoplasm. However, it must be noted that not all the carbon is available for microbial use, and, if nitrogen is lost during the composting process, then C/N ratios may increase during late stages of composting, **Chazirakis, et al., 2011**, therefore, C/N values must be weighed against observed decomposition traits.
As carbon being consumed toward the end of the process accompanied by loss of nitrogen, C/N ratio had decreased; in fact, it turned to be (14.54). Maintaining the C/N ratio for the final compost is an essential factor to assess the quality of finished compost as a soil amendment. Researchers have suggested various ideal C/N ratios from more than 12 to lower than 25, **Rihani, et al., 2010; Al-Zubaidi, 2013** and **Chyad, 2014.**
s C/N data obtained for the final pile being within the range, it may be qualified as satisfactory compost. The degree of stability of the compost is also strictly related to the nitrification index ($N\text{-}NH_4/N\text{-}NO_3$) as shown in **Table 3.**

Table 2. Properties of feedstock and final compost.

O.M%		**O.C%**		**N%**		**C/N %**	
Feed-stock	**Final Compost**	**Feed-stock**	**Final Compost**	**Feed-stock**	**Final Compost**	**Feed-stock**	**Final Compost**
62.34	39.88	34.76	22.15	1.86	1.52	23.00	14.54

Table 3. Nitrification indices (NH_4-N/ NO_3-N).

	Initial Feedstock	**Final (compost)**
NH4+-N(mg/kg)	440.45	410.47
NO3+-N (mg/kg)	1295.44	1320.54
Nitrification index NH4+-N/ NO3-N, ≤ 0.5*	0.34	0.31

***(Brinton, 2000)**

3.5 Phosphorous (P) and Potassium (K) Values

Levels of P and K value in the finished compost are also crucial in determining the quality of compost, for those elements are essential nutrients for plant growth. Phosphorous had an initial amount of (1.73%) and were decreased to (1.53%). The potassium had an initial value of (3.61%) and had turned to be (0.58%) as shown in **Table 4.** NPK value was (1.52-1.53-0.58) % for the Final Composts.

Table 4. P and K percentages in feedstock and final composts.

Item	Initial%	Final%	Standard (TMECC,2002)
P%	1.73	1.53	(0.56 -1.56)
K%	3.61	0.58	(0.62-1.22)

3.6 Heavy metals

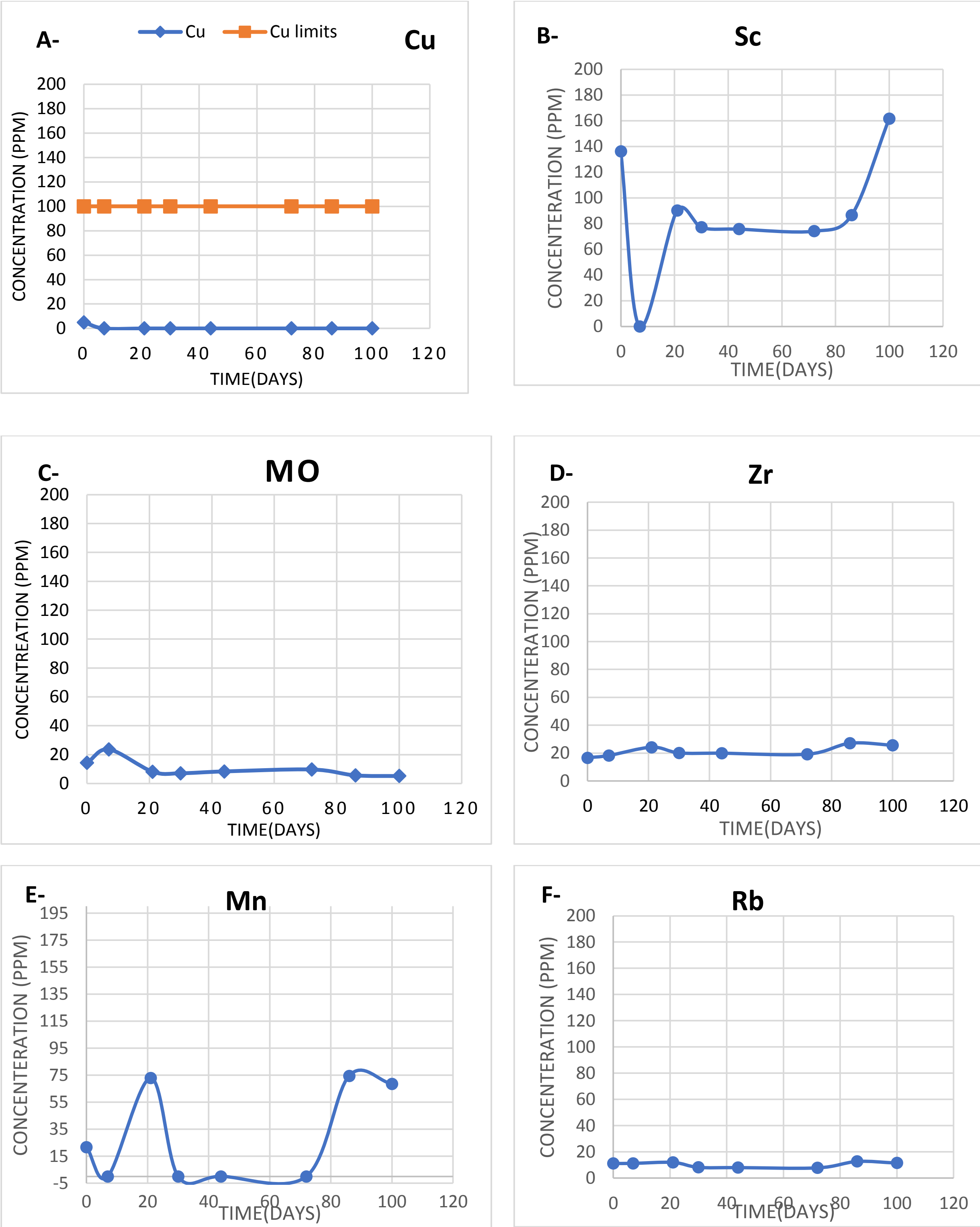
Variation in heavy metals concentrations through composting period are shown in **Fig. 4 (A to L).** In general, high levels of heavy metals in composts represent an obvious concern if they are to be applied to food crops. Heavy metals do not degrade throughout the composting process, and frequently become more concentrated due to the organic matter microbial degradation and the continuous loss of carbon and water into carbon dioxide and water vapor throughout the composting process**.**

Metal concentrations that were measured in source-segregated food waste were related to the natural background contents of metals in food and plant material wastes. In general, Cu and Zn concentrations in the material composted were typically below standards as can be shown in **Fig.4 (A and G).** While high levels of K, Ca, Fe and Ti might be stemmed from manure and soil, as they get often included in animal diet. Referring to **Fig.4 (C, F, and K)** that total concentration of Mo, Rb and Ca decreased over time while Sc, Zr, Mn, Sr, Fe, and Ti were swinging up and down for compost significantly as can be shown in **Fig.4 (B, D, E, H, I, and J).** Cu and K had experienced stabilization and diminishing in concentration with time as can be shown in **Fig.4 (A and L).** These results were is in disagreement with the results reported by **Petruzzelli, et al.,1989, Cooperband, 2000, Veeken and Hamelers, 2002, Hseu, 2004,** and **De Guardia, et al., 2010**, for they declared that heavy metals increased through the composting process. This probably was because they did not consider the net losses of organic matter and the level of the inorganic constituents that inevitably occurred during composting.

In general, the decrease in heavy metals concentration might be due to the losses caused by leaching, while the different oscillating behavior of the metals could be due to their different solubility in leachate or probably due to different bounds strength to organic components. As may be concluded from the information in **Table5** the quality of current compost meets the requirements of safe compost of USA and Canada regulations, and in **Table 6** Oman and European regulations.

Total metal contents in compost are of concern when repeated applications to land. Field trials involving MSW compost application to soil have all reported an increase in soil and plant metal concentrations (e.g., Ni, Pb, Zn, and Cu) **Achiba, et al., 2010.**

Generally, increasing the overall heavy metal burden of the soil may be undesirable, yet the application of composts poses little risk in terms of phytotoxicity or metal contents of crop tissue, **Veeken, and Hamelers, 2002.** This is probably due to the relatively small proportion of the heavy metal that is naturally contained in the feedstock (food waste)**.** The risk of metal contamination from MSW-derived composts is of similar magnitude to that posed by biosolids application to the land which is now a widely accepted practice.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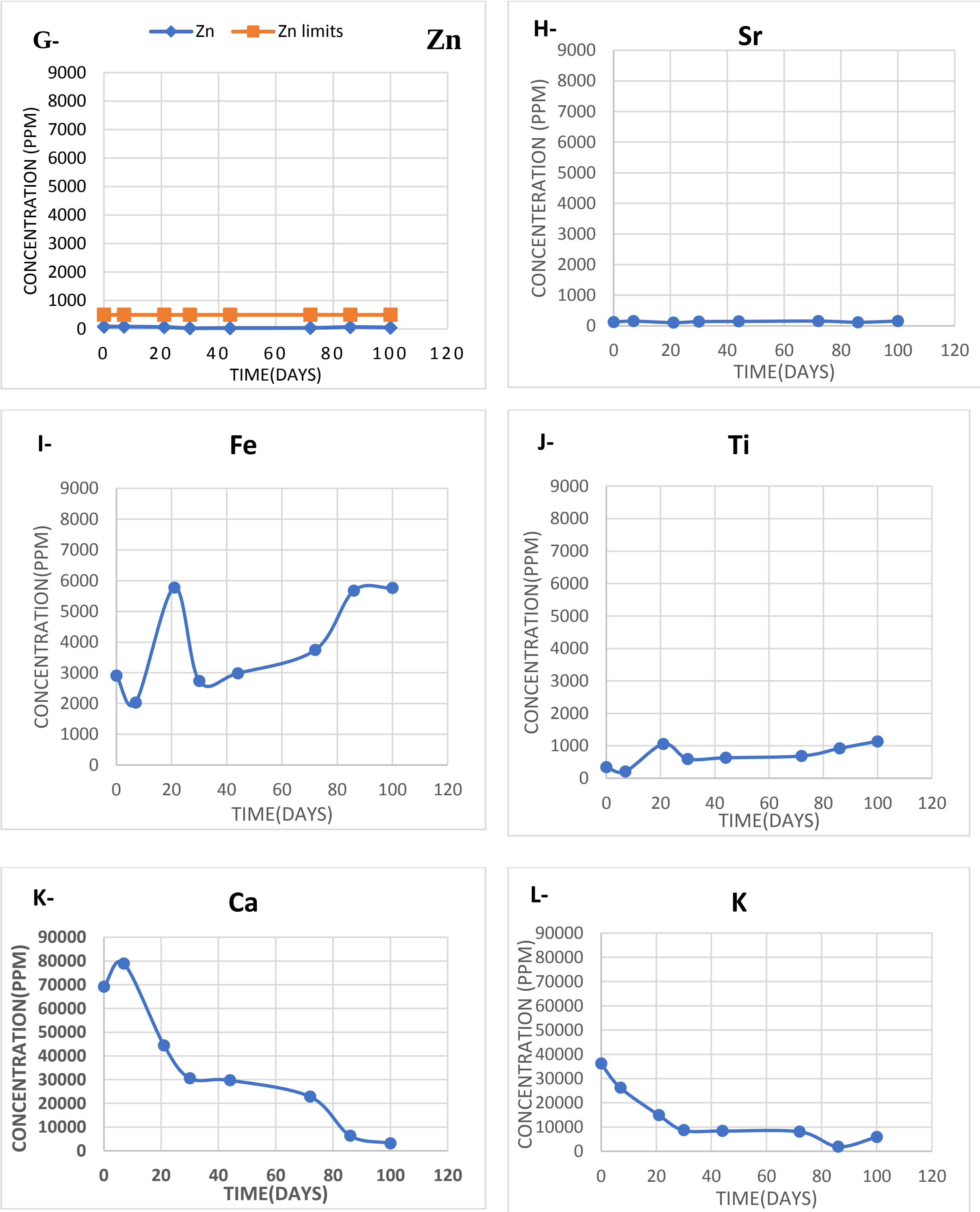

Figure 4. Concentration of heavy metals (ppm) for compost, A: Cupper (Cu); B: Scandium (Sc); C: Molybdenum (Mo); D: Zirconium (Zr); E: Manganese (Mn); F: Rubidium (Rb); G: Zinc (Zn); H: Strontium (Sr); I: Iron (Fe); J: Titanium (Ti); K: Calcium (Ca); L: Potassium(K).

Table 5. Physical and chemical properties of compost compared with USA and Canada compost quality standards, **Hogg, et al., 2002.**

Characteristic	Compost Quality		Permissible Concentrations of Trace Elements in Compost	
	Initial	Final	USA	Canada
Appearance	1.Had an offensive odor. 2.Wet, compacted, green mass of putrefactive material	1.Had no odor (Pleasant earthy odor). 2.Dark brown color. 3.Uniform particle size. 4.Absence of clumps. 5.No visually identifiable contaminants	--	--
Heavy metal (ppm, dry weight basis)	**Result Compost**			
Zn	49.562		2800	500
Cu	0		1500	100
C/N	14.54			

Table 6. Physical and chemical properties of compost compared with EU and Oman compost quality standards, **Abou el Wafa, et al., 2008**.

	O.M% dry wt.	C/N	pH	N% dry wt.	P% dry wt.	K% dry wt.
MSW						
EU	45-53	24.5	7.5-8	1.0-1.2	0.68	1.01
Oman	55	19	6.63	1.3	0.4	0.6
Result Compost						
	39.88	14.54	7.03	1.52	1.53	0.58

3.7 Compost quality and germination tests

The outcomes of the germination tests were given in **Table 7**. Germination index (GI%) was found to be (85.5%), which is higher than the value of (60%) for cress suggested by **Diaz, et al., 2003**. Relative seed germination was (90%), and relative root growth was (95%).

Calculation sample:

$$\text{Relative seed germintation } (\%) = \frac{82}{91} \text{ x } 100 = 90\%$$

$$\text{Relative rootgrowth } (\%) = \frac{0.95}{\sqrt{1}} \text{ x } 100 = 95\ \%$$

$$\text{GI}(\%) = \frac{(90)\text{x}(95)}{100} = 85.5\%$$

According to the literatures above and standards, the final compost appears to be satisfactory for plant growth.

Table 7. Outcomes of the germination test.

Item/ Parameter	Control Test	Extract of Final Compost	Extract of Commercial Compost
Total seeds	100	100	100
Germinated seeds	91	82	71
Mean root length (cm)	1	0.95	0.77
Relative seed germination %	-	90	78
Relative root growth %	-	95	77
Germination index %	-	85.5	60

4. CONCLUSIONS

Successful reduction in mass quantity was significantly observed, as wastes mass was reduced by almost 69%. C/N had decreased to 14.54 which was within the range to be qualified as satisfactory compost. The acquired ratios of nitrification index ($N\text{-}NH_4/N\text{-}NO_3$) was (0.31).

Biomass with lower than 0.5 nitrification ratio is considered as mature compost. Concentrations of Cu and Zn in final compost were typically far below standards, Mo, and Ca levels decreased over time. Zr, Mn, Sr, Sc, Ti, and Fe concentrations were swinging ups and down significantly. K and Cu concentrations had experienced stabilization and diminishing in concentration with time. Germination index (GI%) was found to be (Ave. 85.5%).

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NOMENCLATURE

C/N = carbon to nitrogen ratio.
GI = germination index.
MSW = municipal solid waste, (kg/capita. day).
NPK = nitrogen, phosphorus and potassium content.
OC = organic carbon.
OM = organic matter.
PPM = parts per million.
SWM = solid waste management.
TMECC = test methods for the examination of composting and compost.
X- RF = X- Ray Fractionation.