

Article

Co-Composting of Khat-Derived Biochar with Municipal Solid Waste: A Sustainable Practice of Waste Management

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Abstract: Biochar is a way to improve the performance of the composting process and the quality of compost. This study was aimed to investigate the optimum ratio of khat straw (*Catha edulis*) biochar and organic municipal solid waste mixtures to improve the quality of the resulting co-composts. Khat-derived biochar during pyrolysis at 350 °C was added to organic municipal solid waste mix and four co-composting treatments were prepared with the compositions (% w/w): control compost (no biochar) and 5%, 15%, and 25% co-composted biochar in three replicates. The total organic carbon, organic matter, total nitrogen, available phosphorus, and potassium values ranged as 16.76–21.45%, 30.77–40.26%, 0.97–1.68%, 0.58–0.76%, and 12.72–15.29%, respectively. The results confirmed that 5% and 15% co-composted khat biochars had significantly reduced ($p < 0.05$) organic matter loss and increased the contents of cation exchange capacity, pH, phosphorous, potassium, calcium, magnesium, and zinc compared to the control compost, while some heavy metals (Fe, Cu, and Mn) and EC values in co-composted biochars are lower than the control compost. Khat-derived biochar could be added to municipal organic waste mix at 5–15% (w/w) in order to get better quality of compost, which can be used as biofertilizer.

Keywords: biochar; co-composted biochar; compost; municipal solid waste mix

1. Introduction

The sustainable management of solid waste has become a major problem of the municipalities in the world in general and developing countries in particular [1,2]. Jimma, South-west Ethiopia as city of a developing country, solid waste collection rate is the lowest among the growing cities of Ethiopia, where only 30% of the total waste is collected and disposed on landfills [3]. The remaining part of the waste is usually burned or disposed in open space. According to Getahun et al. [3], the total waste generated daily in Jimma city was ca. 88,000 kg, and the average per capita generation rate was 0.55 ± 0.17 kg/capita/day. In addition, according to [3], biodegradable organic waste constitutes 88.6% by weight. Thus, the proper management of organic solid waste is crucial for the successful disposal of municipal solid waste.

Composting has been considered as the most sustainable way to recycle organic wastes for the ever-increasing volume of municipal solid wastes being generated [4–7]. Composting is a method for converting organic wastes into compost, and it has advantages over other disposal strategies because

it reduces the volume of waste by 40–50% and provides nutrient-rich biofertilizer. In recent years, compost and other organic amendments has received increasing attention over chemical fertilizers in both providing enough nutrients and improving the soil environment, which leads to increased yields of crops [8].

However, composting had been associated with greenhouse gas emission (CO_2 , N_2O , and CH_4), leachate generation, but this emission is not as equally harmful for climate as coal combustion [9,10]. More recently, studies have showed that biochar is a way to improve the performance of the composting process and the quality of compost [11,12]. Experimental evidences of biochar impact on composting especially in tropical systems are limited to a few studies to date. However, the available literature reported that biochar addition during composting provides positive effects such as adjusting the C:N-ratio and serving as a bulking agent [13], reducing ammonia (NH_3) and greenhouse gas (GHG) emissions [14], increasing heavy metal stabilization and rapid organic matter degradation [15], enhancing microbial activities [16], and upgrading compost quality by increasing the available nutrient content [17,18]. Biochar can either be mixed with composting feedstocks during the composting process, i.e., “co-composted,” or added directly to stored matured compost [14].

Biochar is charcoal produced from biomass by pyrolysis in a low-oxygen environment for use as a soil amendment or carbon sequestration [19]. Although some recent studies have indicated that biochar alone application to soil can improve soil fertility and plant growth [20,21], the combined use of biochar with other, nonpyrolyzed organic amendments (i.e., compost, manure, plant litter, etc.) has been proposed [11,22,23]. The properties of biochar depend on the type of the feedstock and pyrolysis conditions [24]. The selection of a specific type of feedstock is to a great extent determined by the availability of this material in the area where the biochar is likely to be produced. Large quantities of khat straw are produced during chewing khat leaves has left large quantity of khat straw as major part of municipal solid waste that is dumped in large quantity in Jimma city. With its low moisture content and local availability in the municipal waste, khat straw could be an important feedstock for biochar production. However, the ability of khat straw-derived biochar to affect compost quality might vary depending on its characteristics. It is, therefore, essential to investigate the properties before wide application of khat straw-derived biochar.

On the other hand, a biochar impact on composting has been ranged in a wide proportion of biochar, from 2% to 50% (*w/w*), which is yet not fully understood [11,13,25,26]. Knowledge about an optimum proportion of biochar addition would be necessary to maximize the potential benefit of biochar and compost on the future use [17]. It is, therefore, crucial to investigate the optimum ratio of khat straw (*Catha edulis*) biochar and organic fraction of municipal solid wastes to improve the quality of the resulting composts.

2. Materials and Methods

2.1. Municipal Solid Waste Collection

All personnel collecting, handling, and transporting of the wastes were performed using proper procedures according to the waste established classes. The municipal solid organic wastes used for the pyrolysis and composting experiments were khat (*Catha edulis*) straws, dry grass and leaves, coffee ground, and vegetable wastes (cabbage, avocado and banana peel). These wastes were obtained by a door-to door collection and source segregation from households, hotels, roads, markets, and shops in Jimma city for a week in sealed bags until ready for biochar and compost production. These waste ingredients were selected on the basis of their availability in the municipal solid wastes. Biochar was used as bulk agent for composting process. Sun-dried grass clippings and fallen leave wastes were used as a source of carbon and coffee grounds and vegetable wastes (cabbage, avocado, and banana peel) were used as sources of nitrogen for composting. Wastes such as onion and garlic, which repel earthworm, and anything containing meat, fat, oil, and dairy products, which bring bad smell, were avoided.

2.2. Biochar Production

The khat (*Catha edulis*) straw waste was used for biochar production. Laboratory experiments were conducted with a laboratory-scale pyrolysis reactor at Jimma University agricultural college. The biomass samples were washed and dried. Some sample of khat straw was powdered and subjected to initial compositional analysis and the remaining was used for pyrolysis and composting experiments. Khat straw waste was pyrolyzed at a temperature of 350 °C at a heating rate 5 °C/min for 4 h (Figure 1). Approximately, 7.0 kg of khat straw wastes was used in the batch slow pyrolysis experiments. After cooling and opening the kiln, the biochar was removed and weighted. About 2.04 kg (29.4%) of char was produced from each of the batch experiment. Ref. [27] in their studies have showed that feedstocks with higher content of lignin have higher biochar yield, while biomass with higher content of cellulose and hemicellulose resulted in production of more volatile compounds. The biochar yield for typical slow pyrolysis process is about 35% [28]. So, from our finding we observed that khat straw has a good content of lignin since it's biochar yield is about 29.4%.

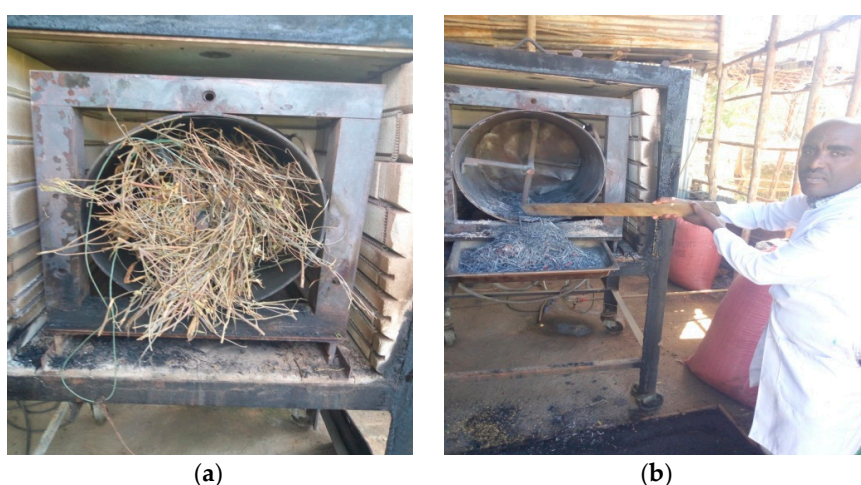


Figure 1. Preparation of biochar during slow pyrolysis of khat straw: (a) khat straw into the reactor and (b) biochar collected from the reactor.

2.3. Compost and Composted-Biochar Production

The production of compost with and without biochar was carried out in three replicates with a laboratory-scale chamber compost bioreactor made of clay with a total working capacity of 1 m³ in October–December 2018 (about 88 days) at Agricultural College Research Center, Jimma University, Ethiopia. On the basis of their availability and to optimize the C:N ratio, the organic municipal waste feedstocks were mixed with a proportion of 40 kg of vegetables (banana (15 kg) + cabbage (20 kg) + avocado (5 kg)), 100 kg of sun dried fallen leave and grass, and 40 kg of coffee ground wastes. Following the initial organic municipal waste mixtures, four co-composting treatments were prepared with biochar in three replicates (Table 1). C:N ratio is among the parameters, which mainly affects the quality of the end compost. Data reported by [18] showed that 2–50% (*w/w*) biochar application rates led to different effects on the quality of compost and composting process.

Table 1. The types of compost treatments and proportions of organic municipal waste feedstocks mixture and biochar.

Sr. No.	Types of Compost Treatments	Organic Waste Mix (% <i>w/w</i>)	Biochar (% <i>w/w</i>)
1	Control compost mix (no biochar)	100	0
2	5% co-composted biochar	95	5
3	15% co-composted biochar	85	15
4	25% co-composted biochar	75	25

The experiment was carried out in the laboratory with an average room temperature of 23 ± 2.0 °C and relative humidity as 70%. The co-composting substrates were turned every week until the end of the experiment and four types composts (Figure 2) were produced.

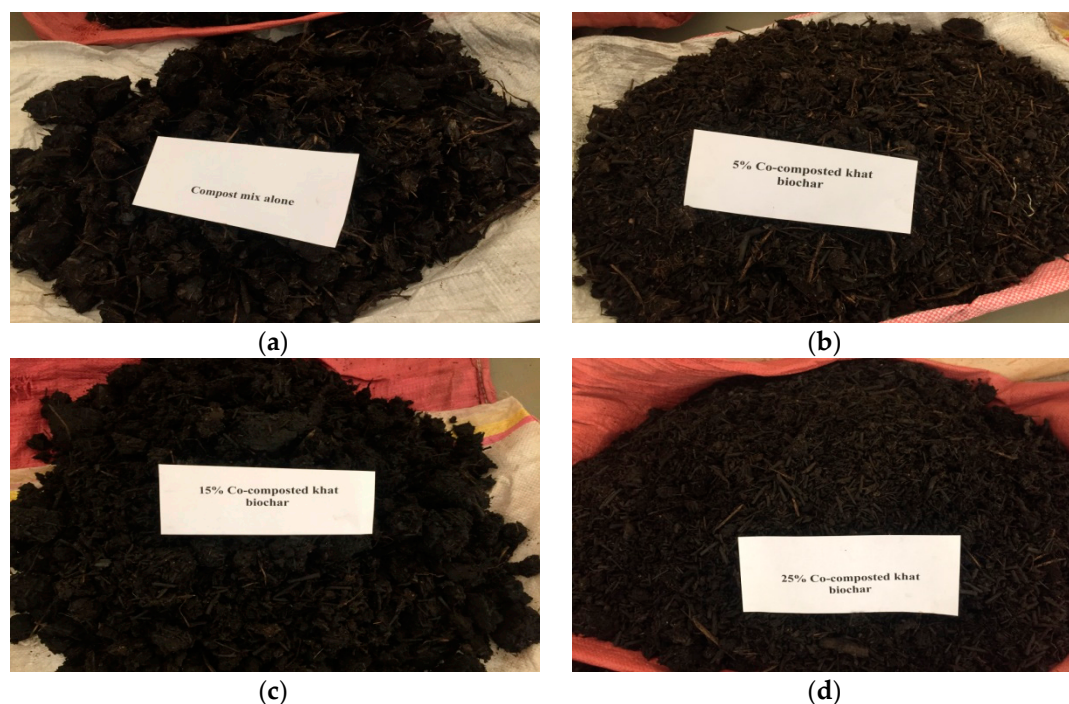


Figure 2. The co-composted khat biochar produced by mixing organic fraction of municipal waste with (a) 100% organic waste mix (no biochar), (b) 5% of khat biochar, (c) 15% khat biochar, and (d) 25% khat biochar.

2.4. Physicochemical Analysis

The moisture contents of khat biochar, organic waste mix, and composts were determined by placing 5.0 g of each sample in a dry Petri dish in a hot air oven for 24 h at 105 °C, after the moisture was removed, the organic matter was determined from mass loss by furnace ignition at 550 °C for about 8 h.

Total nitrogen was determined by Kjeldahl method and organic carbon (OC) was determined by the Walkley and Black titration method, which is based on the oxidation of biomass by potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid mixture followed by back titration of the excessive dichromate by ferrous ammonium sulfate [29]. The pH and electrical conductivity (EC, dS/m) were determined in the supernatant solution of 1:5 compost or feedstock/water ratio (*w/v*) [30] using a pH meter and conductivity bridge/meter [31], respectively. Potassium (K), calcium (Ca), and magnesium (Mg) were determined from 2 gm of dry compost sample extracted with 10 mL of 1 N ammonium acetate kept for overnight and filtered using Whatman paper number 42 and final volume was diluted up to 50 mL deionized water. Ammonium acetate extract of the compost samples was determined by atomic absorption spectroscopy (AAS) [32] and cation exchange capacity (CEC) by the ammonium acetate method [33]. Heavy metals (Fe, Mn, Cu, Zn, Cd, Cr, and Pb) were determined by atomic absorption spectroscopy (model NOVA 400P AAS) after digestion of the composts and biochar with a blend of HNO_3 and $HClO_4$ [31]. Available phosphorus was determined by leaching the sample with 0.002 N H_2SO_4 (1 soil: 200 H_2SO_4 suspension *w/v*) and shaken for at least 30 min and filtered through Whatman filter paper No. 42 to get a clear solution. The amount of phosphorus in the extract was estimated by chlorostannous reduced phosphomolybdate blue color method using spectrophotometer at the wavelength of 690 nm [31].

2.5. Statically Analysis

Statistical analysis was carried out using statistical package SPSS (IBM SPSS Statistic 24). One-way analysis of variance (ANOVA) was applied to evaluate the significant differences among the mean values of treatments; F values ($p = 0.05$) were tested. Means were tested by Tukey's HSD test at a 5% level of confidence [34]. All samples were analyzed in triplicates ($n = 3$). The results were presented as mean values \pm standard deviation, $n = 3$.

3. Results and Discussion

3.1. The Physicochemical Properties of Khat Straw Biochar

The physicochemical properties of khat straw biochar are presented in Table 2. It has low moisture content (9.7%), which initiates khat straw biochar to use as bulking agent during composting. This value is lower than the finding by [12] for biochar produced from bamboo tree. It has an electrical conductivity (EC) value of 1.6 dS/m, which is much less than the maximum limit (4.0 dS/m) of Greek's standard for agricultural uses [35]. The electrical conductivity is the measure of water-soluble salts. The EC value of this biochar is good because it is low. Khat biochar has also weak alkaline pH (8.9) value, which is important to neutralize the acidic organic waste mix during composting or to amend acidic soil. This pH value was less than the findings by [14] for biochar prepared from holm oak, which was pyrolyzed at 650 °C, but greater than the finding by [13] for biochar prepared from Eucalyptus grandis pyrolyzed at 300–450 °C. The results also showed that khat straw biochar has high organic matter (88.4%) as well as major nutrients such as total nitrogen (1.50%), phosphorous (0.40%), potassium (0.26%), calcium (6.4 g/kg), and magnesium (2.3 g/kg) contents with low levels of trace metals. These results were within the range of the values found by [36], in which biochars were pyrolyzed from six feedstocks types, the nutrient contents (%) ranged as total organic carbon from 34.96 to 48.93, N from 0.56 to 2.00, P from 0.49 to 2.49, and K from 1.41 to 7.49. Wu et al. [24] also reported that the rice straw-derived biochars produced at 400 °C had high pH (10.1) and cation exchange capacity (57.2 cmol/kg) and high levels of available phosphorus (830 mg/kg) and extractable cations, which were higher than the values from our observation. In the findings by [14], some of the results, pH (10.1), C (74.2%), P (2.4 g/kg), and Ca (69.8 g/kg), were greater and others, EC (0.67), OM (77.8%), and N (0.5%), were less than our results. The variation in the physiochemical properties of biochar vastly depend on pyrolysis condition and the feedstock used [37].

Table 2. The physicochemical properties of khat straw biochar pyrolyzed at 350 °C. Results expressed as mean values \pm SD, $n = 3$.

MC	EC	pH	OM	OC	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
%	dS/m	(H ₂ O)	%	%	%	%	%	g/kg			mg/kg		
9.7 \pm 0.23	1.6 \pm 0.02	8.9 \pm 0.01	88.4 \pm 0.67	47.7 \pm 0.36	1.5 \pm 0.03	0.4 \pm 0.09	0.26 \pm 0.01	6.4 \pm 0.02	2.3 \pm 0.01	1.1 \pm 0.01	0.3 \pm 0.00	0.1 \pm 0.00	0.2 \pm 0.00

Thus, the physicochemical properties of khat straw biochar indicate that it could be used as bulking agent for composting or to amend degraded soil either alone or in synergy with compost or inorganic fertilizer.

3.2. The Chemical and Moisture Contents of Organic Municipal Waste Mix and Compost with and without Khat Biochar Amendments

The chemical properties of initial municipal organic waste mix and compost with and without khat-derived biochar are presented in Table 3. The electrical conductivity (EC) values ranged from 0.42 to 0.75 dS/m for the different compost types. The EC value of initial organic waste mix (2.22 dS/m) was significantly reduced during composting for both with and without khat-derived biochar ($p < 0.05$) (Table 3). During the composting process, the clay reactor chambers were closed and there was no

loss of leachates, but gases mainly ammonia could be lost, which decreased the EC values of the resulting compost piles. There were contradicted ideas in literature about EC values during composting. Zhang et al. [38] observed an increase in EC, while Wu et al. [17] reported a decrease in EC values during composting. The decrease in EC of the initial organic waste mix during composting was because of the soluble forms of heavy metals, which were accumulated and immobilized, or precipitated mineral salts in the weak alkaline compost mixture [39]. Previous studies showed that heavy metals are converted to insoluble forms in neutral or alkaline media. Electrical conductivity (EC) is one of simple indicators of suitability of a waste for agricultural uses, because it reflects the salinity of the resulting organic amendments and low salinity is suitable for agriculture. The maximum limit of EC value of compost for agricultural use in Greek standards is 4.0 dS/m [35]. Since, all the under studied composts' EC values were less than the maximum limit, they are suitable for agricultural applications in terms of EC values.

Table 3. The physicochemical properties of initial municipal organic solid waste mix and the four different types of co-composted khat-derived biochars. Results are expressed as mean values \pm SD, $n = 3$.

Parameters	Units	Treatments				
		Initial Organic Waste Mix	Control Compost	5% Co-Composted Biochar	15% Co-Composted Biochar	25% Co-Composted Biochar
EC	dS/m	2.22 \pm 0.0 a	0.75 \pm 0.0 b	0.51 \pm 0.0 c	0.63 \pm 0.0 d	0.42 \pm 0.0 e
pH (H ₂ O)		6.12 \pm 0.0 a	8.24 \pm 0.3 b	8.29 \pm 0.3 b	8.52 \pm 0.4 b	8.61 \pm 0.2 b
Moisture content	%	63.09 \pm 1.6 a	53.8 \pm 1.2 b	47.57 \pm 0.9 c	46.85 \pm 0.6 c	44.54 \pm 0.8 c
Organic matter	%	58.24 \pm 3.9 a	33.32 \pm 0.4 b	40.26 \pm 0.8 c	37.09 \pm 0.9 c	30.77 \pm 1.3 b
Total organic carbon	%	31.45 \pm 2.1 a	18.00 \pm 0.5 bde	21.45 \pm 0.8 cd	19.38 \pm 0.3 bcd	16.76 \pm 1.1 be
CEC	cmol(+)/kg	73.41 \pm 0.5 a	105.4 \pm 0.7 b	177.95 \pm 1.1 c	121.61 \pm 0.7 d	112.06 \pm 2.7 e
C:N ratio	g/g	17.42 \pm 1.8 a	11.26 \pm 0.6 b	14.97 \pm 0.8 c	16.07 \pm 1.7 ac	17.33 \pm 0.8 a

Tukey HSD ($p < 0.05$; means within a row followed by different letters are significantly different).

The pH (H₂O) values of the different composts are in the range of weak alkaline media (8.24–8.61) and acidic (6.12) for initial organic waste mixture (Table 3). The findings of this study showed that the variation in pH was significant ($p < 0.05$) between the initial organic waste mix and all composts, but the same between the control compost and khat-derived biochar amended composts (Table 3). The result was higher than the finding by [40]. Our results showed that during composting, the pH of the initial organic waste mixture was increased for both with and without khat-derived biochar. This is because the khat-derived biochar had higher contents of basic cations (K, Ca, and Mg), and these cations are leached to the compost piles from the biodegradation of organic waste and biochar mixture during composting. There were contradictory ideas in recent literatures on the pH value during composting. According to the observation by [38], the addition of wheat straw biochar from 0% to 15% (w/w) reduced the pH during composting. Vandecasteele et al. [14] observed that biochar addition slightly increased the initial pH of the compost mixture. Experimental evidences showed that a biochar amendment increases the pH of a soil. The pH value increased with increasing the rate of khat-derived biochar. There was slight increase in the pH value with increasing rate of khat-derived biochar. The trend is similar with the report by [13], in which the application of alkaline biochar as a bulking agent at highest rate in poultry manure compost obtained the highest pH for the matured compost. The pH values of all composts were within the optimum range (6–8.5). The results were in agreement with the investigation by [40] for compost prepared from organic fraction of municipal solid waste in which the pH ranged from 6 to 8.5.

The pH values of the under investigation composts showed that they are suitable for soil application especially for acidic soil. Compost could correct the pH of the soil to the optimum, and it has buffering effect. The pH is a chemical parameter, which affects the amount of nutrients available in the soil, the solubility of heavy metals, and the metabolic activity of the important microorganisms

in the soil. The optimum soil pH suitable for crop growth ranges from 6 to 8. In this pH range, essential soil nutrients are available for plants in the soil solution, while toxic heavy metals converts to insoluble forms.

The cation exchange capacity (CEC) values for the under studied composts ranges from 73.41 to 177.95 cmol(+)/kg (Table 3). CEC is one of the important chemical parameters, which indicate the quality of matured compost. According to literature, matured and better quality compost has high CEC value [41]. In this study, we observed that there was significant variation ($p < 0.05$) (Table 3) between CEC values among the investigated composts, while 5% khat-derived biochar amended compost had the highest value of CEC (177.95 cmol(+)/kg) and control compost (without khat-derived biochar) had the lowest CEC value (73.41 cmol(+)/kg). This showed that all the composts with khat-derived biochar were more matured than the control compost. The high value of CEC in biochar amended composts is because of the high contents of basic cations such as K, Ca, and Mg in the khat-derived biochar (Table 2). CEC is also correlated with the degree of degradation of biomass during composting, so that the rate of the decomposition was higher in khat-derived biochar amended compost than the control.

The average moisture content during the composting experiment was 63.09%. According the findings by [42], the suitable initial moisture content for the efficient composting of poultry manure mixed with wheat straw ranged from 65% to 80%. The finding by [43] suggested that pile moisture was maintained between 53% and 60% during the composting period. At the end of composting experiment, the different composts' moisture content ranged from 44.54% to 50.57% (Table 3). According to literatures, the optimum moisture contents value of the final compost ranged from 35% to 45% [44]. The moisture content greatly influences the changes in physical and chemical properties of waste material in course of degradation of organic matter because it affects the microbial activities and aeration. The 5% khat-derived biochar amended compost caused lower loss of moisture from the compost piles, and the highest loss of moisture was for 25% khat-derived biochar amended compost. Studies have found the enhanced moisture storage capacity in biochar amended soils even if no direct evidence supported the claim that biochar addition can increase the moisture storage capacity of compost piles [18].

Khat-derived biochar increased the organic matter and the total carbon of composting (Table 3). The organic matter and total organic carbon contents of the different composts ranged from 30.77% to 40.27% and 16.76% to 21.45%, respectively. The organic matter content of initial organic municipal feedstocks mix was 58.22%. The loss of organic matter from biomass during composting was mainly as CO_2 , CH_4 , NO_x , N_2O , NH_3 , SO_x , and H_2S . The loss in organic matter content was in the order of 47%, 43%, 37%, and 30% for 25% khat-derived biochar amended compost, control compost, 15% khat-derived biochar amended composts, and 5% khat-derived biochar amended composts, respectively. The organic matter loss was greater in compost without khat-derived biochar than 5% and 15% khat-derived biochar amended composts but, lower than 25% khat-derived biochar amended compost. This is because, biochar is characterized by stable carbon, and the composting mixture prepared with biochar underwent an organic matter degradation with lower loss. However, the loss of organic matter during decomposition was optimum for the khat-derived biochar rates from 5% to 15% (w/w). The result was agreed with the investigation by [13] in which the organic matter loss for composting of biochar with poultry manure was 30%. According to [45], the degradation of organic matter was between 19% and 39% within 133 days. The total organic carbon content was also changed among the compost treatments in similar fashion with the observation for organic matter. The organic matter was lost during composting as CO_2 , CH_4 , and CO , and the initial total organic carbon was reduced in the compost piles. However, the rate of loss of organic carbon was highest for the compost without biochar amendment than with biochar. This is because the biodegradation process during composting derives carbon to the compost piles from the khat-derived biochar and also mixing biochar with compost can accelerate this process and reduce nutrient losses [17]. According to [26], the addition of biochar in combination with barley straw to hen manure reduced total GHG emissions (as CO_2 equivalents) by 27–32% compared with barley straw addition alone.

The C:N ratio of the composts and the organic fraction of municipal solid wastes under studied are given in Table 3. The C:N ratio ranged from 11.26:1 to 17.33:1 for the different co-compost khat-derived biochar types. Jindo et al. [46] found that the C:N ratio of biochar amended poultry manure compost was about 21.7, which is greater than our observations. Khan et al. [43] also found that the C:N ratio of final compost containing chicken manure and sawdust mixed with biochar at rates of 5% and 10%, respectively, ranged from 31.5:1 to 35.7:1, which was much higher than our observations. The findings of this study are in agreement with the results by [47], which support that the application of biochar increased the C:N ratio. The C:N ratio is a traditional parameter, which has been used to evaluate the compost maturity and stability [48]. Previous studies showed that the optimum C:N ratio of the final compost should be reduced to between 10:1 and 15:1 as an indicator of better quality of compost [49]. Microorganisms require C, N, phosphorus (P), and potassium (K) as the primary nutrients. The C:N ratio is particular importance, which influences the composting process, microbial community, and also the composition and quality of the end product. During the composting experiment, we used dry leaves and grass clippings as sources of carbon and cabbage, avocado, banana and coffee ground wastes as nitrogen sources. The initial organic waste mix C:N was 17.42:1, which was satisfactory. The initial C:N ratio between 15 and 30 will consistently bring about good composting results [49].

The concentrations of total nitrogen (N) for the municipal organic waste mixture and the different composts are showed in Table 4. The total N content (%) ranged from 0.97 to 1.68 for the composts and 1.81 for the initial organic municipal waste mixture. The result showed that the optimum khat-derived biochar amended compost (5% *w/w*) had the highest contents of N than the control compost. The nitrogen loss was about 8.2% for 5% khat-derived biochar amended compost and 24.3% for compost without biochar. The results indicated that during composting process, the nitrogen loss was 16.1% higher for compost without biochar than with optimum khat-derived biochar rate (5%) amended compost. The results also showed that above the optimum rate of khat-derived biochar, the loss in N was the highest during composting. Lopez-Cano et al. [50] also found that the incorporation of a small amount of biochar (4%) into composting of olive mill waste reduced the total nitrogen loss by 15%. About 3% of the initial N amount was lost in municipal solid waste compost with 10% (*v/v*) biochar addition compared with 22% of initial N amount loss in the control [14]. According to [15], the loss of nitrogen during composting is primarily regulated by the initial C/N ratio with the optimal values from 20:1 to 30:1. The findings of different studies showed that the rate of loss of nitrogen during composting of different organic waste varies and can constitute even more than 70% [15]. During composting N is mainly lost as ammonia (NH₃) [51]. From the study, we observed high content of nitrogen in the studied composts. This is because the volatilization of NH₃ is reduced at lower environmental temperature in which the composting experiment was performed at lower room temperature (23 °C). Vandecasteele et al. [14] also indicated that the higher ammonium adsorption was found in the case of the feedstock mixture amended with biochar. Another mechanism of biochar during composting is elevating the C:N ratio that causes the threat of nitrogen immobilization [52].

Table 4. The concentrations of macronutrients in the initial organic waste mix and different types of co-composted khat-derived biochar. Results are expressed as mean values \pm SD, n = 3.

Parameters	Units	Treatments				
		Initial Organic Waste Mix	Control Compost	5% Co-Composted Biochar	15% Co-Composted Biochar	25% Co-Composted Biochar
N	%	1.81 \pm 0.03 a	1.37 \pm 0.03 b	1.68 \pm 0.10 c	1.54 \pm 0.02 d	0.97 \pm 0.05 e
P	%	0.26 \pm 0.09 a	0.58 \pm 0.04 b	0.76 \pm 0.10 c	0.64 \pm 0.06 d	0.62 \pm 0.20 e
K	%	7.49 \pm 0.15 a	12.7 \pm 0.15 b	13.6 \pm 0.02 c	14.7 \pm 0.11 d	15.3 \pm 0.20 e
Ca	g/kg	8.91 \pm 0.05 a	9.65 \pm 0.03 b	9.91 \pm 0.08 c	9.56 \pm 0.05 d	9.42 \pm 0.02 e
Mg	g/kg	2.54 \pm 0.02 a	2.77 \pm 0.15 b	2.86 \pm 0.4 c	2.99 \pm 0.50 d	3.21 \pm 0.15 e

Tukey HSD ($p < 0.05$; means within a row followed by different letters are significantly different).

The concentrations of available phosphorous (P) and potassium (K) among the composts with and without khat-derived biochar amendments and the initial organic waste mixtures are illustrated in Table 4. The values of available P ranged from 0.58% to 0.76% for the under studied composts and 0.26% for the initial organic municipal feedstocks mixture. From the study, we observed that the initial available phosphorous content was increased significantly ($p < 0.05$) for all treatments during composting. The improvement of phosphate content in compost with biochar was mostly due to high phosphorus (P) reserves in the biochar added [27] and mineralization and microbial utilization of organic P compounds [14]. As showed in Table 4, khat-derived biochar also increased the available P during composting, and the maximum P was recorded for 5% khat-derived biochar amended compost. The optimum khat-derived biochar rate (5%) increased the available P by 69.2% more than the control compost (compost without khat-derived biochar). All the composts had enough contents of P and proved to be important sources of available P, and the contents were above the requirements (10–15 mg/kg P) for most crops range [53]. Kidder et al. [54] suggested that the amount above 57 mg/kg of P is risky, and it causes pollution of surface water.

The concentration of K (%) were 12.72, 13.61, 14.70, and 15.29 for control and 5%, 15%, and 25% khat-derived biochar amended composts, respectively. The concentration of K for the initial organic waste mix was 7.49%. As showed in Table 4, the concentrations of K increased significantly ($p < 0.05$) in all types of composts relative to the initial organic waste mixture. Addition of khat straw-derived biochar increased the concentration of K compared to the control (no biochar). Literature showed that the quantitative changes of all nutrient contents in the end composting product depends on the quality of the feedstocks and input materials. So, the improvement in K concentration is a result of additional K from the khat-derived biochar, which has high content of available K (Table 2). Many of potassium compounds are water soluble, and during composting, the biodegradation of compost piles leaches soluble K to the porous of khat-derived biochar. Both composts with and without khat-derived biochar are considered to be suitable for agricultural application, which have enough contents of K, and are above the requirements of low K soil (20–35 mg/kg) for most crops range [53].

The contents of calcium (Ca) and magnesium (Mg) for the different composts ranged from 9.42 to 9.91 and 2.77 to 3.21 g/kg, respectively, and the values in the initial organic waste mix were 8.91 and 2.54 g/kg, respectively (Table 4). The results showed that the concentration of Ca and Mg was increased significantly ($p < 0.05$) in khat-derived biochar amended composts than the initial organic waste mix and control. This increase is a result of the adsorption of the basic cations on the organic negative charges (COO^-) of biochar. This result agreed with the findings by [54], in which biochar increased the availability of exchangeable base cations (Ca^{+2} , Mg^{+2} , and K^+) than without biochar. Meller et al. [55] found that the contents of Ca and Mg in municipal solid waste compost were 2.94 and 71.26 g/kg, respectively. Thus, the concentration of Ca by far less than and concentration of Mg was similar with this finding.

Ca and Mg are essential macronutrients of plants next to N, P, and K. These nutrients may be removed from soil by different mechanism such as leaching and removed by plants. Soil is acidic as a result of removal of basic cations (Ca^{2+} , Mg^{2+} and K^+) from the soil solution mainly as a result of leaching. The application the understudied compost, co-composted biochars and biochar to infertile and acidic soil is a greater opportunity in terms of solving the current worldwide soil acidity and infertility problems in which inorganic fertilizers could not do. This is because of the understudied organic fertilizers have enough contents of K, Ca and Mg, for example concentration of Mg higher in these organic fertilizers than the lower limit of Mg is soil, i.e., <15 mg/kg [53].

The concentrations of iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), and chromium (Cr) for the under investigated composts ranged from 7.22 to 14.27, 3.69 to 7.41, 0.14 to 0.22, 0.96 to 1.10, 0.11 to 0.17, and 0.15 to 0.29 mg/kg, respectively, whereas cadmium (Cd) concentration was negligible (Table 5). The low levels of heavy metals in all the under studied composts were due to lower portion of e-waste in the municipal solid waste in Jimma city. The concentrations of the heavy metals were by far lower than the results found by [56]. According to literature, the effect of biochar during composting

is reducing the heavy metal contents in the compost pile [57]. Ho et al. [58] also found that heavy metals in the initial biosolids were converted from labile fractions into relatively immobile phases upon maturation of compost. During composting, the initial concentrations of Pb, Cr, Fe, Mn, and Cu in the organic waste mix were reduced, whereas the concentration of Zn in the initial organic waste mix was increased for all the compost treatments. The results also indicated that the khat-derived biochar amended compost had the greater capacity for reducing the contents of Pb, Cr, Fe, Cu, and Mn than the controlled compost. This means the sorption strength of Fe, Mn, and Cu on khat-derived biochar is higher than Zn. The maximum adsorption capacities (mg/g) of metals by sesame straw biochar were in the order of Pb (102) > Cd (86) > Cr (65) > Cu (55) > Zn (34) in the monometal adsorption isotherm and Pb (88) > Cu (40) > Cr (21) > Zn (7) > Cd (5) in the multimetal adsorption isotherm [59]. In the presence of different heavy metal ions (Pb^{2+} , Cd^{2+} , Cu^{2+} , Zn^{2+} , and Ni^{2+}), Pb^{2+} and Cu^{2+} showed preferential adsorption on the surface of biochar [60]. According to the study by [61], the removal percentages (%) of heavy metals (Fe, Mn, Cr, Cu, Zn, Ni, and Pb) from sludge compost by artificial zeolite significantly reduced Cr (43.7%), Mn (35.8%), and Fe (29.9%), which are higher than Zn. However, there is lack of data on the sorption strength of Fe and Mn on the surface of compost and biochar pores. Yang et al. [62] found that the Zn sorption rate decreased as the compost ratio increased in amendment mixtures. So, the concentration of Zn decreased with decreasing the portion of organic mix from 5% to 25% khat-derived biochar amended composts. The reduction in the contents of the heavy metals in the under investigated composts was similar with the findings by [57].

Table 5. The concentrations of trace metallic elements in the initial organic waste mix and different types of co-composted khat-derived biochar. Results are expressed as mean values \pm SD, $n = 3$.

Parameters	Units	Treatments				
		Initial Organic Waste Mix	Control Compost	5% Co-Composted Biochar	15% Co-Composted Biochar	25% Co-Composted Biochar
Fe	mg/kg	17.03 \pm 0.04 a	14.27 \pm 0.02 b	7.22 \pm 0.03 c	9.02 \pm 0.11 d	12.61 \pm 0.04 e
Mn	mg/kg	10.05 \pm 0.09 a	3.69 \pm 0.03 b	6.88 \pm 0.03 c	7.01 \pm 0.16 c	7.41 \pm 0.02 e
Cu	mg/kg	0.28 \pm 0.00 a	0.22 \pm 0.00 b	0.14 \pm 0.00 c	0.17 \pm 0.01 d	0.18 \pm 0.00 e
Zn	mg/kg	0.88 \pm 0.02 a	0.97 \pm 0.02 b	1.10 \pm 0.2 c	0.98 \pm 0.01 b	0.96 \pm 0.00 b
Pb	mg/kg	0.17 \pm 0.02 a	0.14 \pm 0.01 b	0.13 \pm 0.01 bc	0.15 \pm 0.01 bd	0.11 \pm 0.00 e
Cd	mg/kg	—	—	—	—	—
Cr	mg/kg	0.29 \pm 0.02 a	0.28 \pm 0.01 a	0.22 \pm 0.02 c	0.21 \pm 0.02 c	0.15 \pm 0.01 e

Tukey HSD ($p < 0.05$; means within a row followed by different letters are significantly different).

Generally, the organic matter in the compost is able to adsorb heavy metals and reduce their solubility resulting in immobilization [63]. This effect is enhanced by application of biochar during composting. Previous study has showed that in biochar, having small and low-volume pores, surface area availability is high for the adsorption or chemical reactions to take place [64]. The weakly alkaline media of the biochar also reduce the solubility and facilitate immobilization and accumulation of these metals. So, the decrease in heavy metal content has been associated to accumulation and immobilization of mobile metal fractions in the pores of biochar and organic matters of compost pile.

There is a requirement for limits on the contents of heavy metals to ensure that compost is safe to use for agriculture. High contents of heavy metals in municipal solid waste compost affect soil microbes. Heavy metals are plant nutrients at trace level but, they are toxic when they are accumulated. All the heavy metals are within the quality control limit of the fertilizer order by [65].

Although essential heavy metals are required with trace level by plants, recently studies showed that the application of trace essential elements such as zinc-based fertilizer increases the productivity of crops. So, to incorporate compost for the correction of trace metal deficiency in soils, it can be concluded that the compost under investigation can be valuably applied in Zn deficient soils, as the concentrations of other heavy metals (Pb, Cr, Fe, Mn, and Cu) were found to be lower than the permissible levels.

4. Conclusions and Recommendation

The initial organic waste mix nutrient increased significantly due to the addition of khat-derived biochar during composting than without biochar. This is due to khat derived biochar optimized the mineralization and adsorbs nutrients from the organic waste mix. In addition high preserves of nutrients in khat-derived biochar also increased important nutrient in the co-composted biochar piles. In our study we concluded that the 5% and 15% (*w/w*) khat derived biochar rates were the optimum rates which increased significantly the total N, total organic carbon, P, K, Ca, Mg, CEC, pH and Zn compared to the control compost (no biochar). So, it is recommended to apply khat-derived biochar with rates of 5–15% during composting of organic fractions of municipal solid waste. The findings from this experimental study showed that co-composting of khat-derived biochar and organic fractions of municipal solid waste could be the suitable and sustainable practice to improve waste management in municipalities of Ethiopia through production of enough quality biofertilizer. Although, khat derived biochar and khat-derived co-composted biochar from municipal solid waste sources preserve enough contents of plant nutrients, field experiment test and health risk assessment are essential before for large scale applications.

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