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ORIGINAL RESEARCH

Composting of grease trap scum waste and green waste: Studying the effects of mix composition on physicochemical and biological process parameters

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Abstract

Purpose A huge number of sewer blockages are caused due to scum depositions. The scum waste from the kitchen wastewater can be converted into a resource by composting it. This study investigates the degradation of Grease scum or Fats, oils, and grease (FOG) waste from grease trap with Vegetable waste (VW) and Grass clipping waste (GW) by passive aerobic bin composting for 55 days by evaluating variations in some of their physicochemical and biological process parameters.

Method Five 80 L vertical composters were designed with a provision for leachate collection. Five mixes with varying FOG concentrations of 0%, 4%, 8%, 12%, and 16% with the rest of the mix containing VW and GW in 85:15 proportion in each bin was studied. Temperature, pH, EC, Moisture content (MC), Total volatile solids (TVS), Total Organic Carbon (TOC), Lipid content, and CO_2 Evolution rate were monitored during the composting period.

Results All the composting mixes maintained temperatures above 40˚C for 6-9 days and were found to be stable, with their final CO_2 evolution rates in the range of 1.0 to 3.47 mg CO_2-C/g VS/d at the end of composting. Mix 4 recorded maximum moisture, organic matter, and carbon content reduction with low CO_2 evolution rate and so is the optimum mix containing FOG waste of 12%, VW of 74.8%, and GW of 13.2%.

Conclusion Results in this study indicated that the grease scum waste can be significantly degraded when composted with suitable materials, but could require durations longer than this study period.

Keywords Bin composting, Grease trap waste, Grass clippings, Passive aeration, Solid waste, Vegetable waste

Introduction

Indians spend around 8% to 10% of their total food expenditure outside their homes in foodservice establishments like cafeterias, restaurants, etc. The wastewater generated from these establishments contains high organic content along with FOG concentrations (Klaucans and Sams 2018). Studies in 2015 showed increasing levels of FOG production of around 50 kg/year/citizen in developing countries and 20 kg/year/citizen in non-developing countries (Klaucans and Sams 2018). When the FOG-loaded wastewater enters the environment it can increase BOD levels which can rob dissolved oxygen from the surface waters, leading to fish death and eutrophication. FOGs generally tend to solidify and cause great

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problems by clogging the sewerage pipeline systems and pumps in wastewater treatment plants, leading to high operation and maintenance costs. Every year around 50 to 75% of sanitary sewer overflows are caused just by FOG depositions in the UK with the water utilities spending about £15- £50 million annually to remove FOG deposits and ensure sewer networks remain operational (Wallace et al. 2017).

The basic treatment for the wastewater released from these food processing units is that, before it is discharged into the public sewerage system they are allowed to pass through a grease trap that separates the floatable and settle-able materials. They are usually box-shaped civil works installed either outside or inside the kitchen, within the drainage line between the sinks of the kitchen and the sewer system to separate the solids and scum from the wastewater. The grease scum which has very low density raises to the surface and the food solids being heavier sink to the bottom of the trap while only allowing the wastewater to run down the sewerage system. Hence the grease trap waste typically consists of grease scum, kitchen wastewater, and food solids. The food solids separated can either be anaerobically digested or composted whereas the grease scum is comparatively highly resistant to anaerobic digestion, though it could be digested at very low concentrations. The grease scum is generally scraped off and sent for landfilling or just dumped aside of the grease trap leading to environmental nuisance and a resource loss. Direct spray application of grease trap waste on the fields where the crops or the vegetation are being grown can cause several negative effects like poor gas exchange of the above-ground portions of the plant. If roots are not coated as well, the plants might recover but the yields get largely reduced. Also, spray application of grease scum could clog soil pores. Therefore, it is to be managed properly for resource or energy recovery. FOG, the lipid-rich substance, has energy values higher than carbohydrates and proteins, making them ideal for energy recovery. Fundamentally FOG is triglycerides which contain a unit of sugar alcohol called glycerol ($C_3H_8O_3$) and three units of free fatty acids (FFA). The typical fatty acids found are lauric acid, myristic acid, palmitic acid, stearic acid, oleic acid, linoleic acid, and linolenic acid.

The production of a natural fertilizer/ compost using FOG as a substrate is found to be rarely studied. Composting FOG waste with an appropriate mix of other wastes and maintaining the optimum C/N ratio required for composting could result in effective thermophilic conditions since FOG waste is energy (lipid) rich. Their high energy levels promote higher temperatures which result in higher degradation rates and destruction of pathogens during composting. Aside composting FOG, biodiesel produced from it, is generating interest as an energy alternative, with energy independence being the main driver (Mizik and Gyarmati 2021). India is the second-largest producer of fruits and vegetables in the world with about 20-40% post-harvest losses (Maiti et al. 2018) which add up to the organic fraction of municipal solid waste (MSW).The MSW contains about 40-60% organic materials, 30-40% ash and fine earth, 3-6% of paper, plastic, glass and metal materials (Sharholy et al. 2008). Management of the MSW in India is becoming more complicated and expensive due to the lack of required infrastructure, improper maintenance of the system and huge manpower requirements. Unscientifically and illegally dumping of the wastes leads to more emissions of greenhouse gases and also leachate production. The leachate generated from these wastes contaminates groundwater which consequently affects human health and the environment. Compared to incineration and landfilling, composting can reduce the associated environmental impact on climate change by 40 to 70% (Antón et al. 2005). In a tropical country like India, decentralized composting systems have been anticipated to be the best accessible practice, with a significant positive impact on MSW management plans. Since India is largely dependent on agriculture as its main economy, the composting of organic solid waste is a bonus that would lead to a significant reduction of the volume of waste to be handled and disposed of. This practice fits in perfectly for such a densely and highly populated country with scarcity of suitable free lands for landfills development. This study therefore aims to contribute towards identifying the best combination of FOG waste with vegetable waste (VW) and grass waste (GW) to produce quality compost under optimum composting conditions in a bin composter system. Composting is a waste management method, where a variety of complex physical, chemical and biological processes takes place i.e. soil animals, microorganisms and enzymes mineralize biodegradable waste transforming it to biogenic elements (of C, N, O, etc.). During composting, the microorganisms consume oxygen while feeding on organic matter and release by-products such as CO_2, water, and heat (Bhatia et al. 2012). Around 50% of the initial organic matter becomes fully mineralized, mostly due to the degradation of easily degradable compounds like proteins, cellulose, and hemicellulose (Sudharsan Varma and Kalamdhad 2014).

In this research work, an in-vessel vertical bioreactor is designed as mentioned by Rawoteea et al. (2017), with further modifications to the design as mentioned in Karnchanawong and Suriyanon (2011) for better results.

Materials and methods

Study area and scope details

This study is carried out in National Institute of Technology Warangal (NITW) campus which is located in Warangal, Telangana state, India at the coordinates 17.9835˚N, 79.5308˚E.

FOG waste is rich in carbon content, so nitrogen-rich materials are to be added, to attain an optimum C/N ratio of 30:1 (as recommended for better microbial degradation; carbon provides energy for the microbes and the nitrogen provides proteins) for composting to take place. Vegetable and grass waste are the nitrogen-rich wastes generated in large quantities on daily basis within the campus, hence were used in proper portions for composting of FOG waste, in this study.

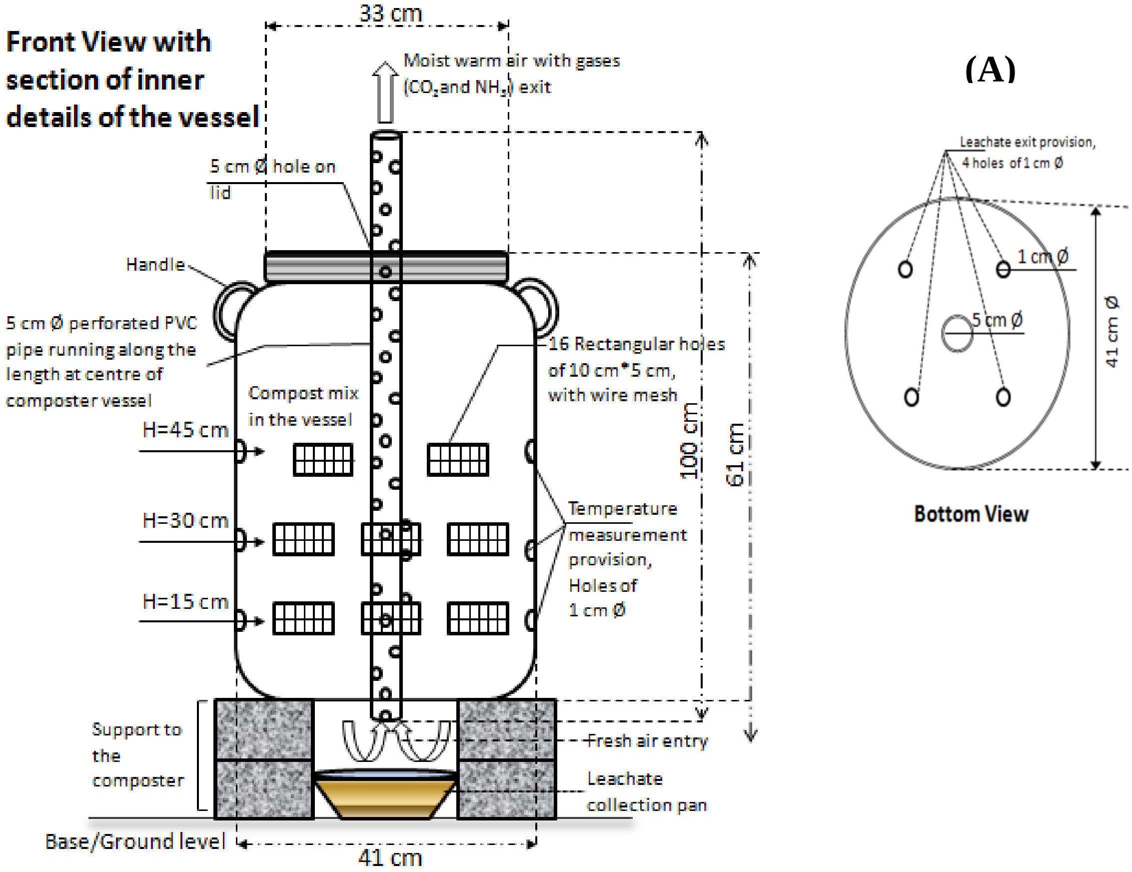
GW was collected from multiple garden and lawn areas, VW was collected from the hostel messes/ canteens, and the FOG waste was collected from the grease traps installed outside the mess buildings in the campus. About 70 to 100 kg of Vegetable waste (Carrot, cauliflower, cabbage, onions, tomatoes, chilies, etc.) and 10 to 20 kg of Grass waste was generated in the campus on daily basis. Since an average of 85 kg VW and 15 kg GW was generated, a mixed proportion of 85 (VW): 15 (GW) was maintained in the bins. They were manually chopped to a size of 5-10 cm and then pulverized to the size of 10–30 mm using a mini pulveriser. For initial compositional analysis, a known amount of this pulverized material was used while the remaining was taken for composting experiments.

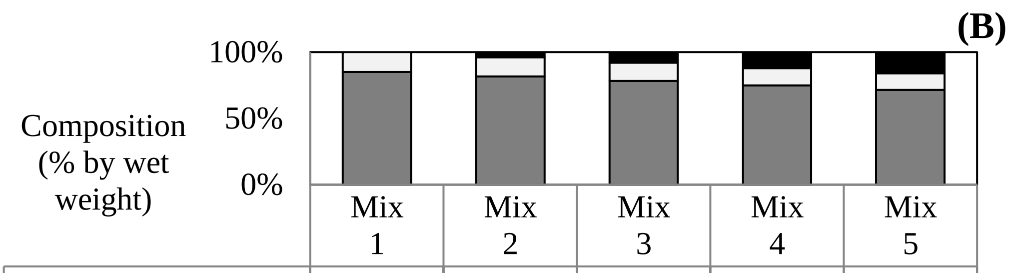
The whole setup was placed in a shed facility within the campus, far away from the hostels and other utility areas. The facility was spacious enough to provide good sunlight and aeration and the bins were free from rainfall and other disturbances.

Design of composting bin/ vessel

Five 80 L Medium density polyethylene bins were designed to be used as cylindrical vertical composters (Fig. 1A). A total of 16 rectangular holes each of 10 cm*5 cm were made on the bin surface along its circumference for optimum aeration. Metal wires mesh was loosely wrapped around the bin surface to secure the waste material in each bin. A 5 cm diameter perforated PVC pipe of 1 m long was allowed to pass along the height of the bin. This pipe was perforated with 3 mm holes at 1 cm c/c on its surface along its length, which allowed optimum passive aeration i.e. to allow the air to pass through the compost inside the bin and to expel hot air from the bin, as a result, to maintain aerobic conditions within the composter.

Nine-1cm holes were made on the bin surface at heights of 15 cm (bottom-P1), 30 cm (middle-P2), and 45 cm (top-P3) measured from the bottom for recording temperature in the bin periodically using a probe food thermometer. Four 1 cm diameter perforations were made at the bottom of each bin to allow leachate generated to get collected in the leachate collection pan provided. Rectangular concrete blocks were provided to support the bin and to place them in a position about 20 cm above ground level, allowing leachate collection and also preventing any other means of contamination or disturbances to the system.





	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
■ FOG	0.0%	4.0%	8.0%	12.0%	16.0%
□ Grass clipping waste	15.0%	14.4%	13.8%	13.2%	12.6%
■ Veg waste	85.0%	81.6%	78.2%	74.8%	71.4%

Fig. 1 (A) Schematic diagram of the compost bin (B) Composition of mixes (% by wet weight)

Preparation of substrates

Initial physicochemical characteristics of raw materials were calculated prior to starting the composting setup (Table 1). The moisture content (MC) of FOG waste was 40.76%, while VW and GW had 91.59% and 68.58% respectively, have comparatively higher moisture. The total organic carbon (TOC) of FOG waste was very high compared to the TOC of VW.

Table 1 Physicochemical Characteristics of composting raw materials

Parameters	Vegetable waste	Grass clippings	Grease scum
MC (%)	91.59 ± 0.89	68.58 ± 1.75	40.76 ± 2.06
pH	5.67 ± 0.247	7.78 ± 0.015	4.93 ± 0.025
EC (µS/cm)	1538 ± 5.31	1888 ± 0.58	107 ± 26.89
TOC (%)	16.72 ± 2.53	76.97 ± 1.95	99.14 ± 0.11
TVS (%)	87.03 ± 0.1	86.27 ± 1.36	98.86 ± 0.72
Lipid content (%)	-	-	92.29 ± 6.23

(Note: Mean ± Standard deviation, n=3)

In this study, a total of five composting bins were set up. Mix composition details were graphically shown in Fig. 1B. Each bin was filled with a total of 15 kg of waste. In Bin 1, 85% of VW and 15% of GW was taken. In the Bins 2, 3, 4, 5, the FOG waste accounted 4%, 8%, 12%, 16% while remaining 96%, 92%, 88%, 84% of waste was VW and GW in (85:15) proportion respectively. The FOG waste was added to the VW and GW, in such a way that the C/N ratio of all the mixes was in the range of 20-30. As seen in Table 2, the C/N ratio of the five mixes was found to be 20.76, 22.07, 24.91, 29.35, and 29.654 respectively, which were well within this optimum range required to support better-composting conditions.

Table 2 Physicochemical Characteristics of preliminary Composting feedstock mixes

Parameters	Mix 1 (0:85:15)	Mix 2 (4:81.6:14.4)	Mix 3 (8:78.2:13.8)	Mix 4 (12:74.8:13.2)	Mix 5 (16:71.4:12.6)
MC (%)	85.13± 0.3	79.22 ± 2.21	79.58 ±0.47	78.99 ± 0.59	78.8 ±1.68
TVS (%)	85.92 ± 1.5	87.84 ± 0.2	87.97 ± 0.5	88.35 ± 0.42	91.56 ± 0.12
pH	8.6 ± 0.02	7.7 ± 0.06	8.33 ± 0.01	7.1 ± 0.05	6.9 ± 0.06
EC (dS/m)	1.66 ± 0	1.61 ± 0	1.79 ± 0.01	1.53 ± 0.02	1.07 ± 0.01
TOC (%)	31.4	31.64	33.62	41.42	43.01
TKN (%)	1.512	1.434	1.349	1.411	1.450
C/N	20.767	22.070	24.911	29.351	29.654

(Note: Mean ± Standard deviation, n=3)

Turning and mixing of waste

Turning frequencies play a key role in deciding the compost quality. Proper mixing of waste ensures equal exposure of air to all the organic matter within the bin as much as of the ones at the surface and is the simplest form of aeration. This activity releases heat, water vapor, and other gases from the system and also helps the microorganisms to readily feed on the organic matter for bioconversion (Paul et al. 2019). It helps in restoring the gaps formed during decomposition and enhances the composting process, reducing GHG emissions and nutrient loss (Nguyen et al. 2020). An L-shaped stick was used in this study to turn the waste mix once a week in the first three weeks of composting and in the later weeks; no turning was carried out to prevent the loss of heat required for faster degradation.

Sampling and laboratory analysis

Sampling was carried out once every 4 days, taking representative samples from 9 different points from the bottom, middle, and top of the compost mix which were thoroughly mixed to ensure a homogenized sample. About 250 grams of the sample was collected. It was immediately dried and ground to pass through a 0.2 mm sieve and stored for physicochemical analysis. The wet sub-samples were stored at 4°C for biological analysis and were used within 2 days. All samples were stored in airtight sampling bags.

The parameters monitored during this study were Temperature, pH, EC, Moisture content, Total volatile solids content, Total Organic Carbon, Lipid content, and CO_2 Evolution rate. The temperature was measured on a daily basis with a probe food digital thermometer (ACETEQ Multi-probe thermometer). The readings taken were at three locations in each of these three levels,, bottom, middle, and top sections of the bin through the temperature holes. The pH and EC of samples were measured in the aqueous extracts (1:10) obtained after stirring for 2 hrs and then filtering it, analyzed using a calibrated digital pH meter and digital Electrical conductivity meter respectively. The Moisture content was determined by oven-drying the samples in a hot air oven at 105℃ for 24 hours. The oven-dried samples were heated in a muffle furnace at 550℃ for 2 hrs and volatile content was measured. The total organic carbon content of the compost was estimated by Walkley Black chromic acid wet oxidation method (Nelson and Sommers 1983). The compost aqueous extract (1:100) was obtained by shaking the compost mix solution on a horizontal shaker for 3 hrs and filtered and then was analyzed for Ammonia nitrogen and Nitrate nitrogen by the Phenate method and Ultraviolet Spectro - photometric screening method respectively (Eaton et al. 2005).

For quantitative determination of Lipid content, chloroform and methanol extraction of lipid extraction by Bligh and Dyer method was used. After extracting the chloroform layer, it was poured into the weighting bottle heated to constant weight, i.e. dried and weighted. The lipid content was calculated by mass difference (Bligh and Dyer 1959; Phillips et al. 1997). The CO_2 Evolution was monitored through the Jar test. A fresh compost sample of 25 g was placed in a jar and 25 ml of 1M NaOH was pipetted into a small beaker. This beaker was then placed in the jar carefully. Following a 24 h of incubation, this NaOH was titrated with 1M HCl using phenolphthalein indicator. The quantity of carbon dioxide evolved represents the action of microbes in the pile during the experiment, and therefore assesses the stability of the compost sample, the respiration test was performed (Francou et al. 2008). The leachate collected from each bin was transferred back into the bins to primarily prevent the loss of nutrients from the system.

Statistical analysis

All the experimental analyses were carried out in triplicates except TOC and the mean values with standard deviation were presented. The data obtained in this study were analyzed using two-way ANOVA (Analysis of Variance) at a 95% confidence limit, with compositional mix ratio (treatment) and composting time as the factors. For statistical analysis, Microsoft Office Excel 2007 was used.

Results and discussion

Temperature variation

Fig. 2 and Fig. 3 illustrate the temperature variations at three levels in the five mixes. The temperatures were monitored from the day of the setting up of the bins for up to 55 days. The waste addition was carried out for 5 days. The initial temperature was around 30˚C while the ambient temperature was 28.5˚C showing the start of the activity. The temperatures were found to be continuously increasing in all the mixes. Heat generated as the microorganisms were breaking down the materials in the compost mixtures. Temperature variations during composting depend on various factors like the initial C/N ratio, method of composting, nature of composting materials, moisture content, and many other important factors (Cesaro et al. 2019). It was observed that the temperatures of mixes considered in this work have followed the typical temperature profiles reported in earlier works of other composting experiments such as, in Chen et al. (2019), Onursal and Ekinci (2015), Huang et al. (2010) and Oviedo-Ocaña et al. (2015).

According to the evolution of Temperature, in the dynamics of composting, four phases exist; they are mesophilic, thermophilic, cooling and maturation phases (Rawoteea et al. 2017). An increase in temperature from 28.5˚C to 30–40˚C during the second day indicated that the system was in the mesophilic stage. During this stage, psychrophilic and mesophilic microorganisms multiply and undergo microbial respiration. They emit a large amount of heat by metabolizing simple organics like sugars, proteins, and lipids. Also, the presence of a high level of the native microbial population in initial raw waste materials leads to a rise in temperature in the beginning stages i.e. within 3-6 days of the composting period. The temperatures reached a peak value of 47.9˚C (5th day), 49.1˚C (5th day), 49.6˚C (6th day), 49.7˚C (5th day), and 47.8˚C (3rd day) in the mix 1, 2, 3, 4, and 5 respectively. The mix 5 attained the peak quicker than the other mixes as it contained higher FOG waste (energy-rich). All the peak values observed were in the bottom layers (P1) of the composting bins (showing higher biological activity), while the next higher was observed in the middle (P2) with considerably further lower temperatures in the top layers (P3). Conversely, it can be assumed that the top surface of the composting mass being in contact with the atmospheric air might have led to heat loss, despite the composter lid. The temperatures stayed in the range of above 40˚C for 6 days in mix 1, 2, and 3 and about 9 days in mix 4 and 7 days in mix 5, majorly in the bottom layer of the composter. A maximum of 49.7˚C was achieved in mix 4, showing utmost organic matter reduction, and temperature was more than 40˚C for about 9 days, which can be considered as an extended thermophilic stage, resulting in more organic matter degradation and pathogen removal. The prolonged thermophilic phase in mix 4 and 5 was due to their high initial C/N ratio (higher FOG waste, i.e. higher energy). The thermophilic bacteria, thermophilic fungi, and actinomycetes grow in number and degrade the slow decomposing and complex organic compounds such as cellulose, hemicelluloses, and lignin (Awasthi et al. 2014; Pandey et al. 2016). It has been reported that temperatures between 52–60˚C during composting represent a high thermophilic activity (Mohee and Mudhoo 2005). It can be understood that, due to the low volume of the waste material, temperatures >50˚C were not observed, but it is likely that these mixtures will ensure an overall sanitation at large scale, since in large composting masses, thermal inertia effect exists.

A sharp decrease in temperatures was observed after 9-10 days in all the mixes due to lower microbial activity, showing that all the easily degradable carbon-containing substrates were exhausted.

The volume of mixes reduced to half of its initial level by the end of the second week. A minor temperature rise may be attributed to the turning of compost mixes as it helps in aerating and homogenizing the mix. Mesophiles slowly take over during the cooling and maturation phases that slowly degrade the organic matter and stable compost is formed (Keng et al. 2020). By the end of 55 days of composting, stabilization (i.e. temperature of the system reached ambient temperature) in all the mixes was achieved in this study.

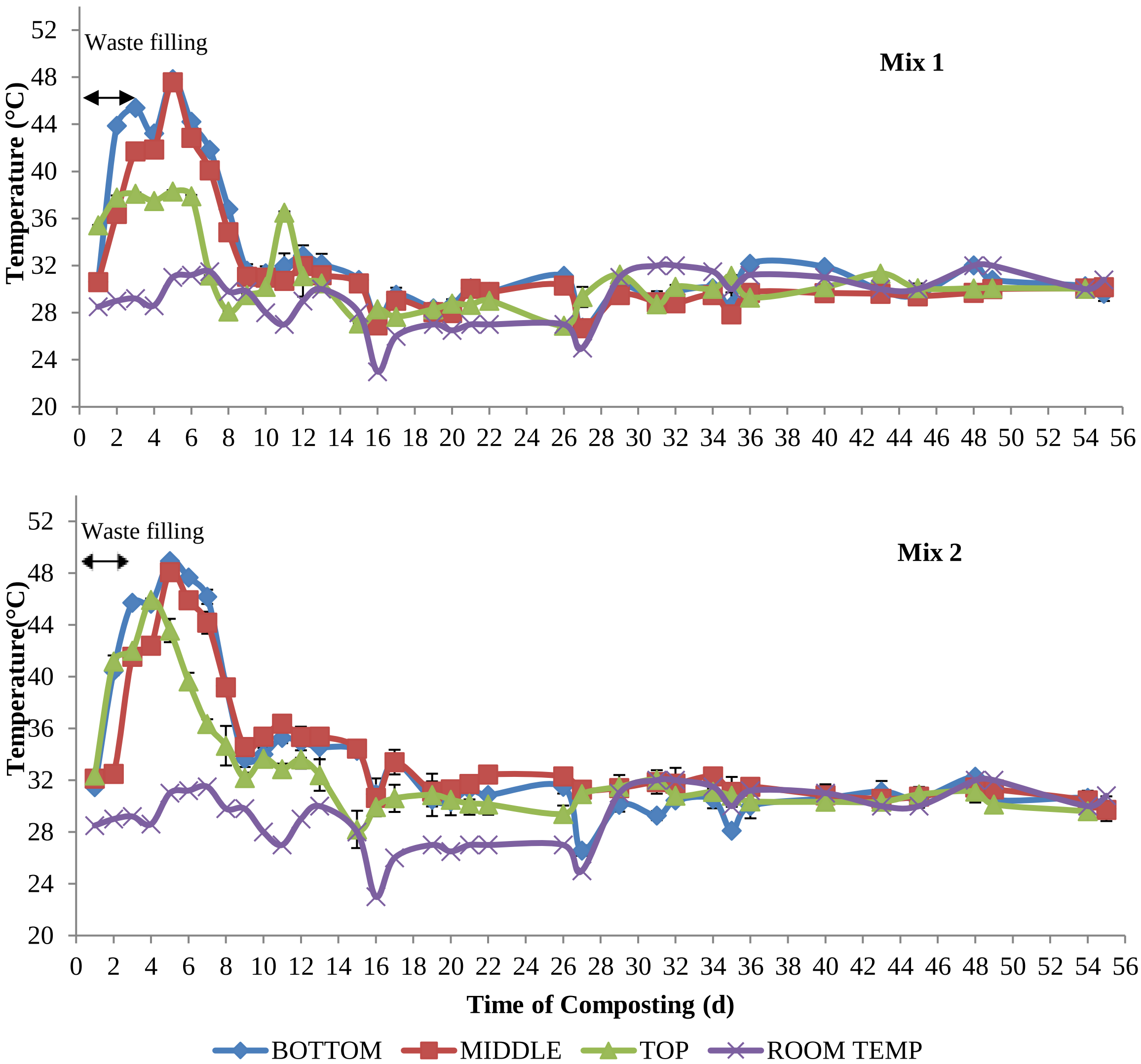


Fig. 2 Temperature profile in the mixes 1 and 2 at different levels during composting period

Moisture content, total volatile solids and leachate production

Moisture content is a major factor to decide the survival of microorganisms in composting systems. As the degradation continues, temperature rise can be found with loss of MC and reduction in TVS. Therefore moisture loss can be seen as an indicator of decomposition rate during the composting process (Kalamdhad and Kazmi 2009). The biological degradation of scum waste is complex due to its characteristics like insolubility in water (hydrophobicity), low water retention and lack of porosity, and hence the microorganisms find difficulty in access and assimilation of scum, hence slower rates of decomposition is generally observed (Aikaite-Stanaitiene et al. 2010).

The initial MC of the feedstock mixes was found to be about 78 to 85% and it reduced to 49 to 65% in all the mixes (Fig. 4A). Similarly, TVS reduced from 85 to

92% to a final 72 to 80% in the mixes by the end of composting (Fig. 4B).

The average MC and TVS content in all five mixes was uneven during the decomposition process. A similar observation was made by Narkhede et al. (2010), which stated that the altering microbial population in the compost mixture could account for this unsteadiness. From Fig. 4C, a significant reduction in MC in bins 3 and 4 of 37.81% and 36.46% was found, and bin 4 achieved a major 17.95% reduction in TVS, during the composting period.

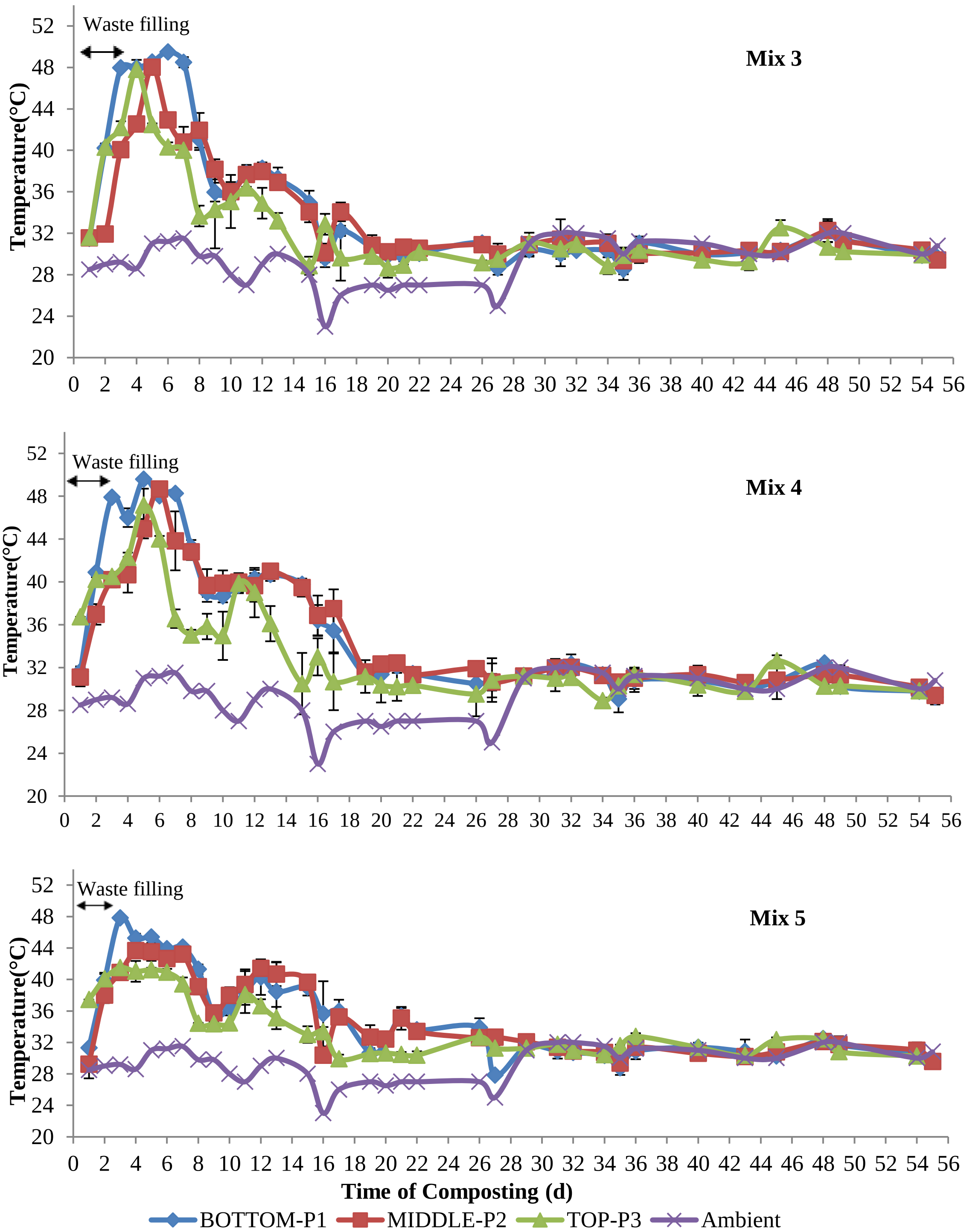


Fig. 3 Temperature profile in the mixes 3, 4 and 5 at different levels during composting period

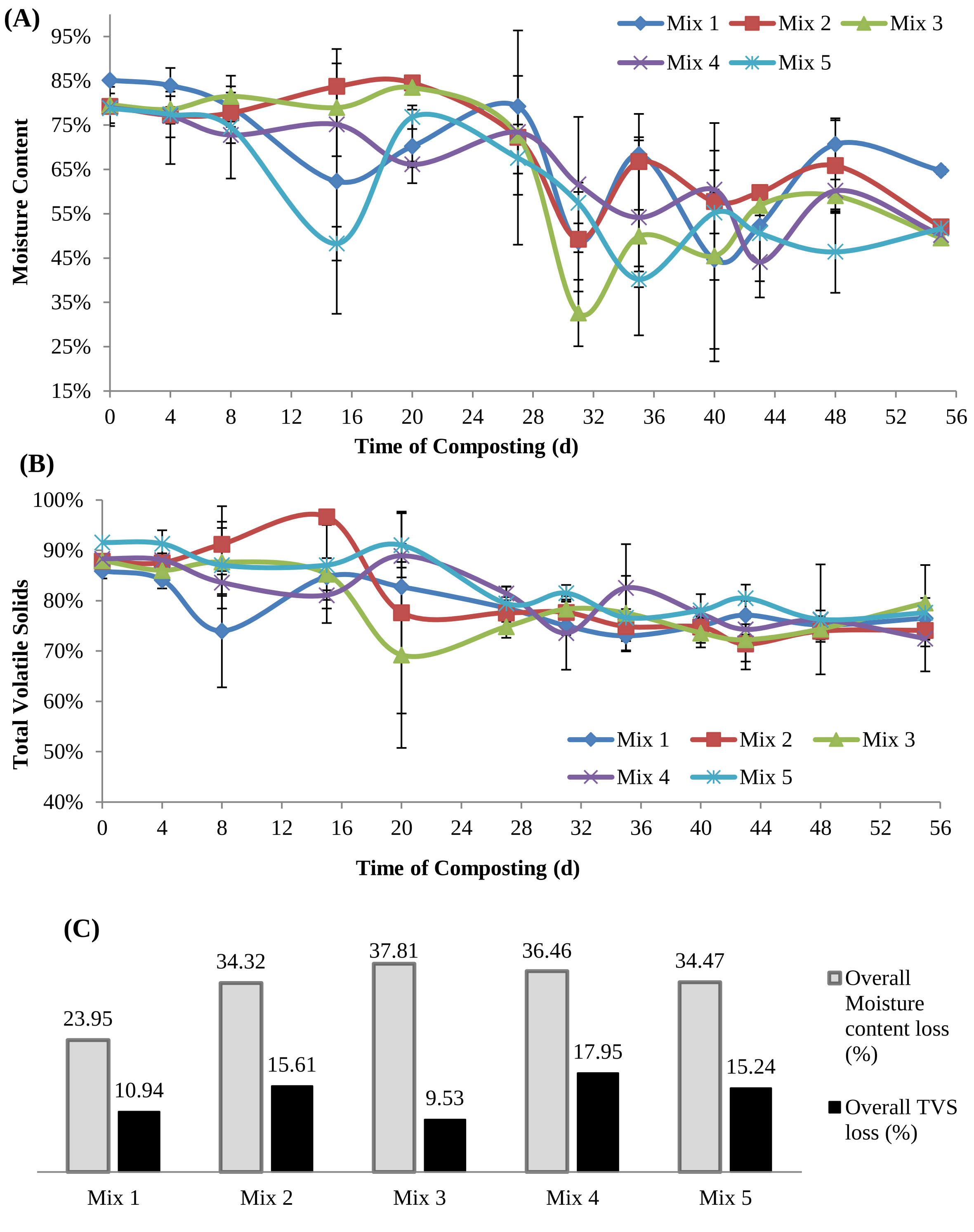


Fig. 4 Variation in (A) Moisture content (B) Volatile solids content (C) Overall reduction in moisture and volatile content during the composting period

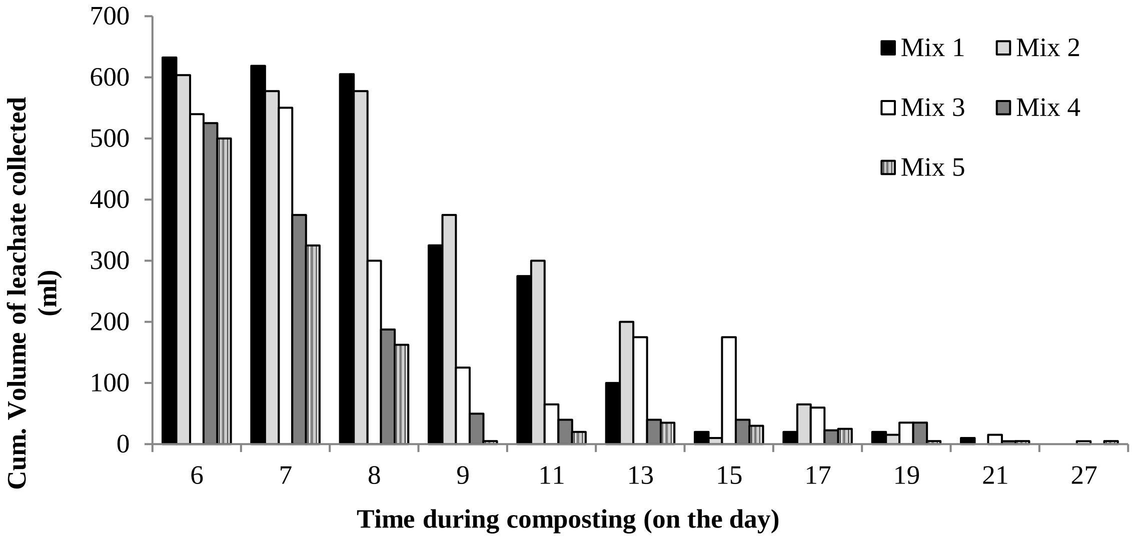


Fig. 5 Cumulative volume of leachate collected during composting

The passive aeration provision lets the air in and out of the bin body and also turning the mix prompted the release of vapors successfully into the environment. Due to the hydrophobic nature of the scum waste which reduces the water holding capacity of the mix, a large quantity of leachate was produced during the thermophilic phase of composting. It was collected in the leachate collection trays placed at the bottom of each bin and added back to prevent the loss of nutrients and to ensure proper MC in the system. A total of 633 ml of leachate was accumulated within the first 6 days of composting from mix 1 while mix 2, 3, 4, and 5 generated 603.75 ml, 540 ml, 525 ml, and 500 ml respectively. It was introduced back into their respective bins as it is collected up to those respective days in the trays, as in Fig.5. Since VW was high in mix 1, it recorded heavy leachate. The GW acted as a bulking agent and prevented heavy loss of moisture as leachate from the bins. After around half of the composting duration that is 27 days; no leachate was found to be further generated from any of the bins. In the early stages, all the compost mixes showed a reduction in the average MC. Yet, a quick decline was observed in mix 1 and 5 during the first 2 weeks followed by a gradual boost to more than 62% and 76% MC respectively. Apart from leachate added to the system, there can be another reason for an increase in MC at certain points; i.e. due to elevated temperatures, the evaporated water gets condensed on the lid and walls of the vessel and subsequently falls back in to mix thus leading to a rise in moisture level since it is a closed system.

pH variations

pH is a vital parameter in controlling the degradation process in composting. The variations in pH in all the five compost mixes were illustrated in Fig. 6.The initial pH levels reduced from mix 1 to 5 indicating an increase in its acidity levels as expected due to the increasing concentrations of FOG (being acidic) accordingly. During the study, the average pH was observed to vary from 8.6, 7.7, 8.33, 7.1, and 6.9 initially to 8.82, 8.8, 8.84, 8.8, and 8.7 finally in Mix 1,2,3,4, and 5 respectively.

These trends showed that all the mixes had higher pH values at the end of composting compared to their initial values. Similar trend was observed in studies by Keng et al. (2020).

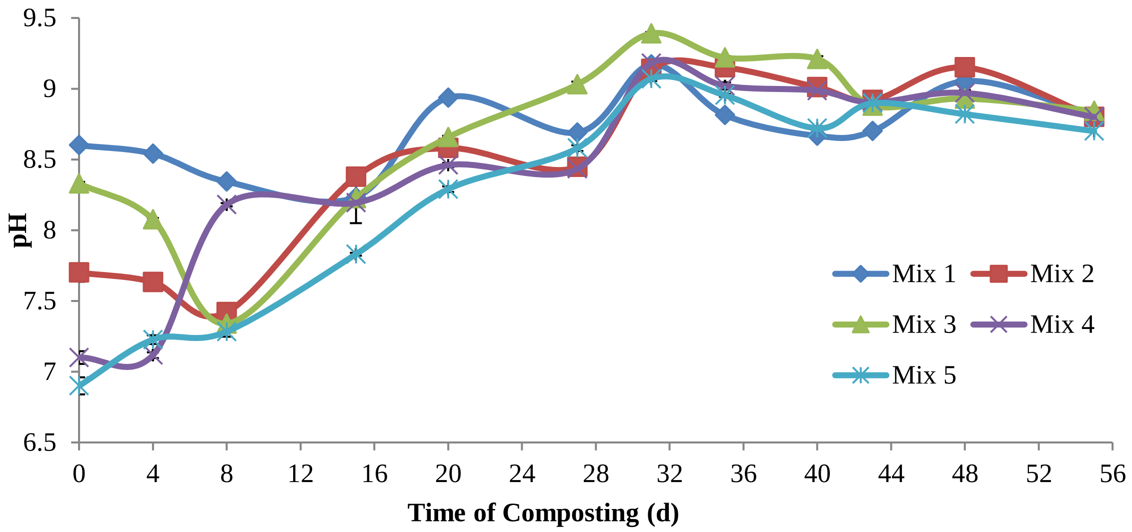


Fig. 6 Variation in pH during composting period

According to Petric et al. (2012), when the acids produced were transformed to CO_2 by the microbial action, initially, the pH tends to shift towards neutrality then towards alkalinity. On the 31[st] day of composting, peak pH values were observed in all mixes. This increase was attributed to the active decomposition of the weak organic compounds and subsequent release of ammonia due to the microbial mineralization of nitrogen sources like protein (Jolanun and Towprayoon 2010). In all the mixes, a subsequent decrease observed in later days attributed to the possible formation of organic acids associated with the temporary localized anaerobic conditions, which caused the hydrolysis of polymeric substrates into amino acids. Again a rise in pH was observed, this could be explained by the overall prevalence of aerobic conditions which then prompted the mineralization of complex molecules like amino acids and proteins into ammonia formation in the composting matrix (Rawoteea et al. 2017). Finally, the pH values were found to remain stable, though are not in the range of 6.5 to 7.5 as per the compost standards, but represent that mixes were approaching compost stabilization due to lower microbial activities.

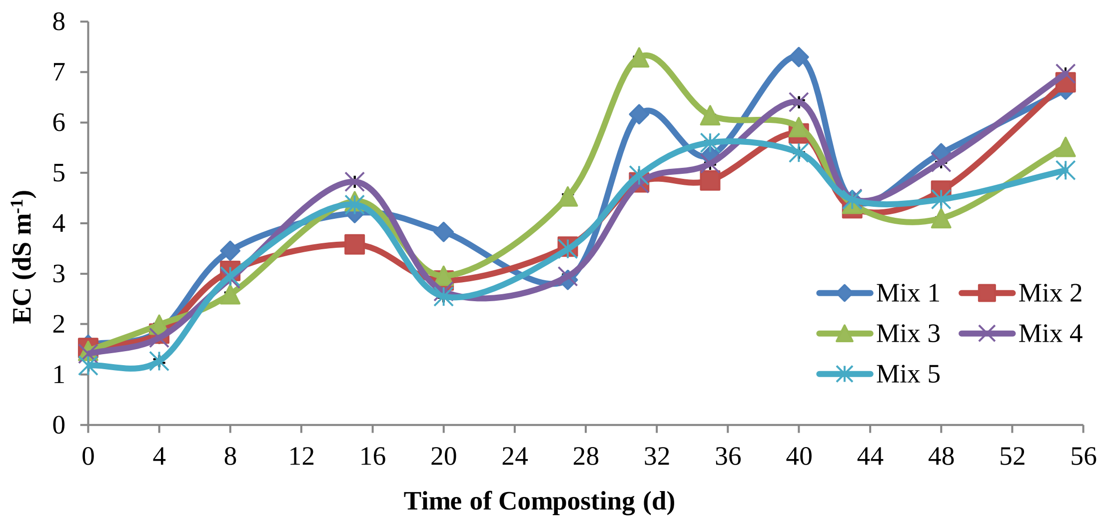


Fig. 7 Variation in EC during composting period

Electrical conductivity (EC) variations

The EC of a sample indicates the total salt content of the composting substrates in the matrix (Shah et al. 2015). Elevated levels of salt content in compost could cause a reduction in crop yields when salt concentrations near the root zone accumulate and reach an extent to which the root can no longer extract sufficient water from the soil-compost solution. Therefore it is very vital to assess the EC in compost since high levels of salt may injure plants, with seedlings and transplants being largely vulnerable to damage (Sullivan et al. 2018). Conversely, high soluble salts represent more soluble nutrients, thus when applied at low concentrations, compost with a high salt content could be a better nutrient source (Sullivan et al. 2018). EC hence reflects the compost quality as a soil amendment. Due to the microbial mineralization of organic fractions, it gets released chiefly in the form of cations (magnesium and calcium) or minerals into the matrix. Initial EC was in the range of 1.00 to 1.80 dS/m which increased to 5.0 to 7.0 dS/m in the mixes by the end of 55 days. This increase could be due to the discharge of mineral salts and ammonium-based ions (Gao et al. 2010; Yang et al. 2016). In the same way, EC peaked at 31 days and 40 days of composting in all mixes in Fig. 7. This increase in EC could be due to the mineral salts such as ammonium ions and phosphates that were released in the course of the decomposition of organic matter. There was no significant difference found in EC among these mixes, in this study.

Total organic carbon (TOC)

TOC is useful for estimating age and physical properties of the compost. During Composting, CO_2 and water vapor are evolved as metabolic end products. Therefore as composting proceeds, the TOC of compost mass reduces (Kumar et al. 2009; Yang et al. 2019). FOG waste is rich in carbon content. Its content was increasing from bin 1 to 5, hence the initial TOC increased from bin 1 to 5 (from 31.4% to 43.01%). During composting, unsteady levels of TOC were observed (Fig. 8). While assessing the samples for TOC, accurate values couldn't be achieved at some points; this could be due to the interference by the grass waste (acting as a bulking agent). The TOC increase at a few points in the first 27 days could be due to the addition of leachate back into the system. Also, there was considerable mass loss and volume loss of the mixes during composting, so the increase in TOC at a few points could be attributed to the loss of nitrogen (as ammonia volatilization, this can be supported with observed pH values being above 8.5 in the latter half of the composting period). The GW acting as a bulking agent and maintaining MC in the system is rich in lignin content, resulting in slower degradation of organic matter. Lignin is the plant component that offers the utmost resistance to biodegradation. It only gets degraded by a few bacteria and fungi. Cellulose has far higher biodegradability than lignin. Therefore, as a whole conversion of the carbon is higher in cellulose containing material than the ones having higher amounts of carbon in the form of lignin. As the FOG content was increasing from bin 1 to 5, increasing carbon content (energy-rich) led to greater thermophilic conditions resulting in higher rates of organic matter degradation in both bins 4 and 5 where bin 4 showed highest levels of degradation (Fig. 8).

Lipid content variation

With time, FOG degradation increases. Also, the corresponding fatty acid composition of a mix defines the breakdown of its lipids, i.e. the degradation of long chain fatty acids increases with their unsaturation degree and aliphatic chain shortening. The high scum concentrations inhibit the activity of fat-splitting microorganisms by having negative influence on oxygen transport. Based on earlier research conclusions, effective decomposition of fat is found to be possible when 5–15% of the fat concentrations are found in soil, and beyond that, the fat degradation rates decrease.

Many researchers established similar results in past (Aikaite-Stanaitiene et al. 2010; Erhan and Kleiman 1997; Nakasaki et al. 2004).

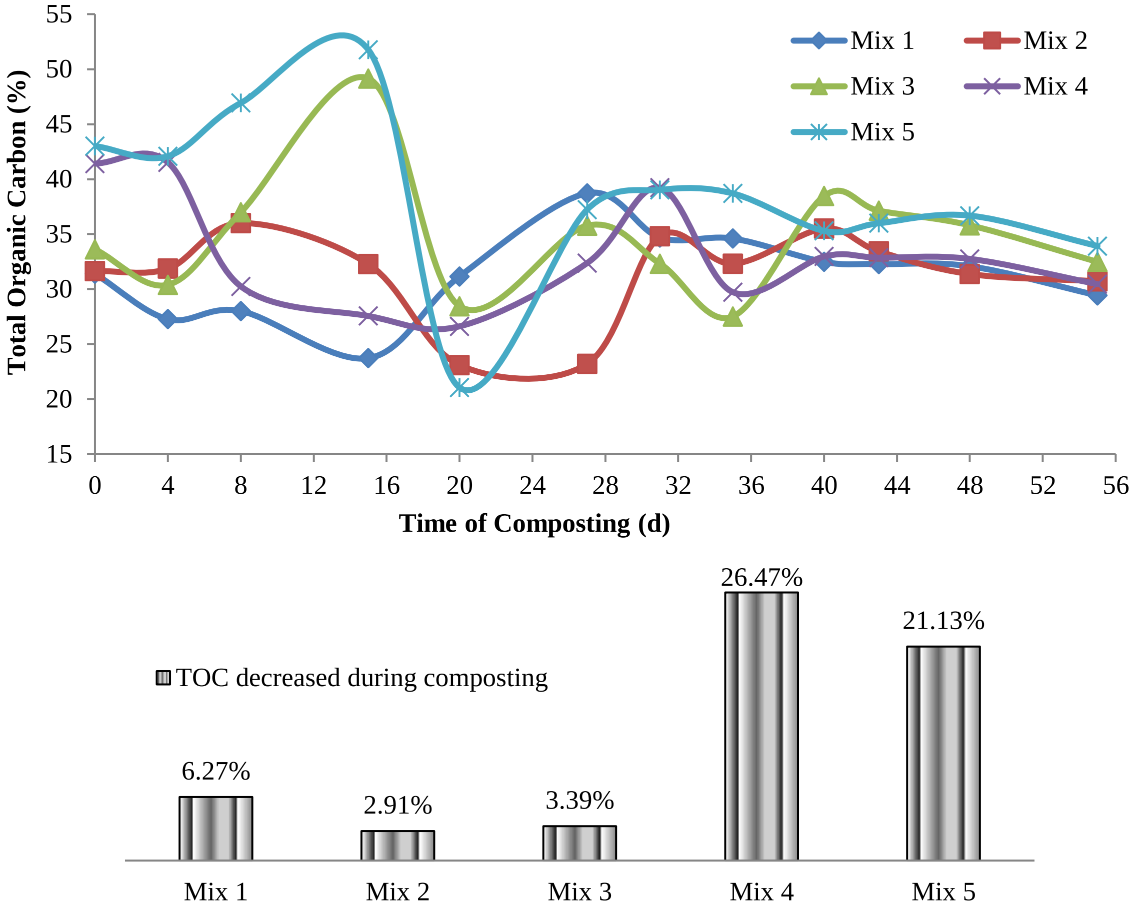


Fig. 8 Variation in TOC and reduction in TOC during 55 days of composting

The initial lipid content was found increasing from bin 1 to 5 as expected since the FOG waste (lipid-rich waste) added increased. Bin 5 showed the highest lipid content of 9.232% on the 4th day of composting. While there were many variations speculated during the course of composting, these could be attributed to the formation of free fatty acids in the process of decomposition of organics. By the end of 31 days of composting a considerable breakdown of the lipids could be seen and all the bins reported <7% of lipid content as shown in Fig. 9. This indicates that the fat waste could be degraded by wild micro-flora and fauna to a good extent. But due to time constraint, lipid content was not measured after 31 days, a furthermore reduction could be expected by the end of 55 days of composting.

Nitrogen content

The whole compost food web is made up of a range of chemical forms constituting N, P, and K which are released and recycled through invertebrates and various microbes as the organic matter undergoes decomposition. Amino acids like cysteine or glycine are formed by the decomposition of proteins. They further decompose to simpler forms of inorganic ions like NH_4^+, NO_3^- and SO_4^{2-} which will be accessible for plants or for microorganisms to consume.

In the compost-water extract, its NH_4-N to NO_3-N ratio has been recommended as a maturity index. Though the ultimate NO_3^- concentration depends on the raw materials used, it generally increases with time so the stage at which this increase begins being measured is a hard task (Gajalakshmi and Abbasi 2008). When nitrates increase and ammonium nitrogen content decreases, this depicts intensive biological degradation being slowed down; in turn, representing that compost matured adequately (Benito et al. 2003).

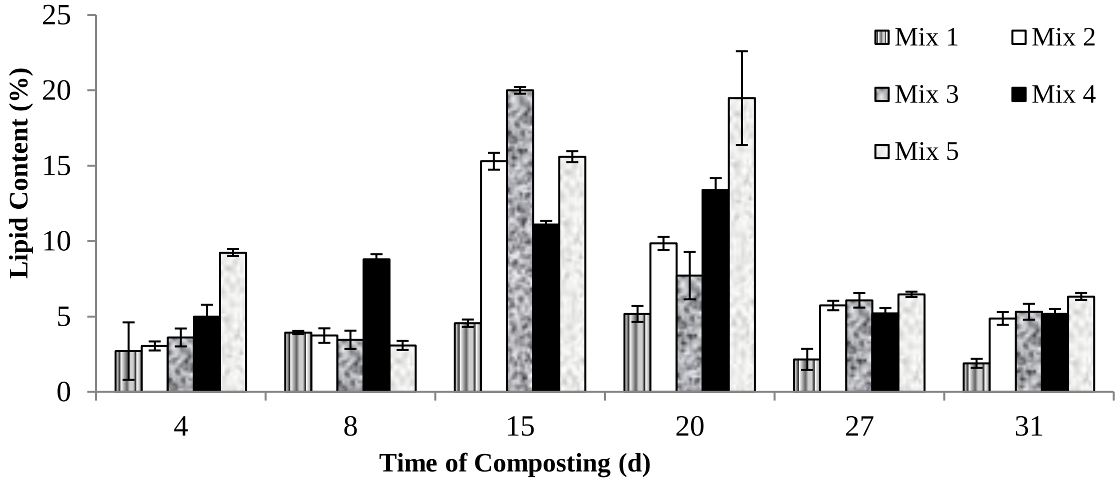


Fig. 9 Variation in lipid content of mixes during composting

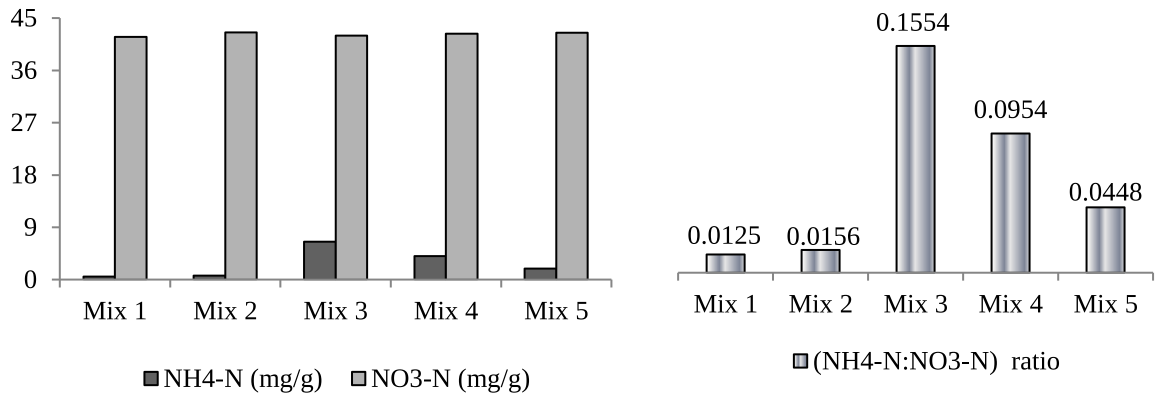


Fig. 10 Variation in NH_4-N and NO_3-N content in all the mixes on 48 days of composting

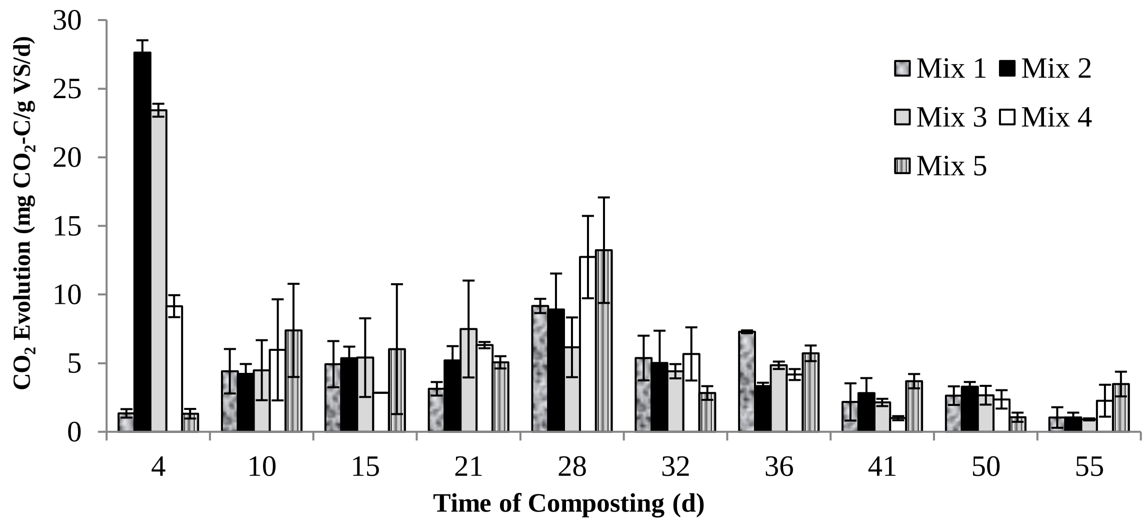


Fig. 11 Variation in CO_2 evolution rate during the composting period

The total Kjeldahl nitrogen content of the initial feedstock mixes when assessed showed higher TKN was in mix 1, which had higher GW and VW. On 48 days of composting, the NO_3-N and NH_4-N content in the compost water extracts could be seen in Fig. 10. NH_4-N in the extracts of all the mixes were much lower while their corresponding NO_3-N concentrations were high, depicting the oxidation of the organic matter i.e. Nitrification. As recommended by Bernal et al. (1998), for mature compost, the highest NH_4-N: NO_3-N ratio is 0.16. All mixes showed ratios lower than 0.16 which depicted their maturity. Mix 1 and 2 reported comparatively very low ratios representing high maturity and could have stabilized faster as they contain lower FOG waste concentrations than the later.

CO_2 evolution rate

The evolution of CO_2 can directly be used to evaluate compost stability because it measures the carbon derived directly from the compost being tested (Kalamdhad et al. 2008). This rate represents the aerobic respiration taking place in the system. In the final stages of composting, the absence of organic matter corresponds to lower biological action and consequently reduced CO_2 emissions, indicating compost stabilization (Awasthi et al. 2018). Fig. 11 depicts the respiration rates of five composting mixes. Very high initial rates of 27.62, 23.43, and 9.15 mg CO_2-C/g VS/d were recorded in bins 2, 3, and 4 respectively. But a drastic decrease was seen as the thermophilic stage ends. Bin 5 took some time for its increment in the CO_2 evolution rate, showing that the microbes were getting acclimatized to the environment in the bin, in turn a slow degradation process was observed. Finally, the CO_2 evolution in mix 1,2,3,4, and 5 reduced to 1.04, 1.05, 0.91, 2.26, and 3.47 mg CO_2-C/g VS/d at the end of 55 days, denoting the stability of compost mixes (a mature compost has < 4 mg CO_2-C/g VS/d) as suggested by CCME (2005). Mix 1, 2 and 3 reported comparatively lower final evolution rates than mix 4 and 5, showing that they have stabilized faster than the later as they have lower FOG concentrations. These final evolution rates of the compost mixes also summarize that FOG waste can be composted effectively with green waste.

Visual observations on primary consumers that feed on the organic matter

Sow-bugs were found in the compost mixes in this study (Fig. 12A). They are the primary consumers, the ones that consume organic residues. A characteristic formation of hyphae was found in the bins which showed the presence of actinomycetes and fungi in the system, which are efficient cellulose degraders (Fig. 12B). At the final stages of composting, both of them generally grow in huge numbers. They are experts at attacking hemicelluloses, cellulose, and lignin polymers (Epstein 1997). Due to repeated turning of compost material, the hyphae could be broken which further can lead to cellulose decomposer's diminished activity (Gajalakshmi and Abbasi 2008), hence a limited turning was carried out in this study.

Final compost characteristics and analysis

The organic compost standards mentioned in the Solid Waste Management Rules, 2015 (MoEF&CC 2015), Guidelines for Compost Quality (CCME 2005), and the Final characteristics of the compost mixes from this study were summarized in Table 3. After about 30-40 days of composting, the mixes 1 to 4 showed no unpleasant odor and corresponded to the earthy smell of compost.

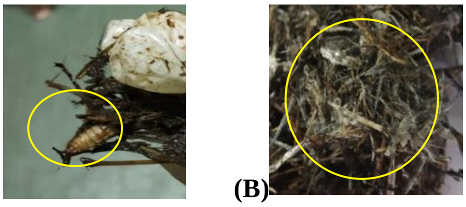

(A) (B)

Fig. 12 (A) Sowbugs acting on compost mix (B) Hyphae growth on the compost mix

Table 3 Physicochemical and biological characteristics of final compost mixes

Parameters	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Standards**	
Colour	Dark brown	Dark brown	Dark brown to black	Black	Black	Dark brown to black color	(MoEF&CC 2015)
Odour	Absence of foul odor	Absence of foul odor	Absence of foul odor	Absence of foul odor	Mild odor	Absence of foul odor	
MC (%)	64.74±0.8	52.03±10.69	49.49±3.70	50.19±4.15	51.64±9.22	15 to 25	
TVS (%)	76.52±10.56	74.13±1.88	79.58±0.95	72.49±1.58	77.61±0.67	-	
pH	8.82±0.01	8.8±0.01	8.84±0.02	8.8±0.02	8.7±0.01	6.5-7.5	
EC (dS/m)	6.65±0.02	6.8±0.02	5.52±0.02	6.97±0.01	5.05±0.01	< 4.0	
TOC (%)	29.43	30.72	32.48	30.46	33.92	12 (TOC_{min})	
CO_2 evolution (mg CO_2-C/g VS/d)	1.04±0.75	1.05±0.343	0.91±0.075	2.26±1.163	3.47±0.9	< 4.0	(CCME 2005)

(Note: Mean ± Standard deviation, n=3)

The null hypothesis states that 'there is no significant difference in the variation of parameter values for different treatments' (Rawoteea et al. 2017). Here in Table 4, the treatments referred to the difference in mixes bin. A significant difference was observed among the five mixes ($p<0.05$ and all their respective $F_{statistic}$ values of rows were greater than their corresponding $F_{critical}$ values) concerning Temperature, Leachate, pH, TOC, and Lipid content showing that these parameters were influenced significantly by the treatment (mix composition) when analyzed statistically based on two-factor ANOVA test (Table 4A). Therefore, the null hypothesis was rejected in these above-mentioned parameters except MC, TVS, EC, and Respiration rate where there was no significant difference ($p>0.005$ and corresponding $F_{statistic}$ values were lower than their respective $F_{critical}$ values) found among the mixes studied in this work. While the temperature variation within each bin, when analyzed, concerning bottom, middle, and top layers of the compost mixture, there (their respective compositions with different starting experimental conditions) in column A, and the treatments in column B referred to temperature in the bottom, middle, and top layers of compost mix in each was a significant difference ($p<0.05$ and all their respective $F_{statistic}$ values of rows were greater than their corresponding $F_{critical}$ values) between these layers in all the five compost vessels (Table 4B).

Conclusion

The present study observed variations in physicochemical and biological characteristics, associated with composting five combinations of vegetable waste, grass clipping waste, and FOG waste in a vertical bin composter. A suitable combination of materials and the design of the composter played a key role in supporting the degradation process of scum waste. A maximum TOC reduction of 26.47% and TVS loss of 17.95% was obtained in 55 days by composting a mix with an initial C/N ratio of 29.351 containing 12%

of FOG waste. All the compost mixes were stable with CO_2 evolution rates within standard limits and prolonged thermophilic stage achieved in mixes with 12% and 16% FOG waste represent that it is prudent to compost grease scum waste efficiently with vegetable and grass waste for its further use for agricultural purposes. By allotting furthermore time for maturation and curing, the moisture content, pH, and EC of the mixes could have been brought down to meet the standards, while all the other parameters of mixes 1 to 4 have met organic compost standards in all respects, with mix 4 being optimum, since maximum amount of FOG waste is being managed at the same total mix weight and conditions. It can be concluded that bin composter served its purpose of providing a stable and favorable environment for composting.

Table 4 Two-Factor ANOVA analysis on data sets in this study (values concerning variation in treatment)

	Statistical parameter	p-value	$F_{statistic}$	$F_{critical}$
(A) Variation between the mixes (treatments)	Temperature	4.91E-37	54.807	2.394
	MC	0.092	2.140	2.584
	TVS	0.056	2.495	2.584
	Leachate	3.15E-04	6.705	2.606
	pH	0.007	4.059	2.584
	EC	0.059	2.466	2.584
	TOC	0.007	4.049	2.584
	Lipid content	0.021	3.668	2.866
	Respiration rate test	0.697	0.554	2.634
(B) Temperature variation between the bottom, middle, and top layers	Mix 1	1.53280E-04	10.022	3.132
	Mix 2	1.93592E-04	9.721	3.132
	Mix 3	2.02013E-04	9.666	3.132
	Mix 4	8.51702E-07	17.286	3.132
	Mix 5	3.62385E-04	8.922	3.132

Limitations

The time available to carry out this research and to measure the changes over time was constrained. Composting these mixtures (with FOG waste) for about 70-84 days could have resulted in MC, pH and EC of the mixes, meeting standards (matured compost), based on similar previous studies by Aikaite-Stanaitiene et al. (2010) and Gea et al. (2007).

Future scope

Special biological additives can be incorporated to enhance the production of enzymes and biodegradation of scum waste. The use of selected bacterial strains/ cultures of microorganisms for fat degradation could accelerate the whole natural microbiological processes to a large extent, thereby increasing the scope for even higher levels of FOG content being degraded, with the help of the fat oxidizing microorganisms. Since the extent and the speed of biodegradation depends on various environmental factors, future studies can be carried out by altering the key features of the composting system, like incorporating structural materials (to increase porosity), use of (N-P-K) fertilizers, installation of forced aeration facilities, and pH adjustment during composting by adding calcium carbonate, these alterations can in turn reduce the period of composting.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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