Int J Recycl Org Waste Agricult (2014) 3:52
DOI 10.1007/s40093-014-0052-4

ORIGINAL RESEARCH

Stability and microbial community analysis during rotary drum composting of vegetable waste

V. Sudharsan Varma · Ajay S. Kalamdhad

Received: 6 September 2013 / Accepted: 23 February 2014 / Published online: 18 March 2014

Abstract
Background Disposal of vegetable waste in landfills and illegal sites leads to emission of greenhouse gases and leachate production, thereby imposing major environmental issues. As an alternative, this waste can be successfully recycled for its high nutrient content using composting process.
Results Five trials were made with the ratio of 6:3:1 of trial 1 (50 kg), trial 2 (70 kg), trial 3 (90 kg), trial 4 (120 kg) and trial 5 (150 kg) by adding 10 kg of dry leaves in each of the trials as bulking agent. Due to active microbial population and high biodegradable organic matter in vegetable waste, early thermophilic phase was observed within 18–24 h of the composting process in all of the trials with a maximum of 61.4 °C in trial 3. Total mesophilic heterotrophs were observed in the range of 7.1×10^{11} CFU g^{-1} and gradually reduced to 2.65×10^{6} CFU g^{-1} at the end of 20 days, which was considered due to prolonged thermophilic phase maintained in trial 3. An average of 54–56 °C temperature was maintained for 7 days in trial 3, with spore-forming population in the order of 3.82×10^{9} CFU g^{-1} contributing to higher organic destruction. The populations of fungus, actinomycetes and streptomycetes were observed to reduce during thermophilic phase and remained in the order of 2.85×10^{4}, 3.8×10^{6} and 4.1×10^{5} CFU g^{-1}, respectively, at the end of 20 days. CO_2 evolution and OUR were in the order of 0.89 and 0.32 mg g^{-1} VS d^{-1}, respectively, in trial 3 denoting maximum degradation of organic matter and stabilization of compost. Indicator organisms were found well with the standard limits due to elevated temperature.
Conclusions Combinations of waste materials played a major role in favoring microbial succession. Temperature in the compost system had major effect on the survival of the microbial populations. Elevated temperatures favored higher degradation of organic matter, thereby stabilizing the compost within proposed time of composting and also destructing the indicator pathogens.

Keywords Vegetable waste · Rotary drum composting · Microbial dynamics · Stability

V. Sudharsan Varma (✉) · A. S. Kalamdhad
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, Assam, India
e-mail: svarma2010@gmail.com

Introduction

The major problem associated with the disposal of vegetable waste is mainly due to high moisture content and readily degradable organic matter. Disposal of vegetable waste along with municipal solid waste (MSW) leads to byproducts such as CO_2, NH_3 and leachate production thereby hindering the natural degradation process. India produces 150 million tons of fruits and vegetables with an annual generation of 50 million tons of wastes (Gautam and Guleria 2007). Hence, disposing vegetable waste along with MSW can lead to esthetic problems and could also pollute water and their burning could lead to air pollution. Furthermore, the municipal solid waste (management and handling) Rules, 2000, recommend composting of biodegradable wastes for its stabilization and further processing.

Composting is the biological decomposition of organic matter involving the transformation and mineralization of the organic matter, leading to a stabilized final product with pathogen free and other humic properties (Zucconi et al. 1987). During this transformation process, bacteria, fungi

and other microorganisms involve in the breakdown of organic materials to form a stable and usable organic substance called compost. It also reduces the volume of the mass and destructs weed seeds and pathogenic microorganism (Bernala et al. 2009). More than 90 % vegetable residues are dense materials with high moisture content and organic content that require mixing with other bulking materials for its processing. The combinations of cow dung and dry leaves have produced mature, high-quality compost using full-scale rotary drum composter. Finally, it has concluded that rotary drum composter as one of the best decentralized composting options for vegetable waste by producing stabilized compost within shorter composting period (Kalamdhad et al. 2009).

The optimum C/N ratio for rotary drum composting is in the range of 20–25 (Kalamdhad et al. 2008). Even though low C/N ratio is recommended for drum composting (in-vessel), the production of leachate from organic waste with high moisture content during decentralized composting has been reported (Tchobanoglous et al. 2000). Furthermore, treatment facilities and reuse of leachate related to the reduction and harmless treatment of decentralized solid waste management should be carried out (Zhou et al. 2010). Hence, the present study involved the optimization of vegetable waste composting using rotary drum with different waste combinations, i.e., vegetable waste, cow dung and saw dust in 6:3:1 ratio for five different trials. Trial 1 (50 kg), trial 2 (70 kg), trial 3 (90 kg), trial 4 (120 kg) and trial 5 (150 kg) were carried out by adding 10 kg of dried tree leaves in each of the trials as bulking agent (Table 2). Stability of compost and microbial succession during the composting have been studied extensively during the 20 days of process.

Materials and methods

Feed stock material

Vegetable waste was collected from different hostels of institution and dry leaves from the Indian Institute of Technology Guwahati campus, Guwahati, India. Cow dung was collected from dairy farm and saw dust from the nearby Amingaon village, Guwahati, India. Prior to composting, the maximum particle size in the mixed waste was restricted to 1 cm in order to provide better aeration and moisture control. The initial characterization of waste materials is given in Table 1. The compost was prepared with five different proportions of vegetable waste, cow dung, sawdust and dried tree leaves as detailed in Table 2.

Physico-chemical and stability analysis

Five hundred gram of each grab samples were collected from six different locations by compost sampler without disturbing the adjacent materials. Finally, all the grab samples were mixed thoroughly to make a homogenized sample. Triplicate samples were collected and stored at 4 °C for subsequent analysis. Temperature was monitored using a digital thermometer throughout the composting period. pH of the compost (1:10, w/v waste: water extract) was analyzed as described by Kalamdhad et al. (2009). Analysis of stability parameters such as CO_2 evolution and oxygen uptake rate (OUR) was performed as described in Kalamdhad et al. (2008).

Sample preparation for microbial analysis

Microbial count was done by adding 10 g of waste or compost into 90 ml of sterile distilled water containing 0.85 % (w/v) sterile sodium chloride solution in 250 ml Erlenmeyer flasks. The solution is mixed mechanically at 150 rpm for 2 h at 25 °C. Finally, the waste suspensions were diluted serially and used for microbial counts on appropriate media.

Culture media and conditions

Nutrient agar medium was used for the total count of prokaryotes. Cycloheximide (0.2 g/L) was added to inhibit fungal growth. The final pH of the medium was 7.3 ± 0.1 at 25 °C. Finally, prepared plates were incubated in an inverted position for 24–48 h at 25 and 50 °C for spore-forming bacteria.

Sabouraud 4 % dextrose agar supplemented with 5 g peptone from casein, 5 g peptone from meat, 40 g D (+) Glucose per liter was used for total count of fungus. The final pH of the medium was 5.6 ± 0.2 at 25 °C. The number of viable fungus was determined by plating appropriate diluted suspensions. Finally, prepared plates were incubated for 3–4 days at 25 °C.

Actinomycete isolation agar supplemented/// with 2 g sodium caesinate, 0.1 g L-Asparagine, 4 g sodium propionate, 0.5 g K_2PO_4, 0.1 $MgSO_4$, 0.001 g $FeSO_4$, 5 mL glycerol per litre was used for the enumeration of Actinomycetes. Cycloheximide (0.2 g/L) was added to inhibit fungal growth. The final pH of the medium was 8.1 ± 0.2 at 25 °C. Finally, prepared plates were incubated in an inverted position for 4–6 days at 25 °C.

ISP medium No. 4 supplemented with 10 g starch soluble, 1 g K_2HPO_4, 1 g $MgSO_4.7H_2O$, 1 g NaCl, 2 g $(NH_4)_2SO_4$, 2 g $CaCO_3$ per liter was used for enumeration of streptomycetes. Fungal growth is inhibited by adding 0.2 g

Table 1 Initial characterization of waste materials

Parameters	Waste materials			
	Vegetable waste	Cattle manure	Sawdust	Dry leaves
pH	5.23 ± 0.02	7.92 ± 0.01	6.86 ± 0.02	6.24 ± 0.01
Electrical conductivity (dS m^{-1})	1.88 ± 0.01	3.10 ± 0.02	1.06 ± 0.02	1.22 ± 0.03
Moisture content (%)	91.2 ± 2.2	75.1 ± 0.5	41.0 ± 0.3	12.2 ± 0.8
TOC (%)	50 ± 2.1	32 ± 2.1	53 ± 0.1	35 ± 1.4
TN (%)	2.6 ± 0.1	1.4 ± 0.2	0.55 ± 0.02	0.52 ± 0.03
C/N ratio	19 ± 0.8	24 ± 0.6	95 ± 2.4	69 ± 1.2
CO_2 evolution (mg g^{-1} VS d^{-1})	26 ± 3.2	17 ± 0.4	13 ± 1.3	6.4 ± 1.2
OUR (mg g^{-1} VS d^{-1})	29.4 ± 0.8	18.9 ± 0.7	10.9 ± 0.5	12.4 ± 0.6

Table 2 Waste composition of waste materials

Feedstock material (waste composition)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Vegetable waste (kg)	30	42	54	72	90
Cow manure (kg)	15	21	27	36	45
Saw dust (kg)	5	7	9	12	15
Dry leaves (kg)	10	10	10	10	10
C/N	19.37	17.79	22.15	23.27	23.41
Moisture content (%)					
Initial	59.10	75.38	75.72	74.85	77.54
Final	53.90	68.93	68.46	73.12	72.07
Volatile solids (%)					
Initial	80.47	78.41	72.16	79.05	73.60
Final	77.18	70.33	66.99	71.55	65.34
Total weight (kg)					
Initial	50	70	90	120	150
Final	14.2	16	16.5	34.6	48
Weight loss (%)	71.6	77.1	81.6	71.2	68

Cycloheximide. The final pH of the medium was 7.2 ± 0.2 at 25 °C. Finally, prepared plates were incubated in an inverted position for 4–6 days at 25 °C (Ryckeboer et al. 2003).

Total coliforms (TC) and Fecal coliforms (FC) were analyzed by inoculation of culture tube media with Lauryl tryptose broth and EC medium, respectively, using the most probable number (MPN) method (APHA 1995). Fecal streptococci and enterococci were identified using Azide dextrose broth and Pfizer selective enterococcus agar. Appropriate diluted suspensions were inoculated onto plates and kept for 24–48 h incubation at 35 °C.

Results and discussion

Physical and chemical properties of the compost

Temperature profile during composting process provides the direct relation between the degradation process and active microbial action on the feed materials. Figure 1 details the temperature variation during the process in all trials. Compared to all the trials, trial 3 showed the highest temperature of 61.4 °C and the rise in temperature was observed during the early stages of the process, stating the active microbial action and early degradation process. It was reported that the temperature of 52–60 °C during the composting process was considered to maintain the greatest thermophilic activity (Mohee and Mudhoo 2005). Even though thermophilic phase was high and closer to trial 3 when compared to all other trials, the trial 3 was found to have the maximum temperature and observed with an average of 50–55 °C from day 1 to 7. This higher temperature is considered due to the appropriate amount of waste materials in trial 3 by providing the optimum carbon to nitrogen ratio as reported by Singh and Kalamdhad (2012). Due to higher temperatures, the moisture content was observed to reduce from 59.10, 75.38, 75.72, 74.85 and 77.54 % to 53.90, 68.93, 68.46, 73.12 and 72.07 % in trial 1, 2, 3, 4 and 5, respectively. Correspondingly, volatile solids reduction was observed from 80.47, 78.41, 72.16, 79.05 and 73.60 % to 77.18, 70.33, 66.99, 71.55, 65.34 % in trial 1, 2, 3, 4 and 5, respectively, at the end of composting period (Table 2).

pH greatly affects the composting process and the values should be within the optimal range for the development of bacteria 6.0–7.5 and fungi 5.5–8.0 (Amir et al. 2005). Vegetable waste with rich carbohydrate and protein content can be readily converted to volatile fatty acids through biological conversion process thereby lowering the pH of the process. So, the initial raw waste materials were mixed in appropriate proportions maintaining a neutral pH of 6.4–7 in all the trials. The neutral pH favored the growth of bacterial communities for faster degradation and led to rise in pH towards alkaline conditions. Figure 2 shows the pH profile of all the trials. The final pH of the compost for all trials was in the range of 7.9–8.4, which was observed as a result of effective degradation process. Similar observations were reported with pH range of 7–8 in most of the compost (Liao et al. 1996; Smith et al. 2006).

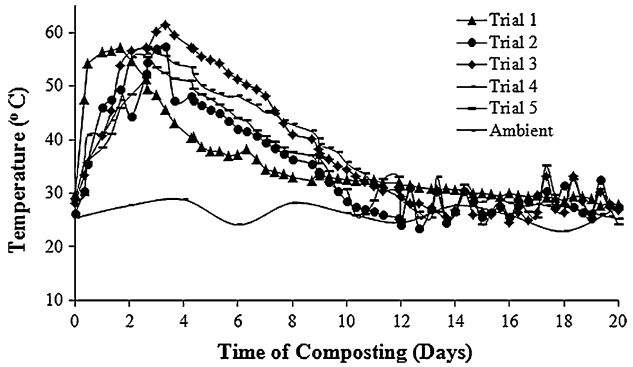

Fig. 1 Temperature profile during composting period

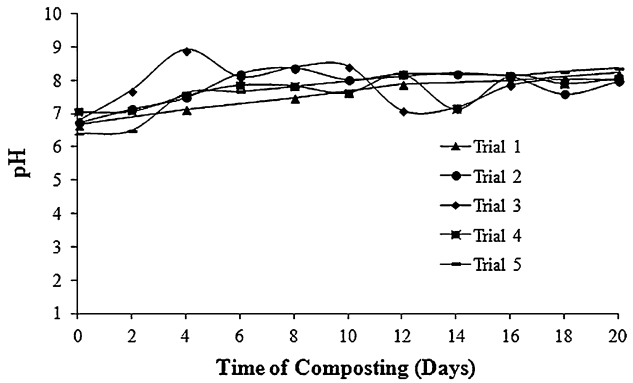

Fig. 2 pH during composting period

Stability of compost

Compost stability is an important aspect of compost quality as it determines the compost nuisance potential, nitrogen immobilization and phytotoxicity (Lasaridi and Stentiford 1998; Hogg et al. 2002). The stability of the compost is measured directly by the carbon dioxide (CO_2) evolution and oxygen uptake rate (OUR) during the composting process. CO_2 evolution is correlated to the aerobic respiration of the biological activity and OUR by evaluating the amount of readily biodegradable organic matter present in the sample (Gomez et al. 2006; Kalamdhad et al. 2008). CO_2 evolution rates decreased from initial values 13.75, 15.20, 7.11, 15.71 and 13.27 mg g^{-1} VS d^{-1} to 4.21, 1.31, 0.39, 0.48 and 3.39 mg g^{-1} VS d^{-1}, respectively, in trial 1, 2, 3, 4 and 5 at the end of 20 days (Fig. 3). A maximum of 94.5 % reduction was observed in trial 3 in comparison to all other trials, stating the stabilization of compost. The rate of evolution was found very low or proceeding the same manner during the final days of composting, stating the loss of readily biodegradable organic matter. The lower CO_2 evolution rate in the final stages of composting was considered due to unavailability of readily available organic matter and the results were supported by Kalamdhad et al. (2008).

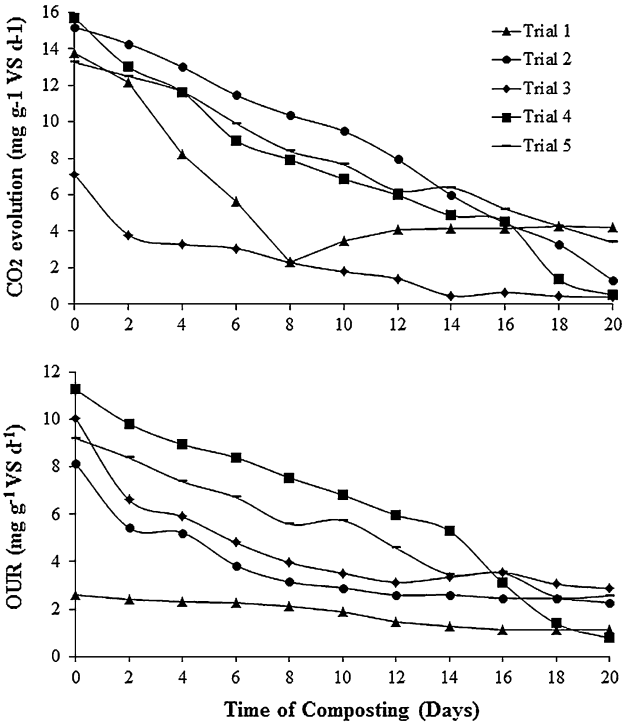

Fig. 3 CO_2 evolution and OUR of composting materials over time

As the microbial population grew faster during the composting process by feeding on the raw materials, OUR will be observed high (Iannotti et al. 1993). Similar results were observed during the present study due to high organic content of vegetable waste in the initial days. The OURs of trial 1, 2, 3, 4 and 5 decreased from initial values of 2.60, 8.14, 10.05, 11.27 and 9.21 mg g^{-1} VS d^{-1} to 1.11, 2.27, 2.87, 0.77 and 2.55 mg g^{-1} VS d^{-1}, respectively (Fig. 3). The reduction in OURs can be considered due to degradation process. As composting proceeds, large organic molecules are broken down to smaller and soluble ones by the action of microbial communities. During the process higher oxygen demand is needed, which is directly observed by the higher OURs during the initial stages of the composting, and once the composting proceeded the final stages lower OURs were observed stating the deprival of readily available organic matter. The lower CO_2 evolution and OURs during the final stages of composting process in trial 4 denotes that the compost has matured with the proved days of composting. Furthermore, the results from trial 3 states that the compost has completely stabilized with lower emissions as supported by Kalamdhad et al. (2008). CO_2 evolution and OUR can be successfully related by representing respiratory quotient (RQ), i.e., the ratio between CO_2 produced and O_2 consumed (Kalamdhad et al. 2008). Atkinson et al. (1997) have reported that the respiration quotient (RQ) is approximately equal to 1 under aerobic conditions. However, in the present study the

RQ for the composting process was in the range of 5.2, 1.8, 0.7, 1.3 and 1.4 on day 0, finally observed to reduce to 3.7, 0.5, 0.1, 0.6 and 1.3 at the end of composting period. Smars et al. (2001) reported a value of 1.02 in the composting of source-separated household waste and the results were in accordance with the reports by Kalamdhad et al. (2008), stating the stability of compost.

Analysis of microbial community

Composting is essentially a phenomenon of microbial activity influencing and being influenced by the temperature during the process through biological degradation and acting accordingly by change in different microbial communities. Based on the temperature, the rate at which the microbial populations prevail and act will vary distinctly. In addition, monitoring the microbial succession during the composting process will be an effective management of the process and it further reflects the quality of maturing compost (Lasaridi and Stentiford 1998). Therefore, microbial dynamics was observed during the different stages of composting and the effect of temperature and other external factors on the microbial community was discussed extensively.

Mesophilic and spore-forming bacteria

The indigenous population of total heterotrophic mesophilic bacteria in the initial raw material during day 0 was fairly high in all the trials and it was considered to be dependent on the total weight of waste residues used in each of the trials as reported by Gazi et al. (2007). The initial amount of total heterotrophs was in the range of 7.7×10^9, 1.65×10^{10}, 7.1×10^{11}, 9.1×10^{11} and 8.1×10^{11} CFU g^{-1} in trial 1, 2, 3, 4 and 5. These mesophilic heterotrophs are responsible for the rise in temperature in composting systems by breaking down the organic material into simpler units by releasing CO_2 and heat as byproducts. Thermophilic stage was observed within 18–24 h of the process and reaching a maximum of 58–61.2 °C in all the trials. Due to the rise in temperature, the decline in mesophilic heterotrophs was observed drastically and found in the range of 3×10^6, 6.6×10^6, 2.65×10^6, 7.1×10^6 and 3.3×10^7 CFU g^{-1} in trial 1, 2, 3, 4 and 5, respectively (Fig. 4). The reduction in microbial count is considered due to the transition from mesophilic to thermophilic conditions and these mesophiles are not resistant to such temperatures leading to inactivation of their populations (Haug 1993; Weppen 2001; Sundberg et al. 2004). In addition reports by Ryckeboer et al. (2003) were supported during the present study on the relation between temperature and decline of the total microbial population. Furthermore, depletion of organic matter can also lead to the decline of bacterial count, as lower CO_2 emissions and OUR were observed during the final stages of the composting.

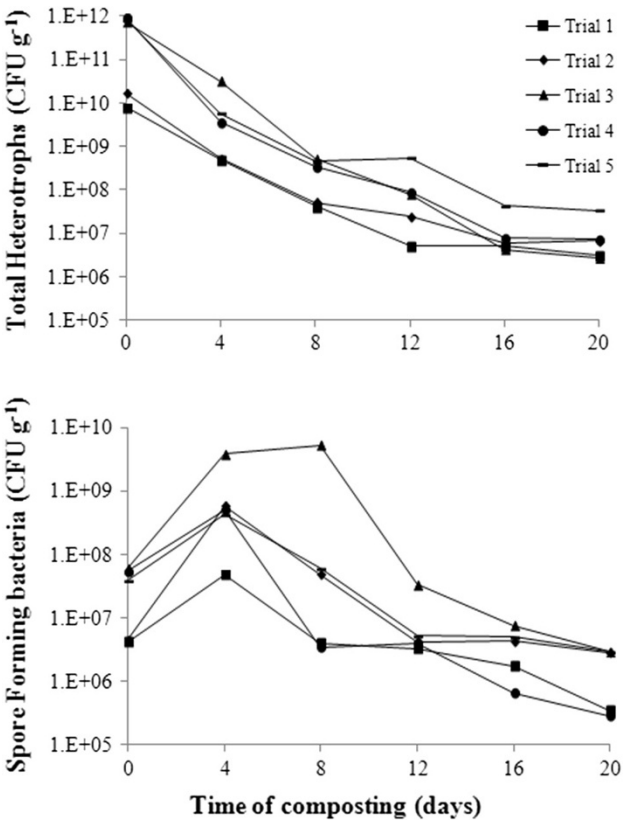

Fig. 4 Total heterotrophic and spore-forming bacteria during composting period

Hence, it can be considered that the populations of mesophilic bacteria were greatly influenced by higher temperature and readily available organic matter, rather than cellulose, hemicellulose and lignin. These mesophiles are not capable of forming spores like fungi, yeasts and streptomycetes which can survive at high temperatures that can also add for the reduction in their numbers (Ryckeboer et al. 2003). With decline in mesophilic bacteria due to rise in temperature, proliferation of spore-forming bacteria was observed extensively. These spore-forming bacteria were found throughout the composting process in all trials and increased 100 fold in trial 3 due to higher temperatures in the composting system. These results were supported by Gazi et al. (2007), where it was reported the same observation of spore-forming units throughout the process, except the rise of population during the composting process. In the present study, due to early thermophilic stage, rise in spore-forming bacteria from 6.0×10^7 to 3.82×10^9 CFU g^{-1} in the order of 100 fold was observed within 3 days and was maintained till day 8 in trial 3 of being highest compared to other trials, whereas from the

above-stated reports it was observed on day 63. However, the other trials also had considerable amount of populations in the range of 4.1×10^6, 4.4×10^6, 6×10^7, 5.35×10^7 and 3.8×10^7 CFU g^{-1} in trial 1, 2, 3, 4 and 5 and reduced to 3.4×10^5, 2.8×10^6, 2.9×10^6, 2.8×10^5 and 2.9×10^6 CFU g^{-1}, respectively at the end of 20 days. Hence the relation between temperature and mesophilic bacteria survival can be related to each other from the present findings.

Mesophilic bacteria are dominant during the early stages of composting by degrading the organic matter; thereby raising the temperature of the system. Once the thermophilic stage has reached, spore-forming bacteria are considered to take over and act upon the organic matter, which is clearly observed with the rise in populations of spore-forming bacteria especially in trial 3 and at the same time decline in mesophilic bacteria was observed in all the trials. The results were in accordance with the reports by Ishii et al. (2000), stating the significant role of temperature over the populations of one another. In comparison to all the trials, trial 3 reached a maximum reduction of bacterial count with highest temperature and with higher spore-forming bacterial count during the process. The higher temperature may be observed due to the combinations of waste materials in appropriate amounts in trial 3, which favored the growth of mesophilic and spore-forming bacteria to act effectively during the composting process.

Fungi

Fungi have been reported to be an important group and are considered to play a very significant role in the biodegradation and conversion process during composting (Anastasi et al. 2005). This fungal diversity is reported to utilize many carbon sources mainly of lignocellulosic polymers and is mainly responsible for compost maturation (Miller 1996). In the present study, the populations of fungi were found in the range of 5.6×10^7, 3.8×10^7, 1.8×10^8, 8.25×10^8 and 7.4×10^8 CFU g^{-1} in trial 1, 2, 3, 4 and 5 and reduced to 7.7×10^4, 3.1×10^5, 2.85×10^4, 3.9×10^5 and 3.9×10^6 CFU g^{-1}, respectively, at the end of 20 days (Fig. 5). The major reduction in fungal populations was observed during the thermophilic stage of composting process. This decline in numbers is mainly considered due to higher temperatures maintained in the order of 50–63.2 °C during the composting process, which led to the death of most of the fungal species. The results were in accordance with the fact that fungi are generally more resistant to acids and less tolerant to temperatures greater than 35–40 °C, when compared to bacterial species (Atlas and Bartha 1998). Since the highest temperature was observed in trial 3 due to appropriate combinations of waste materials, major drop was observed during the

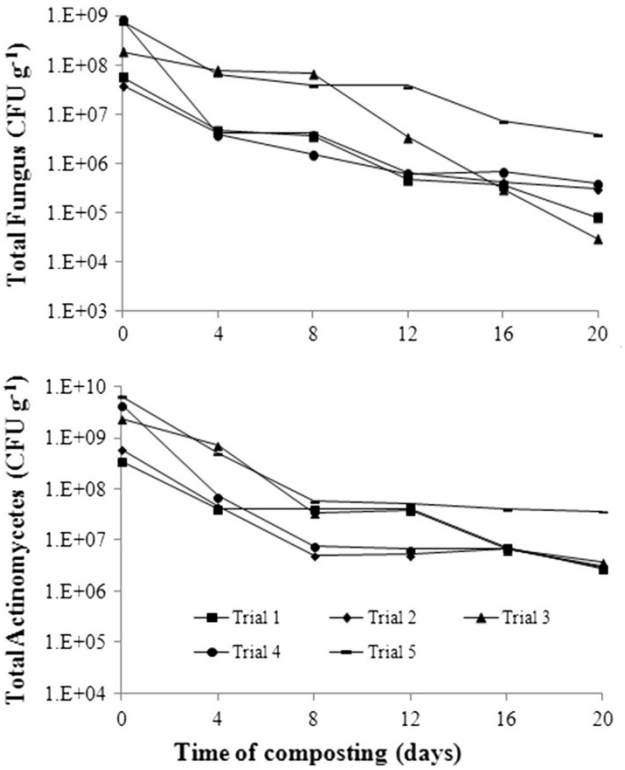

Fig. 5 Total fungus and actinomycetes during composting period

thermophilic stage and finally fungal numbers were observed in the range of 2.85×10^4 CFU g^{-1} at the end of 20 days, being least in comparison to all other trials. Even though complete inactivation of fungi is reported in few studies during composting process (Bhatia et al. 2012), the present study observed considerable decrease in the amount of fungal numbers, with no such complete inactivation at the end of 20 days. The reason might be due to the presence of lignocellulosic carbon food available for the survival of fungi in the later stages. However, the effect of temperature on the inactivation of fungi followed the same pattern as reported by Bhatia et al. (2012) in the present study. Ryckeboer et al. (2003) also reported the death of fungi due to high temperature (76 °C) to almost totally zero during thermophilic stage.

Actinomycetes and streptomycetes

Actinomycetes are generally considered to act during the later stages of composting and are involved in degradation of recalcitrant organics such as lignocellulose and elimination of pathogenic and allergenic microorganisms (Rebollido et al. 2008). Higher populations of actinomycetes were found in all trials in the range of 3.6×10^8, 6.1×10^8, 2.45×10^9, 4.55×10^9 and 6.7×10^9 CFU g^{-1} and reduced to 2.8×10^6, 3.1×10^6, 3.8×10^6,

3×10^6 and 3.6×10^7 CFU g^{-1} at the end of 20 days (Fig. 5). Actinomycete isolates were classified by observing the morphology of sporophores and color of aerial mycelium as reported by Miyashita et al. (1982). Only mesophilic actinomycetes were identified in the present study at 25 °C, since most of the actinomycetes are thermo resistant and play an important role in the degrading natural polymers at higher temperature and aerobic conditions (Song et al. 2001). Hence due to their thermo resistivity and presence of lignocellulosic material, populations of actinomycetes were found in considerable amounts at the end of 20 days, however, trial 3 was observed with higher reduction. The actinomycetes group has found potential use in biodegradation process and in the production of bioactive compounds such as antibiotics and enzyme. In addition, the population size and composition of actinomycetes are mainly dependent on the type of organic content materials and also on the physical conditions of the environment (Miyashita et al. 1982).

In addition to actinomycetes, streptomycetes are also considered to play an important role in the degradation of recalcitrant macromolecules. They are also biologically important for their vast potential in producing a wide variety of secondary metabolites, including antibiotics and extracellular enzymes (Inbar et al. 2005). Since, ISP-4 medium is not strictly selective for streptomycetes; therefore, only the colonies with aerial mycelium (powdery, wrinkled, or pasty) were counted sensibly as reported by Ryckeboer et al. (2003). The populations of streptomycetes were found in the range of 6.1×10^7, 4.1×10^7, 2.8×10^8, 3.8×10^8 and 3.9×10^8 CFU g^{-1} in trial 1, 2, 3, 4 and 5 and reduced to 4.7×10^5, 3.1×10^5, 4.1×10^5, 6.5×10^5 and 7.4×10^6 CFU g^{-1}, respectively, at the end of 20 days (Fig. 6). These higher populations at the end of 20 days in all trials may be due to the presence of complex organic materials such as lignin and cellulose. However, streptomycetes are generally considered to secrete antibiotics for the control of pathogens, which might also be responsible for the reduction of mesophilic bacteria and certain species of fungi in addition to elevated temperatures.

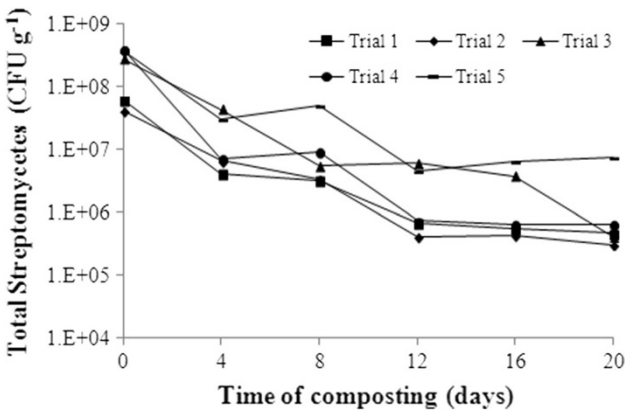

Fig. 6 Total streptomycetes during composting period

Total and fecal coliform

The recommended fecal coliform and streptococci densities for compost hygienization are 5.0×10^2 and 5.0×10^3 MPN g^{-1}, respectively (Vuorinen and Saharinen 1997). The presence of coliform bacteria is often used as an indicator of overall sanitary quality of the compost (Kalamdhad et al. 2009). The control of these pathogens is carried out with two major factors, i.e., temperature and the release of antibiotics as discussed earlier. The average number of total coliform bacteria was initially observed in the range of 1.5×10^{11}, 11×10^{11}, 4.6×10^{11}, 2.1×10^{12} and 11×10^{12} MPN g^{-1} in trial 1, 2, 3, 4 and 5 and finally reduced to 0.75×10^3, 2.4×10^3, 2.1×10^3, 4.6×10^4 and 4.6×10^4 MPN g^{-1}, respectively, at the end of 20 days. However, the fecal coliform were in the order of 2.1×10^7, 11×10^7, 2.4×10^6, 4.6×10^7 and 4.6×10^7 MPN g^{-1} in trial 1, 2, 3, 4 and 5 and reduced to 0.091×10^2, 2.4×10^2, 2.4×10^2, 1.5×10^3 and 1.2×10^3 MPN g^{-1}, respectively, at the end of 20 days. It is very clear from the results observed that the effect of elevated temperature and the presence of antibiotic releasing streptomycetes during the composting led to inaction of these indicator organisms. The observed results were in accordance with the reports by Kalamdhad et al. (2009).

Streptococci and enterococci are suspected pathogens in most groups of vertebrates. These are responsible for diseases in most of the birds, fishes and various mammals (Chanter 1997). Enterococci have been considered as the best indicator of health risk in salt water used for recreation and as a useful indicator in fresh water as well. USEPA (1986) has recommended moderate and lightly full body contact recreational water should have 124 and 276 densities enterococci per 100 mL. At the end of 20 days enterococci was found in the range of 4,400, 290, 240, 340 and 580 CFU g^{-1}. Similarly, streptococci were also observed to reduce in considerable amounts from 3.3×10^5, 4.4×10^5, 5.8×10^5, 5.5×10^4 and 6.4×10^5 CFU g^{-1} to 640, 940, 88, 120 and 890 CFU g^{-1} at the end of 20 days.

Conclusion

Despite various microbial communities during vegetable waste composting, each community is observed to act accordingly to temperature and nature of substrate

available. Irrespective of the trials, microbial population growth was influenced by the temperature and also the effective organic matter degradation. However, combinations of waste materials played a major role in favoring microbial succession. Spore-forming bacteria are majorly observed in the degradation process during thermophilic stage. Final stages of composting process were observed with considerable amount of fungi, actinomycetes and streptomycetes. These populations were considered to act more predominantly due to the presence of lingo-cellulosic material, even though lower CO_2 evolution and OUR were observed during the final stages. Hence, it can be concluded from different trials that trial $3 > 4 > 2 > 5 > 1$ was observed the best in terms of stability and microbial dynamics. Overall, higher diversity of microbial community prevailed throughout the composting process resulting in high stabilized compost with higher degradation and pathogen-free compost in shorter duration of composting.

Acknowledgement The authors gratefully acknowledge the financial support of the Ministry of Drinking Water and Sanitation, Government of India (Grant No. W. 11035/07/2011-CRSP (R&D) 12/12/2012).

References

Amir S, Hafidi M, Merlina G, Revel JC (2005) Sequential extraction of heavy metals during composting of sewage sludge. Chemosphere 59:801–810

Anastasi A, Varese GC, Marchisio VF (2005) Isolation and identification of fungal communities in compost and vermicompost. Mycologia 1:33–44

APHA (1995) Standard methods for the examination of water and wastewater, 17th edn. American Public Health Association, Washington

Atkinson CF, Jones DD, Gauthier JJ (1997) Microbial activities during composting of pulp and paper-mill primary solids. World J Microbiol Biotechnol 13:519–525

Atlas RM, Bartha R (1998) Microbial ecology. Fundamentals and applications, Chapter 8. Addison Wesley Longman, Menlo Park, California

Bernala MP, Alburquerquea JA, Moralb R (2009) Composting of animal manures and chemical criteria for compost maturity assessment—a review. Bioresour Technol 22:5444–5453

Bhatia A, Ali M, Sahoo J, Madan S, Pathania R, Ahmed N, Kazmi AA (2012) Microbial diversity during Rotary Drum and Windrow Pile composting. J Basic Micro 1:5–15

Chanter N (1997) Streptococci and enterococci as animal pathogens. J Appl Micro 83:100–109

Gautam HR, Guleria SPS (2007) Fruit and vegetable waste utilization. Science Tech Entrepreneur

Gazi AV, Kyriacou A, Kotsou M, Lasaridi KE (2007) Microbial community dynamics and stability assessment during green waste composting. Global NEST J 1:35–41

Gomez RB, Lima FV, Ferrer AS (2006) The use of respiration indices in the composting process: a review. Waste Manag Res 24:37–47

Haug RT (1993) The practical handbook of compost engineering. Lewis Publishers, Boca Raton

Hogg D, Favoino E, Centemero M, Caimi V, Amlinger F, Devliegher W, Brinton W, Antler S (2002) Comparison of compost standards within the EU, North America and Australia. The Waste and Recourses Action Program (WRAP), Oxon. ISBN 1-84405-003-3

Iannotti DA, Pang T, Toht BL, Elwell DL, Keener HM, Hoitink HAJ (1993) A quantitative respirometric method for monitoring compost stability. Compost Sci Util 1:52–65

Inbar E, Green SJ, Hadar Y, Minz D (2005) Competing factors of compost concentration and proximity to root affect the distribution of streptomycetes. Micro Eco 50:73–81

Ishii K, Fukui M, Takii S (2000) Microbial succession during a composting process as evaluated by denaturing gradient gel electrophoresis analysis. J Appl Microb 89:768–777

Kalamdhad AS, Pasha M, Kazmi AA (2008) Stability evaluation of compost by respiration techniques in a rotary drum composter. Resour Conser Recyc 52:829–834

Kalamdhad AS, Singh YK, Ali M, Khwairakpam M, Kazmi AA (2009) Rotary drum composting of vegetable waste and tree leaves. Bioresour Technol 100:6442–6450

Lasaridi KE, Stentiford EI (1998) Biological parameters for composting stability assessment and process stabilization. Acta Hortic 469:119–128

Liao PH, Jones L, Lau AK, Walkemeyer S, Egan B, Holbek N (1996) Composting of fish wastes in a full-scale in-vessel system. Bioresour Technol 59:163–168

(2000) Manual on municipal solid waste management, Ministry of Urban Development, Government of India

Miller FC (1996) Composting of municipal solid waste and its components. In: Palmisano AC, Barlaz MA (eds.) Microbiology of solid waste. CRS Press, Florida, pp 115–154

Miyashita K, Kato T, Tsuru S (1982) Actinomycetes occurring in soil applied with compost. Soil Sci Plant Nutr 28:303–313

Mohee R, Mudhoo A (2005) Analysis of the physical properties of an in-vessel composting matrix. J Powder Technol 155:92–99

Rebollido R, Martínez J, Aguilera Y, Melchor K, Koerner I, Tegmann R (2008) Microbial populations during composting process of organic fraction of municipal solid waste. Appl Ecol Environ Res 6:61–67

Ryckeboer J, Mergaert J, Coosemans J, Deprins K, Swings J (2003) Microbiological aspects of biowaste during composting in monitored compost bin. J App Micro 94:127–137

Singh J, Kalamdhad AS (2012) Concentration and speciation of heavy metals during water hyacinth composting. Bioresour Technol 124:169–179

Smars S, Beck-Friis B, Jonsson H, Kirchmann H (2001) An advanced experimental composting reactor for systematic simulation studies. J Agric Eng Res 78:415–422

Smith DR, Cawthon DL, Sloan JJ, Freeman TM (2006) In-vessel, mechanical rotating drum composting of institutional food residuals. Compost Sci Util 14:155–161

Song J, Weon HY, Yoon SH, Park DS, Go SJ, Suh JW (2001) Phylogenetic diversity of thermophilic actinomycetes and thermoactinomyces spp. isolated from mushroom composts in Korea based on 16S rRNA gene sequence analysis. FEMS Microbiol Lett 202:97–102

Sundberg C, Smars S, Jonsson H (2004) Low pH as an inhibiting factor in the transition from mesophilic to thermophilic phase in composting. Bioresour Technol 95:145–150

Tchobanoglous G, Theisen H, Vigil S (2000) Integrated solid waste management engineering principles and management issues. McGraw-Hill, New York 978

USEPA (1986) Guidance for recreational waters and beaches. United States Environmental Protection Agency, Washington

Vuorinen AH, Saharinen MH (1997) Evolution of microbiological and chemical parameters during manure and straw co-composting in a drum composting system. Agric Eco Environ 66:19–29

Weppen P (2001) Process calorimetry on composting of municipal organic wastes. Biomass Bioenergy 4:289–299

Zhou C, Wang R, Zhang Y (2010) Fertilizer efficiency and environmental risk of irrigating Impatiens with composting leachate in decentralized solid waste management. Waste Manag 6:1000–1005

Zucconi F, de Bertoldi, Ferranti MP, Hermite PL (1987) Compost specifications for the production and characterization of compost from municipal solid waste Compost: Production Quality and Use, Elsevier, Barking, pp 30–50