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Assessing consistency in the aerobic co-composting of faecal sludge and food waste in a municipality in Ghana

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Abstract

Background A faecal sludge (FS) co-composting study assessed the extent of consistency in compost characteristics between and within batches. The study focused on the consistency of the co-composting process by measuring the variability of key parameters.

Method The set up consisted of 12 FS and food waste (FW) co-composting piles in three successive batches (1, 2 and 3). Consistency was assessed in the three successive batches of co-composted FS and food waste (FW). Within batches, consistency was assessed in each of them by dividing it into four separate replicate piles. Characteristics of interest were *E. coli*, as well as selected physico-chemical parameters (pH, EC, Mg, Ca, N, NH_4-N, NO_3-N, P, avail. P, and K) and heavy metals (Se, Fe, Cd, Cu, Hg, Ni, Pb and Cr). Data were subjected to analysis of variance (ANOVA) using SPSS.

Result Results show that, *E. coli* levels were not consistent between the successive batches during the entire co-composting process. While variations between batches were only observed for EC and nutrient parameters, variations were evident for several measured characteristics within batches. The measured coefficient of variations (CVs) within batches ranged between 0–125% and 3–111% for heavy metals and nutrients, respectively.

Conclusion In conclusion, there was less consistency in nutrients between successive batches and CV within batches was wide. Consistency levels for *E. coli* may not be an issue if pathogen inactivation is complete.

Recommendation It is recommended that a threshold value be created for determining what is an acceptable level of variation in FS co-composting.

Keywords Faecal sludge, Co-composting, Variation, Traceability, Batch productions, Consistency, Food Waste

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Background

In recent years, composting has increasingly been promoted as a reliable and low-cost method for sanitizing faecal sludge (FS) from onsite sanitation systems, particularly where there are opportunities to use the recovered nutrients in agriculture (Wang et al. 2022). FS in developing countries remains one of the most challenging waste generated and the fast threatening pollutants as it facilitates the spread of pathogens (Crocker et al. 2016; Coffey et al. 2017; Velkushanova et al. 2021). Composting is considered one of the best options due to its sustainability and integration into circular bioeconomy concept, which is what the current European system is committed to (Razza et al. 2018) and Ghana is beginning to develop systems and commitments to fully integrate composting. This process generates a safe and stable bioproduct, the compost, which can be used as organic fertiliser (Soobhany et al. 2017). Moreover, the high temperatures reached during the process eliminate possible pathogens and, in addition, could reduce antibiotic resistance genes (ARGs) present in the raw materials (Zittel et al. 2020).

Composting or co-composting is often preferred as a treatment method for FS in sub-Saharan Africa due to its low energy requirements and efficacy in terms of the recovery of critical nutrients (Nitrogen, Phosphorous and Potassium) (Manga et al. 2021) and organic matter which can be used for agriculture. Co-composting of FS and other organic solid waste streams particularly uncooked food waste (FW) from markets, food stores, restaurants etc. contributes as an efficient waste management tool and allows for recycling of nutrients and organic matter into agriculture thereby closing the nutrient loop (circular economy). The technologies chosen for co-composting usually depend on the geographical location, available capital, quantity, and type of feedstock to be used etc. There are generally two main types of aerobic co-composting systems namely open systems such as windrows and static piles, and closed systems such as vessel systems (Alamin 2017).

According to Manga et al. (2021), the effectiveness of FS co-composting has not been thoroughly explored especially in urban Africa. Robust research studies conducted and published on FS in peer reviewed journals to date are few (Koné et al. 2007; Cofie et al. 2009; Nakasaki et al. 2011; Berendes et al. 2015; Mulec et al. 2016; Al-Muyeed et al. 2017; Nartey et al. 2017; Mengistu et al. 2018; Thomas et al. 2018; Oarga-Mulec et al. 2019; Hashemi et al. 2019). Most of these earlier studies have addressed the optimization of FS co-composting with various organic residues and the effectiveness of the different bulking agents on FS sanitization, during open-air composting in one-time experiments or trials (Cofie et al. 2009; Berendes et al. 2015; Al-Muyeed et al. 2017; Nartey et al. 2017; Mengistu et al. 2018). Undoubtlessly, co-composting of FS has been, and it is being extensively practiced globally, both informally and formally (Manga et al. 2021). However, little or no information is available on the consistency of the FS co-composting process over successive batch productions. Process consistency is a cornerstone for consistent quality product for both producers, consumers, and regulators in the value chain and helps to instil confidence in its quality and acceptability. Understanding consistency helps producers communicate with certainty the quality of co-compost or faecal derived fertilisers (FDF), promotes user's trust (farmers, landscapers etc.), and facilitates replication and easy regulations.

The importance of consistency in FS co-composting especially in sub-Saharan Africa cannot be overemphasized. The characteristics is affected by the type of initial feedstock, the process of composting itself and the maturity of the final product (Alamin 2017). Feedstock type and treatment processes play a critical role in the characteristics of final compost hence its quality. This is because FS which is the primary feedstock is very variable in nature because of the different on-site sanitation systems, sludge collection and transportation methods, etc. (Heinss et al. 1999; Bassan et al. 2013; Ward et al. 2019). The characteristic of FW is equally affected by the types of foodstuff and vegetables available in time which in turn is influenced by the seasonality, local food trade etc. (Fisgativa et al. 2016). Treatment processes, particularly where it is mostly consisted of manual process steps like turning of heaps could introduce some variability.

Understanding the changes and extent of consistency in FS co-composting over continuous production cycle is critical for instilling confidence in the quality and use of FDF as well as assessing appropriate management strategies to ensure quality and safe FDF are produced from such co-composting enterprises to meet international guidelines. To encourage public/consumer confidence in FDF quality and acceptability, the product and process must satisfy two criteria. Firstly, the FDF must meet key quality standards and secondly, the co-composting process must be consistent to contribute to having a reliable quality. In this study, we focus on the consistency of the co-composting process by measuring the variability of key parameters. The objective is to assess the degree of consistency between FDF batches and within batches over time.

Methods

Experimental site, feedstock sourcing and pre-treatments

The study was carried out at field scale at Akorley, Somanya (latitude 60.00'N and 00.30'N and between longitude 00.30'W and 10.00'W, Sadiq 2016) at the Jekora Ventures Limited (JVL) – Yilo Krobo Municipal Assembly (YKMA) Recycling Plant, in the YKMA of Ghana

(Fig. 1). The annual rainfall of the area ranges from 750 to 1,600 mm and it's spans from May to October (bimodal). Average temperatures range between 24 and 30 °C while relative humidity ranges between 60 and 90% (Sadiq 2016). The major soil type is Savanna Ochrosol (Eastern Regional Co-ord Council 2016). It has low nutrient reserves, with the topsoil consisting of dark greyish brown humus sandy or clay loams (Eastern Regional Co-ord Council 2016).

The FW was obtained from JVL's source segregation operations in major local markets and some institutions within YKMA, Ghana. The fraction of FW collected included source-separated fruit waste (citrus, watermelon, pineapple etc.), vegetable waste (cabbages, garden eggs, etc.) and foodstuff waste (plantain stalks, yam peels, potato etc.). At the recycling plant, FW was further sorted out to remove other foreign materials (mostly inert materials) that may have escaped the initial segregation at source. Larger sizes of the FW were cut into pieces of about 2–3 cm to increase their surface area and allow for efficient aeration during the co-composting process. FW used for the study was characterised. The parameters that were considered for the characterisation are described in Table 1. Raw human excreta collected from various on-site sanitation systems and transported by Cesspit Emptiers from in and around YKMA was dewatered on sand drying beds at the JVL-YKMA Recycling Plant. Mixtures of sludge from public toilets and households were loaded onto the drying beds at a ratio of 2: 1 v/v until the bed was full and allowed to dewater. The dewatered FS (DFS) was harvested manually from the drying beds and characterised. The DFS produced on each drying bed was treated as different sources and characterised differently.

Co-compost treatments

The set up consisted of 12 DFS and FW co-composting piles in three production batches (1, 2 and 3) for the between batch tests. Within each batch were four replications of co-composting piles of DFS: FW at 1:3 w/w for the within batch tests. The co-composting piles contained approximately 2.0 tons of materials of 1.5 m high and 10 m base circumference. The interval between

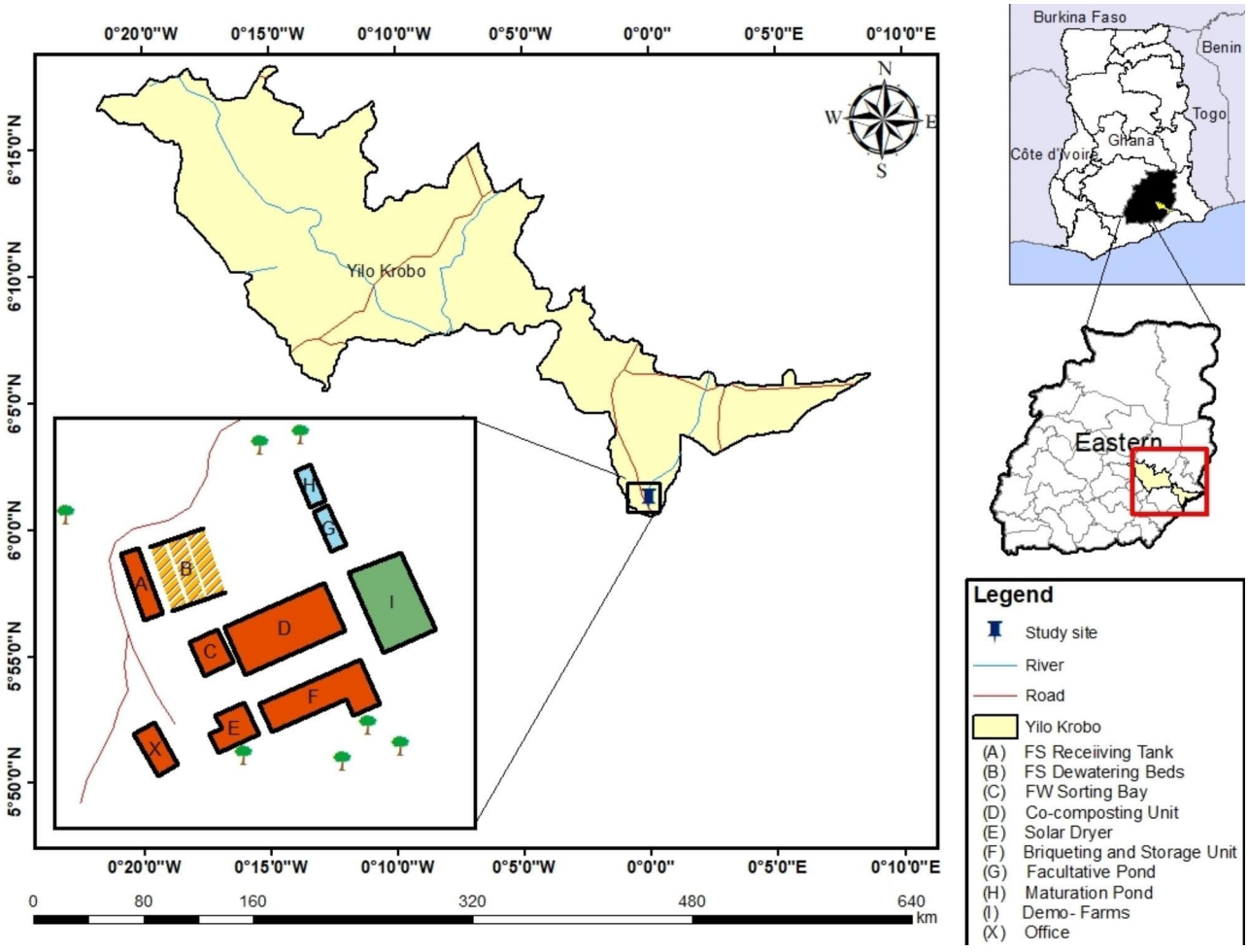

Fig. 1 Map of study site

Table 1 Feedstock and initial characteristics of piles for the different batches

Parameter	DFS		Food waste		Batch 1		Batch 2		Batch 3	
	Mean	Std. Dev (±)	Mean	Std. Dev (±)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
pH (1:5)	6.8	0.4	9.6	0.3	8.8[a]	10	9.2[a]	9	9.0[a]	13
EC (1:10) (ms/cm)	3.34	1.30	6.59	2.81	4.06[a]	14	5.24[a]	30	5.07[a]	27
Total N (%)	2.67	1.02	1.36	0.26	2.04[a]	31	1.54[a]	6	1.55[a]	10
NH_4-N (mg/kg)	1513.91	255.60	652.64	290.80	232.34[a]	23	192.83[a]	45	336.55[a]	33
NO_3-N (mg/kg)	1232.64	917.30	612.34	69.34	366.79[a]	27	380.52[a]	34	501.08[a]	42
Org. C (%)	26.56	6.30	37.85	5.65	22.25[b]	13	35.78[a]	3	36.02[a]	6
Total P (%)	3.77	1.14	0.43	0.08	2.93[a]	41	1.92[a]	14	1.98[a]	60
Avail. P (mg/Kg)	9.88	0.65	11.46	1.75	9.95[a]	11	9.93[a]	16	5.26[b]	36
Total K (%)	0.63	0.14	0.93	0.06	1.34[a]	21	1.17[a]	67	1.83[a]	15
Avail. K (mg/Kg)	0.13	0.03	6.34	2.74	0.33[a]	26	0.25[a]	50	0.40[a]	10
Ca (%)	2.53	0.38	0.76	0.32	3.52[a]	16	2.14[a]	76	2.66[a]	21
Mg (%)	0.64	0.28	0.29	0.09	0.33[a]	21	0.32[a]	10	0.36[a]	18
Mn(mg/Kg)	36.82	2.38	17.56	8.70	14.01[a]	26	15.14[a]	25	19.72[a]	4
Cu(mg/Kg)	18.25	1.99	2.58	0.46	4.86[a]	21	4.78[a]	60	3.68[a]	35
Zn(mg/Kg)	350.22	81.75	906.39	293.50	422.57[a]	6	617.82[a]	41	474.49[a]	14
Fe(mg/Kg)	566.24	62.34	333.35	105.40	289.03[a]	8	283.32[a]	21	257.73[a]	9
Pb(mg/Kg)	106.10	6.49	77.47	17.68	55.72[a]	12	78.92[a]	33	78.12[a]	8
Cd(mg/Kg)	2.38	1.17	4.93	1.05	5.84[a]	16	3.31[a]	45	5.29[b]	18
Cr(mg/Kg)	63.58	14.29	159.81	11.23	57.56[a]	25	57.18[a]	28	62.81[a]	13
Hg(mg/Kg)	0.01	0.01	0.82	0.11	0.24[a]	33	0.52[a]	51	0.46[a]	21
Ni(mg/Kg)	0.23	0.03	0.47	0.32	0.05[a]	90	0.08[a]	58	0.03[a]	126
Se (mg/Kg)	0.18	0.06	0.36	0.09	0.09[a]	32	0.12[a]	84	0.03[a]	153
E. coli (CFU/g)	8.1×10^3	1.1×10^4	1.3×10^3	8.0×10^2	5.2×10^{4a}	36	6.9×10^{6a}	128	1.7×10^{7a}	87
Total coliform (CFU/g)	9.6×10^4	1.3×10^5	3.3×10^3	2.4×10^3	3.8×10^{5b}	80	6.7×10^{7a}	24	6.0×10^{7a}	83

NB: Same letters on means in the column indicate no significant difference at 5%

batches production was 2 weeks in a successive process. The active composting phase took about 8 weeks, and the curing/maturation phase took about 4 weeks. Within this period, piles were monitored to ensure sanitization conditions were achieved. These included manually turning piles every 3 days for the first 2 to 3 weeks and then once a week afterwards. Moisture contents of the piles were adjusted to 50–60% during turning. Daily temperature recordings were taken with a compost thermometer.

Sampling and analysis

Composite samples were collected from several sub-samples randomly taken from different pile depths (0–30 cm) following methods described in USDA and USCC (2001) every two weeks from the start of co-composting for moisture content, *E. coli*, antimicrobial resistance (AMR) and helminths as well as selected physico-chemical (pH, EC, Mg, Ca, N, NH_4-N, NO_3-N, P, avail. P, and K) and heavy metals and trace elements: Ca, Mg, Mn, Cu, Zn, Fe, Pb, Cd, Cr, Hg, Ni, and Se were determined before and after the co-composting.

A total of 96 samples of approximately 200 g (wet weight) each was collected. Samples were immediately stored in iceboxes and sent to the laboratories. Samples for the physico-chemical parameters were air-dried and ground before analyses. Total N was determined by the modified Kjeldahl method described in Black (1965). Ammonium (NH_4-N), Nitrate (NO_3-N), Total P and K were determined by methods, as described in Okalebo et al. (2002). The pH and EC were measured using 1:5 and 1:10 compost: water w/v ratios, respectively described in USDA and USCC (2001). Organic carbon (OC) was determined by the Walkley and Black (1934) method. The *E. coli* and total coliform counts were done using the spread plate method (APHA-AWWA-WEF 2001). Helminth egg was determined by the flotation and sedimentation method following a modified USEPA method (Schwartzbrod and Gaspard 1998). The heavy metals were analysed by atomic absorption spectrophotometer following methods described by Chapman and Pratt (1962). For the AMR process, pure cultures of *E. coli* were subjected to an evaluation of antibiotic resistance based on the method described by Bauer et al. (1966).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using SPSS statistical package and Genstat 12th edition statistical package. Between batch treatment means found to be significantly different from each other at ($p<0.05$) were separated by the Least Significant Differences (LSD) tests. The LSD tests was more appropriate to compute and determine the smallest difference between

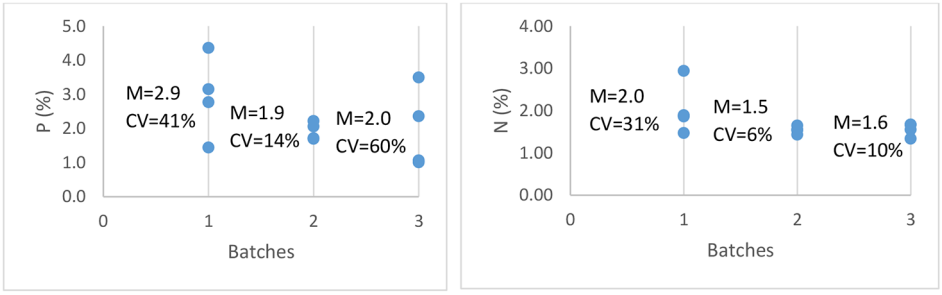

Fig. 2 Consistency within batches for total P and N concentrations at start co-composting

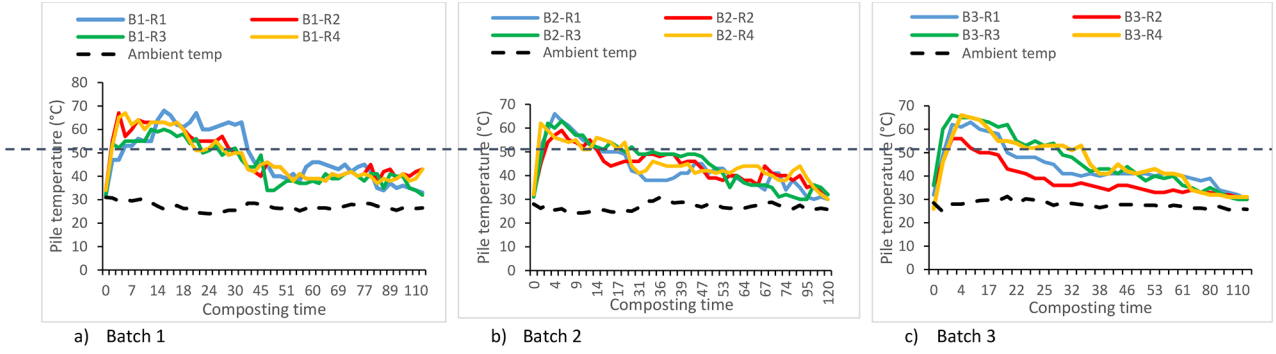

Fig. 3 Temperature profiles of batch piles (**a**, **b**, and **c**)

composting batch means provided the F-test was significant from ANOVA. This gives an idea of the consistency between batches. Within batch tests were carried out by the comparison of the coefficient of variations (CVs).

Results and discussions

Initial characteristics of feedstock and co-composting piles at start

Results indicate that, despite the DFS and FW coming from the same location/sources in this study, the physico-chemical characteristic showed wide variation from the mean (Table 1). The wide variation in the characteristics may have been due to factors surrounding the sources such as seasonality etc. as reported by other studies (Heinss et al. 1999; Bassan et al. 2013; Fisgativa et al. 2016; Ward et al. 2019). At the start of co-composting, it was generally observed that, there was consistency in characteristics between batches 1, 2 and 3 as characterised by no significant differences in the measured parameters between the batches expect for Org C, available P, Cd, and total coliform (Table 1). The level of consistency within batches were wide. It ranged from 9 to 13% for pH and between 14 and 30% for EC. The levels of consistency within batches for nutrients was wide ranging from 4 to 76% (Table 1). For example, there was relatively more consistency observed in the total P and N concentrations in batch 2 than in batches 1 and 3 (Fig. 2).

Temperature and moisture content of profiles

The key indicators of composting are temperature and pH (Cui et al. 2016). All piles within the batch achieved recorded temperatures above 50 °C for weeks needed for pathogen deactivation during the thermophilic phases although the piles did not show identical or similar temperature trends throughout the thermophilic, mesophilic and maturation phases (less consistency in the trends of the pile temperatures) (Fig. 3). While each pile achieved thermophilic temperatures within 2–5 days of co-composting, the period for the thermophilic phase varied within and between batches. An explanation for this phenomenon could be differences in the composition of the FW feedstock used as bulking agent which could have altered the substrate environment to bring an increase or decrease in temperatures. For instance, some components of FW like whole oranges constituted a suitable habitat for microbial proliferation by improving substrate properties like porosity, surface area that enhance microbial activities leading to increase in temperatures (Sánchez-García et al. 2015).

Another explanation can be unintentional inconsistencies introduced by workers during manual turning of piles and moisture adjustment. There can be inconsistency in the frequency of turning and the thoroughness of turning introduced by the workers. However, this was contrary to a previous study (Cofie et al. 2009) that found no significant effect of different turning frequencies on temperature changes. According to the time-temperature

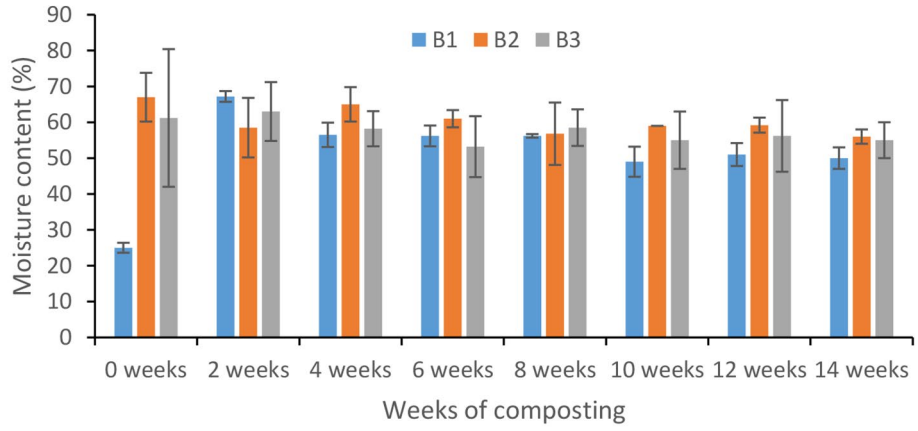

Fig. 4 Changes in pile moisture content between batches. B1 = Batch 1; B2 = Batch 2; and Batch 3

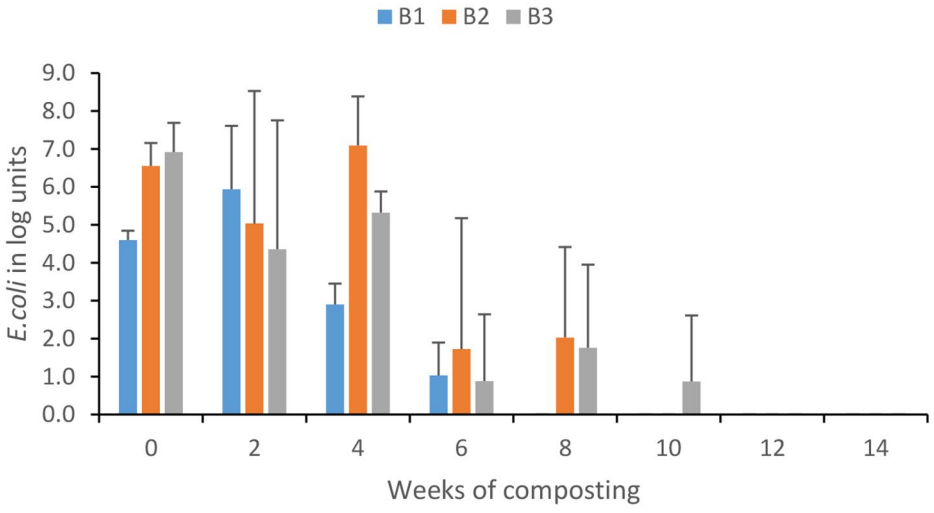

Fig. 5 *E. coli* changes in batch piles in log units. B1=Batch 1; B2=Batch 2; and Batch 3

criteria provided by United States Environmental Protection Agency (USEPA)(USEPA 2003), maintaining composting pile temperatures of >55 °C for 3 days by aerated static pile or in-vessel composting (or 15 days for windrow composting) reduced pathogen concentrations to non-detectable limits when the criterion is achieved.

This criterion was fulfilled by most of the piles in this study. The effect on *E. coli* reduction is discussed in the next section. Moisture plays an essential role for the movement of microorganisms to move around to degrade the substrate and in the process generate heat to increase temperature. It is required that moisture content (MC) is maintained between 50 and 60% for optimal processes. Generally, there were no significant differences at $p<0.05$ in MC levels between batches indicating consistency between batches after the start of the co-composting process (Fig. 4).

The significant differences observed between batches at composting week 0 was probably due to the uneven nature of particle sizes of the feedstock and the fact that it may not have been thoroughly mixed at the start of the composting process. However, consistency within the batches indicated by the standard deviation was wide (Fig. 4). There was generally high standard deviation within batches 2 and 3 than in batch 1 even from the start of co-composting and these could be linked to the specific composition of the FW in the piles (Sánchez-García et al. 2015).

E. Coli, helminths and AMR

E. coli levels were not consistent between the successive batches during the entire co-composting process. There were statistically significant ($p<0.05$) differences in the mean *E. coli* concentrations between the batches (Fig. 5). The differences could be due to the starting *E.*

coli concentrations in the DFS feedstock and the differences in the temperatures generated by each pile. The different time-temperature regimes could have been the major cause of the differences in pathogen deactivation during the process inciting the differences in the *E. coli* levels (Manga et al. 2023). The consistency within the batches were also quite less, characterized by measured high standard deviations amongst the piles in a batch. This could be explained by differences in pile turning during the co-composting process. This process is largely carried out manually by workers with shovels and spades. As a result, there was a high possibility of some piles being thoroughly turned than others. Manga et al. (2023) found that turning frequency has a statistically significant ($p<0.05$) effect on pathogen inactivation in FS compost. The 3 days turning frequency (TF) piles exhibited shorter pathogen inactivation periods (8 weeks) than 7 days TF and 14 days TF piles (10 weeks). Cofie et al. (2009) on the other hand found no significant effect of different turning frequencies on the temperature changes and the quality of mature compost. However, the degree of consistency may be less of importance to the FS co-compost producer, user, and regulator where complete deactivation of *E. coli* at the end of the co-composting period. If the final co-compost quality is meeting the standard, then the extent of consistency in the piles prior to co-compost maturity may be of less significance.

The time-temperature criteria were fulfilled by most of the piles even though there was complete deactivation of pathogen after the 10th week of co-composting. Similar findings of complete deactivation were observed by Manga et al. (2019). and Evans et al. (2015). Other studies (Droffner and Brinton 1995; Cabañas-Vargas et al. 2013) on the contrary, found some pathogens in the final composts even after satisfying the time-temperature criteria for extended periods of time. No helminths were observed in the final co-compost characteristics in all batches. Results of the antimicrobial resistance test reveal that, there were some levels of consistency between the sensitivity of *E. coli* to antibiotics in the successive batches (1, 2 and 3). In all the batches of co-composting, *E. coli* showed sensitivity (susceptibility) to Ceftriaxone (CRO 30), Cefoxitin (FOX 30) and Piperacillin Tazobactam (PTZ 110) and did not seem to be affected by the successive batches. However, differences were observed in the *E. coli* sensitivity to Trimethoprime – Sulfamethoxazole (TS 25) between the batches during the process. There was 50–75% probability *of E. coli*, which were resistant to TS 25 during initial stages of co-composting becoming susceptible to the TS 25 antibiotic during the later stages of co-composting indicating that composting plays a role in reducing or minimizing antimicrobial resistivity. None of the *E. coli* were isolated in the final co-compost showing that FS co-composting can plays an important role in eliminating antimicrobial resistant genes (ARGs) found in raw FS. Similar findings of the efficacy of composting in eliminating ARGs was observed by Lopez – Gonzalez et al. (2021).

Final characterisation of piles at the end of co – composting

Final product testing indicated that there were differences observed between batches (1, 2 and 3) for EC, and some nutrient (N, NH_4, NO_3, K, avail. K, Ca, Mn, and K) parameters indicating inconsistency in those characteristics (Table 2). A closer look at the consistency of measured parameters in replicated piles within batches showed coefficient of variations (CVs) ranging between 0 and 125% and 3–111% for heavy metals and nutrients, respectively (Table 2). For instance, in Fig. 6, there was relatively less consistency in batch 2 for Pb levels but more consistent in N% levels at the end of co-composting. The differences in nutrient levels were largely driven by the variable nature of the feedstock (Bassan et al. 2013; Fisgativa et al. 2016) and manual nature of the co-composting operations and the open-air composting method employed which allowed for different degrees of nutrient losses via gaseous escape and through leachate.

Physical parameters such as pH and EC had CVs ranging between 2 and 7% and 2–15%, respectively for replicated piles within batches, however significant consistency between batches (1, 2 and 3) were observed for co-compost pH. Showing that pH levels was the same between co-compost batches and relatively more consistent within the batches.

Heavy metals (Zn, Pb, Cd, Cr and Hg) levels did not consistently meet the standards allowable in Table 2 between batches. Only Cu levels consistently met the standards over successive batches. The sources of the heavy metals were from the feedstock, in this case FS and FW. The co – composting process itself did not seem to have significantly affected the levels of heavy metals between batches in this study. These findings can inform strategies to optimize the feedstock mixing ratio at the start of co-composting to ensure critical heavy metal standards are met.

Having information and an understanding of the level of consistency or variability in FS co-composting with FW in sub-Saharan Africa would help compost producers especially FS co-compost producers be more assertive about their product quality and be able to communicate with certainty the FS co-compost quality to their buyers. This would promote FS co-compost buyer's trust in the process and quality and therefore enhance the market and adoption options for FS co-compost that would ensure that raw FS are not dumped indiscriminately into the environment to pollute but rather transformed into a valuable product. The information and understanding of

Table 2 Final characterisation of batches of FS and FW co-composting

Parameter	Batch 1		Batch 2		Batch 3		ECN-QAS	ECOCERT Standard
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)		
pH (1:5)	8.7[a]	7	8.9[a]	7	8.9[a]	2		
EC (1:10) (mS/cm)	5.3[a]	15	6.3[b]	2	6.4[c]	2		
Total N (%)	1.0a	20	1.3[a]	3	1.7[b]	12		
NH_4-N (%)	0.13[a]	8	6.65[b]	7	7.04[b]	5		
NO_3-N (%)	0.12[a]	8	11.17[b]	76	6.69[b]	3		
Org. C (%)	13.6[a]	7	14.2[a]	23	12.2[a]	8		
Total P (%)	1.8[a]	11	1.3[a]	31	1.3[a]	8		
Total K (%)	1.8[a]	11	3.0[b]	17	2.6[b]	8		
Avail. K (mg/Kg)	0.14[a]	14	0.19[a]	111	0.48[b]	2		
Ca (%)	0.96[a]	25	1.59[a]	52	3.13[b]	6		
Mg (%)	0.33[a]	24	0.57[a]	40	0.56[a]	9		
Mn (mg/Kg)	14.94[a]	18	23.08[b]	18	24.06[b]	5		
Cu (mg/Kg)	6.21[a]	38	7.07[a]	22	6.98[a]	15	300.0	70.0
Zn (mg/Kg)	531.46[a]	17	701.08[a]	29	500.87[a]	8	600.0	200.0
Fe (mg/Kg)	289.32[a]	4	307.89[a]	24	273.56[a]	4		
Pb (mg/Kg)	66.72[a]	15	64.61[a]	40	71.28[a]	7	40.0	25.0
Cd (mg/Kg)	6.08[a]	18	4.80[b]	45	3.12[bc]	43	1.3	0.7
Cr (mg/Kg)	66.27[a]	14	55.99[a]	17	54.00[a]	10	60.0	70.0
Hg (mg/Kg)	1.08[a]	12	0.37[a]	65	0.33[a]	21	0.45	0.40
Ni (mg/Kg)	0.01[a]	0	0.04[a]	125	0.04[a]	50		
Se (mg/Kg)	0.02[a]	0	0.09[a]	44	0.06[a]	33		

NB: Same letters on means in the column indicate no significant difference at 5%

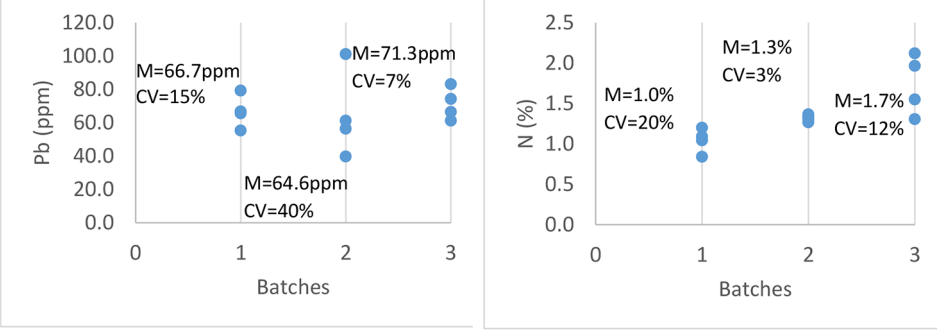

Fig. 6 Consistency within batches for Pb and N concentrations at end of co-composting

the level of consistency would also support policy makers and regulators in framing more responsive industry standards and regulations that are achievable and are reflective of the local context.

It is ideal that FS co-composting processes must have low CVs (consistent) to contribute to a reliable quality. As at the time of discussing these findings, there is no known threshold or rule for determining what an acceptable level of CV for quality parameters should be for FS co-composting. But the question of how low we should go for that threshold value would be determined from future research supported by an exploration of causes of within and between batch variations. This must not only be left to academia but must be a joint dialogue, research and formulation by FS co-compost producers, users, regulators, and academia to create acceptable consistency levels.

Conclusion

In conclusion, the level of inconsistency or variations between FS and FW co-compost batches (1, 2 and 3) were only observed for EC, and the measured nutrient parameters at the end of co-composting as indicated by the significant differences in mean. Replicate co-compost piles within batches exhibited coefficient of variation (CV) of measured parameters ranging between 0 and 125%. There was less consistency in nutrients between successive batches and CV within batches was wide. Consistency levels for *E. coli* may not be an issue if pathogen inactivation is complete. As at the time of discussing

these findings, there is no known threshold or rule for determining what an acceptable level of CV for quality parameters should be for FS co-composting.

Recommendation

It is ideal that, FS co-composting processes and product must have low CVs (consistent) to contribute to a reliable quality. It is therefore recommended that a threshold value be created for determining what is an acceptable level of CV for FS co-composting. This would be supported by a future exploration of causes of within and between batch variations as well as an investigation into ways to ensure consistency. FS co-compost producers, users, regulators, and academia must dialogue to create acceptable consistency levels.

List of abbreviations

FS	Faecal sludge
FW	Food waste
CV	Coefficient of variation
FDF	Faecal derived fertilizer
YKMA	Yilo Krobo Municipal Assembly
JVL	Jekora Ventures Ltd
DFS	Dewatered faecal sludge
EC	Electrical conductivity
USEPA	United States Environmental Protection Agency
MC	Moisture content

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Not applicable.

Authors' contributions

E.G.N contributed to the conception and design of study, data collection, analysis and interpretation of data, as well as drafting the initial manuscript. R.S., S.T. and O.C. contributed to the design of study, reviewing and interpretation of data, reviewing and approval of manuscript.

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Data Availability

Data supporting this study are openly available from CORD at https://doi.org/10.17862/cranfield.rd.24427339

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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