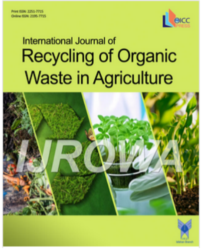

Special Issue (2024), S02 (1-13)

International Journal of Recycling Organic Waste in Agriculture (IJROWA), Special Issue

https://doi.org/10.57647/ijrowa-ty46-8z37

Impact of decomposing sawdust as an inoculum for promoting the composting of sawdust and chicken manure

Muinat Olanike Kazeem[1,*], Taiwo Ayodeji Sorunke[2], Amina Ahmed- El-Imam[1], Mohd Huzairi Mohd Zainudin[3]

[1]*Department of Microbiology, Faculty of Life Science, University of Ilorin, Ilorin, Kwara State, Nigeria.*
[2]*Department of Microbiology, Federal University of Health Sciences, Ila Orangun, Osun State, Nigeria.*
[3]*Laboratory of Sustainable Animal Production and Biodiversity, Institute of Tropical Agriculture and Food Security, University Putra, Malaysia.*

[*]**Corresponding author:** kazeem.mo@unilorin.edu.ng

Original Research

Received:
21 March 2024
Revised:
1 May 2024
Accepted:
5 Jun 2024
Published online:
19 July 2024

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Abstract:

Purpose: Composting process can be accelerated by seeding microbial consortium into compost of plant residues and livestock manure mixture. The consortium could also be sourced from decomposing sawdust due to extensive microbial activity. This study investigated the effect of decomposing sawdust as an inoculant on the microbial and physicochemical properties of sawdust-chicken manure compost.
Method: Decomposing sawdust collected at a depth of 0.6 – 1.2 m and a temperature between 40 – 48 °C was seeded into a sawdust-chicken manure mixture. The composting formulations used were, fresh sawdust + chicken manure (FSCM), fresh sawdust + decomposing sawdust (FSDS), and fresh sawdust + chicken manure + decomposing sawdust (FSCMDS). The composting process involved the use of pyramid piles (1.98 m × 1.89 m × 0.68 m). Physicochemical and microbial enzyme profiling, Scanning electron microscopy (SEM), Fourier transform infrared (FTIR), and plant bioassays were carried out.
Results: The compost formulations without inoculant exhibited higher microbial and enzyme activities throughout the composting process (lasting 37 days). High temperatures (45 – 59 °C) eliminates coliform bacteria after day 10, while thermophilic bacteria increased, with mesophilic bacteria dominating from the 25th day until maturation. The C/N ratio decreased to 12.62 and 15.04 in FSCM and FSCMDS, respectively, with reduced lignocellulosic composition and increased nutrients. The SEM analysis indicated disintegration of the feedstock while the FTIR spectra showed improvement in the aromatic content.
Conclusion: Overall, the FSCM formulation had the greatest effect on compost qualities and *Phaseolus vulgaris* development. FSDS did not promote the composting process. Thus, composting sawdust and chicken manure alone was sufficient to achieve a desirable C/N ratio, nutrient level, efficient degradation, microbial population, compost sanitization and growth of *Phaseolus vulgaris*.

Keywords: Compost; Plant bioassay; Enzyme profiling; Physicochemical; Biological activity; Scanning electron microscopy

1. Introduction

An increasing global population and urbanization indirectly contribute to increasing demand for agro-industrial products. Saw dust is a small particle of timber industrial waste commonly generated in the sawmill industry, pulp and paper industries and wood processing industries, particularly in the southern part of Nigeria. In Nigeria, sawdust is occasionally combusted as a cooking fuel, but its bulk accumulates in heaps in sawmills and other timber/logging factories and is disposed by burning or in landfills. This leads to environmental pollution with harmful effects on plants, animals, and humans. Sawdust, like other lignocellulosic biomass, can be converted into value-added products. Composting is one such transformation route, and it is an excellent technique for utilizing and stabilizing sawdust under regulated conditions through microbial breakdown. (Zhang et al., 2011). However, composting sawdust alone is a daunting task due to the high contents of cellulose, lignin, and other compounds. However, the addition of co-feedstocks, including cattle manure, watermelon, and chicken manure has been reported to improve and hasten the degradation/-composting process and compost quality (Oluchukwu et al., 2018; Qasim et al., 2018; Khatun et al., 2020).

The accumulation and inappropriate disposal of chicken manure can lead to unpleasant odor, groundwater contamination, pathogen proliferation, and nitrogen accumulation. Similarly, excessive manure application can lead to food plant contamination (Muhammad et al., 2020), and phosphorus loss (Qin et al., 2020; Goldan et al., 2023). Hence, the co-composting of chicken manure is an efficient way to address the problems associated with its accumulation and disposal.

Given the growing farmer's knowledge of the harmful effects of chemical fertilizers as a result of the tremendous demand for safe food products and the emergence of the organic farming movement, the need for compost is expected to grow. However, the utilization of immature compost can lead to root hypoxia due to microbial competition for oxygen (Ren et al., 2020). As a result, the use of microbial inoculants has become increasingly important since they accelerate the rate of refractory breakdown and increase microbial enzyme activity, resulting in early maturation and humus formation (Greff et al., 2022).

Microbial inoculants can be inoculated either through a consortium of beneficial microbes or through seed inoculation involving materials containing a highly active microbial population (Zainudin et al., 2022). Seeding composting feedstocks with materials containing a highly active microbial population will also add simple, metabolisable nutrients for immediate use by the native microflora, thereby reducing the lag phase, and ensuring active and progressive degradation. Song et al. (2021), reported that composting food waste digestate (FWD) with sawdust and mature compost effectively produced nitrogen-rich FWD compost due to a reduction of approximately 83% in NH_3 by volatilization. Loakasikarn et al. (2021) composted organic waste using commercial and mature compost as seeding inoculum. The organic matter degradation and enzyme encoding genes were similar irrespective of the seeding material, although the microbial communities were different. According to Karnchanawong and Nissaikla (2014), compared with microbial inoculant, seeded compost resulted in the greatest reduction in volatile solids compared to microbial inoculants. It was obvious from their study that it might not be necessary to add commercial inoculants to facilitate the composting of organic waste.

Composting involving both microbial inoculant and seeded inoculant is mostly characterized by physical and chemical properties (Yang and Zhang, 2022; Yang et al., 2023). However, the link between microbial activity, enzyme succession and structural and morphological changes caused by feedstock conversion are poorly understood. During composting, the physical and chemical parameters including pH, moisture content, temperature, aeration, carbon, and nitrogen (C:N) are the most critical parameters for enhancing microbial activities and their enzymes, and the effects of these activities on the organic matter transformation can be analyzed through SEM and FTIR analysis.

Massive heaps of sawdust are found in Nigeria, where they are decomposed naturally by native microbes. These piles become viable sources of highly active microbe mixtures that may be employed to aid composting. Because there is inadequate of knowledge on the use of decomposing sawdust as a seed inoculant for composting raw sawdust, this study intends to produce mature compost from raw sawdust, decomposing sawdust, and chicken manure. Physical and chemical parameters, microbial activity, SEM, and FTIR were monitored during the composting process. Finally, the effect of the compost produced on cowpea (*Phaseolus vulgaris*) growth was studied.

2. Materials and methods

Composting feedstocks

Fresh sawdust was obtained from Tipper Garage sawmill, Ilorin, while the decomposing sawdust was collected from a 20-year-old sawdust heap in Ipata, Ilorin, from depths of 0.6 m and 1.2 m. The chicken manure also was obtained from a local poultry farm also in Ile-Apa, Ilorin, Nigeria. All materials were labeled and transported to the composting unit of the Biomass and Bioenergy Laboratory of the Department of Microbiology, University of Ilorin, Kwara State, Nigeria.

Composting preparation

The composting process was carried out as described by Berkley's rapid composting method (Raabe, 2001), which involves shredding and frequent turning. Sawdust was examined to remove the unwanted materials such as larger particles. The extraneous materials were also removed from the chicken manure. Three formulations were prepared comprising various mixtures of raw materials as shown in Table 1. The composting materials were mixed to form a pyramid shape of length 1.98 m, width of 1.89 m and height of 0.68 m and adjusted to 70% moisture content with water. The materials were turned at intervals of $2-3$ days with the addition of water to maintain the moisture. Parameters such as temperature, pH, and moisture content were recorded and monitored to ensure that active decomposition was maintained. Physicochemical and other microbiological analyses were performed at intervals until the 37^{th} day. The samples from each pile were collected for micro- and macronutrient analysis. The samples were also collected every 5 days to evaluate the microbial population of the functional microbes such as cellulolytic bacteria. To ensure that the samples were representative of the compost pile, equal amounts were taken from the bottom, center and top of each pile and composited as one sample within the pile.

Table 1. Formulation of piles used for composting.

Treatment	Compost pile formulation	Ratio of formulation
FSCM	Fresh sawdust + chicken manure	2:1
FSDS	Fresh sawdust + decomposing sawdust	2:1
FSCMDS	Fresh sawdust + chicken manure + decomposing sawdust	2:1:1

FSCM = Fresh sawdust + chicken manure, FSDS = Fresh sawdust + decomposing sawdust (obtained from 0.6 m + 1.2 m depths), FSDCM = Fresh sawdust + decomposing sawdust (obtained from 0.6 m and 1.2 m depths) + chicken manure.

Physical and chemical analysis of saw dust-manure stock during composting and in mature compost

The temperature of the compost piles was detected using a glass thermometer, while the moisture content was determined by drying one gram of the sample to a constant weight at 105 °C. The pH was determined in a compost slurry with a 1:10 w/v ratio of compost and distilled water using an electrode pH meter (PCE-228HTE PCE Instruments. UK) while electrical conductivity (EC) of the same slurry was determined using a conductivity meter (Milwaukee MW302 Milwaukee Electric Tool Corp. US). The carbon content was determined using the method of Walkley and Black (1934), while the Kjeldahl method (AOAC, 1980) was used for nitrogen determination. The mineral nutrients and heavy metals were determined according to the method described by the AOAC (2000). The cellulose, hemicellulose, and lignin content were determined by the method described by Goering and Soest (1970). The color change was assessed visually while the odor was assessed by smelling.

Microbiological analysis

The bacterial load was determined on nutrient agar (NA), McConkey agar, and potato dextrose agar (PDA) for viable fungal counts. Briefly, one gram of compost sample was mixed in 10 mL of sterile distilled water, agitated at 150 rpm for 15 min, and then serially diluted and spread onto NA, McConkey agar, and PDA agar plates. The plates were then incubated at 37 °C for mesophilic bacteria, 55 °C for thermophilic bacteria, and 25 °C for fungal counts. Cellulolytic activity was screened by plating on carboxymethyl cellulose (CMC) agar plates containing NA and PDA supplemented with 1% CMC. The cellulolytic potential of the isolates was determined by flooding CMC-agar plates with iodine solution, after 24 h of incubation on NA-CMC agar and 72 h on PDA-CMC agar plates. Isolates showing a zone of clearance were selected for further characterization.

Enzyme assay

The crude microbial enzyme was extracted by mixing 2 g of compost sample in a 50-mL centrifuge tube containing 10 mL of phosphate buffer (pH 7.0). The mixture was vortexed for 2 min and then centrifuged at 10,000 x g for 10 min. The supernatant was withdrawn and used as the crude enzyme. The cellulase activity was determined according to Wood and Bhat (1988). To determine CMCase activity, 0.5 mL crude enzyme was reacted with 0.5 mL of 1% CMC in 0.05 M phosphate buffer (pH 7.0). For xylanase activity, 0.5 mL crude enzyme was added to a reaction mixture containing 0.5 mL of 1% xylan in phosphate buffer pH 7.0. The mixtures were incubated at 50 °C for 30 min and the reaction was stopped by adding 3 mL of dinitrosalicylic acid (DNS) (Essex, UK). Thereafter, the reducing sugars liberated were determined using the 3,5-DNS method (Miller, 1959). One unit of CMCase/xylanase activity was determined as the amount of enzyme required to liberate 1 µmol of glucose in 1 min under the specified assay conditions.

SEM and FTIR analyses

Scanning electron microscopy (SEM) analysis of the raw and mature compost was performed on a scanning electron microscope (JOEL-JSM 7600F Tokyo, Japan). The samples were fixed on double-sided adhesive tape and mounted on an aluminum stub. The gold-coated samples were viewed at an accelerating voltage of 10 kV. The Fourier transform (FTIR) infrared analysis of the different compost treatments was obtained using an FTIR spectrophotometer (GX2000, Perkin Elmer, USA). The compost samples were scanned at a wavelength of 400 – 4000 1/cm and a resolution of 1 cm^{-1}.

Phaseolus vulgaris (cowpea) bioassay

Cowpea seeds were used in three planting experiments. First, three cowpea seeds were planted in a nursery bed containing soil amended with compost formulations (FSCM, FSDS, and FSCMDS) in a 1:1 mix. The seeds were planted in ordinary compost samples in the second experiment, whereas soil alone was employed in the third experiment (control). The nursery was irrigated and weeds were manually controlled. The leaf numbers and stem heights from each treatment were measured on the 16th day. The data were analyzed using ANOVA and Duncan's multiple comparisons test, with significance set at $p < 0.05$.

3. Results and discussion

Changes in the physical and chemical properties of sawdust-manure stock during composting

The Composting process exhibited three temperature phases: thermophilic, mesophilic, and maturation (Fig. 1 a). The FSCM and FSCMDS formulations reached a maximum temperatures of 59 °C and 55 °C, respectively, on the 2nd day, while FSDS, it peaked on the 4th day at 35 °C. The temperature dropped to 45 °C by the 10th day in both the FSCM and FSCMDS formulations, then continually declined up to 33 °C by the 37th day of the composting maturation phase. On the other hand, the temperature declined to 31 °C in FSDS by the 10th day, which persisted until the end of the experiment. This rapid temperature increase is attributed to the aerobic metabolic activities of microorganisms in-

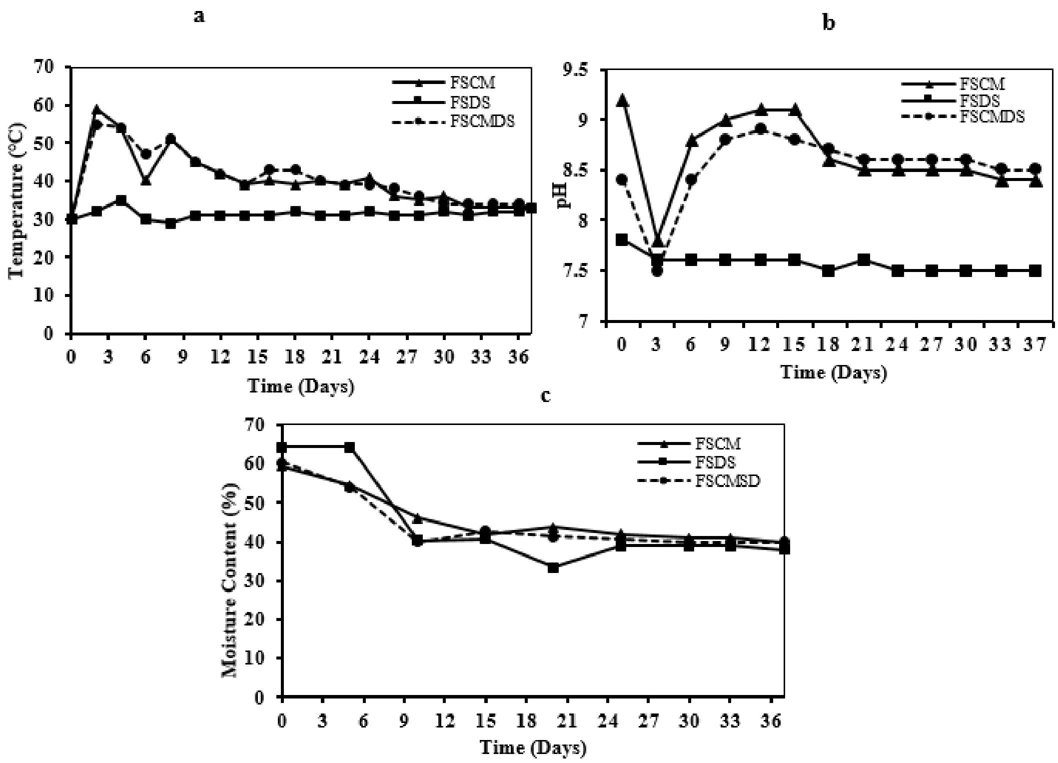

Figure 1. Variation of temperature (a), pH (b) and moisture content (c) profile, during the composting of sawdust and chicken manure formulation, FSCM = Fresh sawdust + chicken manure, FSDS = Fresh sawdust + decomposing sawdust (0.6 m + 1.2 m), FSCMDS = Fresh sawdust + decomposing sawdust (0.6 m + 1.2 m) + chicken manure.

volved in the active biodegradation of organic materials to release energy (Alavi et al., 2017; Wang et al., 2018). One of the main functions of microbial inoculation is to enhance the composting process by accelerating the degradation of organic or cellulosic materials. Microbial inoculant is commonly used either as a single or mixed cultures with various functional activities such as cellulolytic, proteolytic, nitrifying, and denitrifying activities which are responsible for organic matter degradation and transformation. Moreover, the gradual decrease in temperature may be due to a decrease in the organic matter and activities of the microorganisms (Alavi et al., 2017; Wang et al., 2018). Both FSCM and FSCMDS reached temperatures above 50 °C by the second day, suggesting that both formulations better supported microbial decomposition activities than did the FSDS. The steady prolonged mesophilic temperature maintained in FSDS may be due to various factors, including lower organic carbon due to the age of the sawdust heap and lack of chicken manure inoculum as a nitrogen source. Similarly, the sawdust dump might have been subjected to burning during a certain period of accumulation. Hence, there was not sufficient degradable organic C to meet the energy demand of the organisms, thus, heat could not be released during the thermophilic stage. Likewise, the refractory nature of sawdust due to the presence of lignin acted as a bottleneck, preventing efficient degradation by the microorganisms.

With respect to the changes in pH, the pH suddenly decreased, followed by a rapid increase and then gradual decrease until it stabilized (Fig. 1 b). On day 3, the pH of FSCM and FSDSCM decreased to 7.8 and 7.5 respectively and then increased rapidly again while there was negligible pH variation in FSDS. The decrease in pH is possibly due to microbial nitrification leading to the accumulation of nitrite and nitrate (Wang and Ai, 2016). The ammonification process causes a rise in pH while the conversion of ammonia to nitrate by nitrifying bacteria leads to a further decrease in pH until it becomes stable (Li et al., 2021). The composting pH range in this study was within the recommended range of 6.7 – 9.0 (Bernal et al., 2009; Rastogi et al., 2020).

The Moisture content (MC) is crucial for transporting nutrients utilized in metabolic activities during composting. A moisture content higher than required could cause water logs and anaerobic conditions, halting the decomposition process (Makan et al., 2013). The MC decreased gradually throughout the composting process from 60.33% to 46% and 40% in FSCM and FSCMDS, respectively, by day 10 (Fig. 1 c). Notably, a decrease was observed before the end of the thermophilic stage. The increase in temperature at the thermophilic stage likely resulted in evaporation and a decreased in the MC. After the thermophilic stage, the MC was maintained at 40% until maturation. This result is supported by previous studies that indicated similar trends (Suhartini et al., 2020). Again, FSDS had a greater MC than the other piles at the beginning of the composting process, which is likely due to lower metabolic activities.

The chemical properties of the compost formulations before and after composting are presented in Table 2. The C/N

Table 2. Chemical changes of the different compost formulations.

	Cations mg/100g					cmol/kg				Percentage (%)					
	P	K	Ca	Mg	Na	CEC	C	N	C:N	Ni	Cd	Zn	Cellulose	Hemicellulose	Lignin
Raw feedstock															
FSCM	1.0	1.14	3.14	1.37	2.11	8.55	42.66	1.46	29.22	0	0.05	0.22	38.46	20.14	18.4
FSDS	1.1	1.20	2.83	1.34	2.20	7.57	45.63	1.33	34.31	0	0.02	0.08	40.28	21.08	16.23
FSCMDS	1.2	1.25	1.75	1.30	2.14	8.54	47.62	1.71	27.85	0	0.08	0.24	36.48	20.1	16.45
Mature compost															
FSCM	1.0	1.18	3.79	1.87	2.18	27.3	25.25	2.00	12.62	0	4.63	9.42	28.40	12.24	5.60
FSDS	1.1	2.24	2.94	1.34	2.20	18.5	42.70	1.66	25.72	0	1.61	29.94	27.40	10.20	5.36
FSCMDS	1.2	1.36	3.82	1.42	2.25	21.65	36.94	2.18	15.04	0	4.02	11.04	28.14	10.62	5.48

ratio in all composting piles was ≤ 15 except for FSDS, showing that the compost reached maturity. Compared with the initial feedstock, the mature compost exhibited variation in the increased production of minerals as compared to the initial feedstock. The P, K, Ca, Mg, and Na are present in relatively high amounts. A similar increase in minerals was reported previously (Hachicha et al., 2009). Moreover, the presence of heavy metals indicates the extent of contamination in the compost. Compared to the concentration in the initial feedstock, the most abundant heavy metal recorded was zinc. This was mainly due to weight loss resulting from organic matter degradation and mineralization during composting (Hachicha et al., 2009). The cellulose, hemicellulose, and lignin content drastically decreased in all the mature composts. This shows that active degradation occurred during the composting.

Microbiological properties of sawdust-manure stock during the composting process

The role of the inoculant is to promote the degradation of organic matter. In this study, sawdust was used as a carbon source in chicken manure composting. Sawdust consists of recalcitrant compounds such as cellulose and hemicellulose, making it difficult to decompose. Therefore, the isolation of cellulolytic microbes including bacteria and fungi were isolated to evaluate their stability to in enhance the composting process through microbial inoculation. After preliminary screening on a CMC-agar plate, 30 bacteria and 21 fungal species showed a positive hydrolysis zone (HZ), among which species with an HZ > 1 were reported (Table 3). The highest HZs (2.7 mm) for bacteria were recorded for A837T, followed by C737 and A745 with HZs of 2.6 mm and 2.2 mm, respectively. Notably, the fungi species produced higher HZs (≥ 1.5) than did the bacteria species. Here, the ISO4, ISO8, and IS22 isolates produced HZs at 3.4 mm, 3.2 mm, and 3.0 mm, respectively. Higher cellulase production have been reported in fungi than in bacteria due to higher penetration ability (Wei et al., 2009). Diverse microbial biota participated in the composting process with bacteria (thermophilic and mesophilic biota) and fungi (mesophilic biota) being detected at the various stages (Fig. 2 a-c). Generally, mesophilic bacteria (MB) were predominant at the initial stage of the composting. With increasing temperature, the MB count declined sharply before increasing again. The availability of organic substrates and the prevalence of mesophilic conditions supported the high growth of mesophilic bacteria. The thermophilic bacteria (TB) peaked at the thermophilic temperature and then declined until the end of the process. Mesophiles are the primary active degraders, while the thermophiles are stimulated by an increase in temperature at the thermophilic stage, which drives the degradation of more recalcitrant materials such as the lignocellulosic biomass (Federici et al., 2011; Kazemi, 2017). The mesophilic fungi (MF) increased at the initial stage, and subsequently decreased with increasing temperature, followed by a steady growth increase until compost maturity. The MF benefitted from the decrease in temperature, low pH, and moisture content experienced in the process. Both the MB and MF populations had similar trends which is similar to the reports that both increased in the first 30 days of composting of olive mill waste (Hachicha et al., 2009).

The FSCM formulation had the highest (8.69 cfu/g) TB count, followed by FSCMDS (8.30 cfu/g), while the lowest (6.70 cfu/g) was recorded for FSDS. The MB count increased to 8.60, 8.14, and 7.68 cfu/g on the 37^{th} day in FSCM, FSCMDS and FSDS, respectively. The FSDS had the highest (5.85 cfu/g) MF population. This could be a result of the low temperature experienced during the composting. The presence of numerous microbial populations at the maturation stage is crucial for the final degradation of lignocellulosic biomass to obtain a mature compost (Villar et al., 2016).

The risk of plant and human infections by pathogens is a critical problem associated with the direct use of poultry manure in agriculture. Initially, all the formulations showed a high density of coliform bacteria (CB), but it was eliminated by composting. The highest coliform population at 9.77 cfu/g was observed in FSCM, followed by 9.54 cfu/g in FSCMDS, while FSDS had the lowest coliform population at 8.90 cfu/g, which was due to the absence of manure in the formulation. A total decline in the coliform population was observed in the FSCM and FSDS on the 10^{th} day of composting. However, FSCMDS showed the complete elimination of coliform bacteria on day 5 of composting. The sanitization of the compost was achieved at the ther-

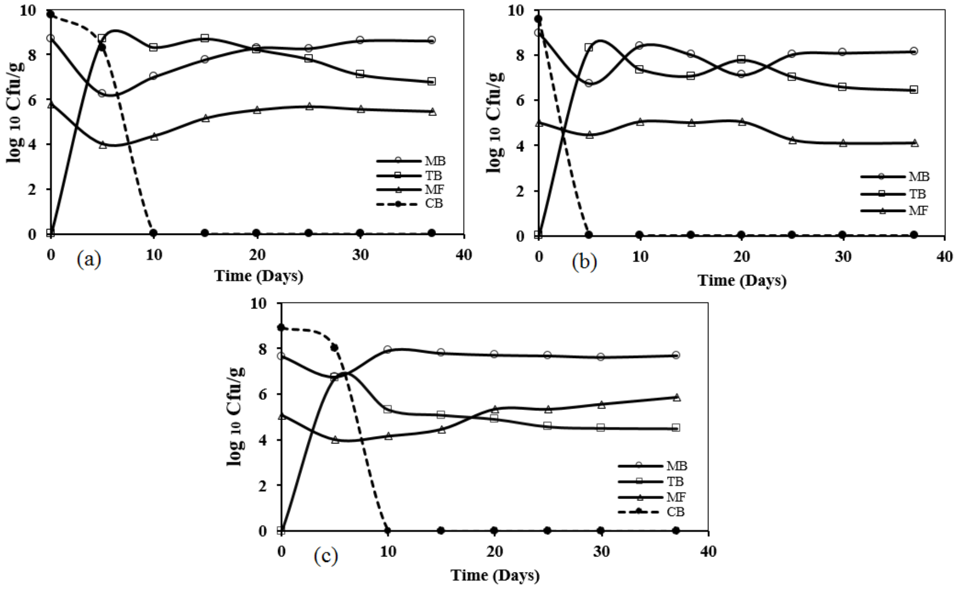

Figure 2. Changes of microbial population during the composting process of (a) FSCM, (b) FSDS and (c) FSCMDS. MB:Mesophilic Bacteria; TB: Thermophilic Bacteria; MF: Mesophilic Fungi; CB: Coliform Bacteria. Values are mean of triplicate ± SD

mophilic stage (45 − 59 °C) in the formulations. This is similar to the reduction of coliform bacteria by 99.9% − 100%, in vegetable fruit waste Topal et al. (2016) and is a better outcome compared to reports that a temperature of 57.7 °C for 4 months can significantly eliminate pathogenic bacteria (Hachicha et al., 2009).

Changes in enzyme activities during composting of the formulations

The cellulase and xylanase activities exhibited at various composting process stages are evidenced (Fig. 3 a-b). Generally, xylanase activity was observed to be higher than cellulase activity. The cellulase activity profiles of FSCM and

Table 3. Hydrolysis zones of cellulolytic bacteria and fungi on CMC-Agar.

Bacteria Isolate	Hydrolysis zone (mm)	Fungi isolate	Hydrolysis zone (mm)
A837T	2.7 ± 0.2	IS11	2.1 ± 0.3
A837	1.4 ± 0.1	IS12	1.5 ± 0.3
B737	1.3 ± 0.4	IS15	1.7 ± 0.7
C737	2.6 ± 0.2	IS21	2.2 ± 0.2
A745	2.2 ± 0.8	1S22	3.0 ± 0.6
B745	1.9 ± 0.3	IS20	2.8 ± 0.5
C745	1.5 ± 0.6	IS08	3.2 ± 0.4
C745S	2.1 ± 0.1	IS04	3.4 ± 0.3
B845	2.0 ± 0.1	IS14	2.8 ± 0.1
C745T	1.2 ± 0.2	IS23	1.5 ± 0.5

The values are presented as the means of triplicate measurements ± S.Ds

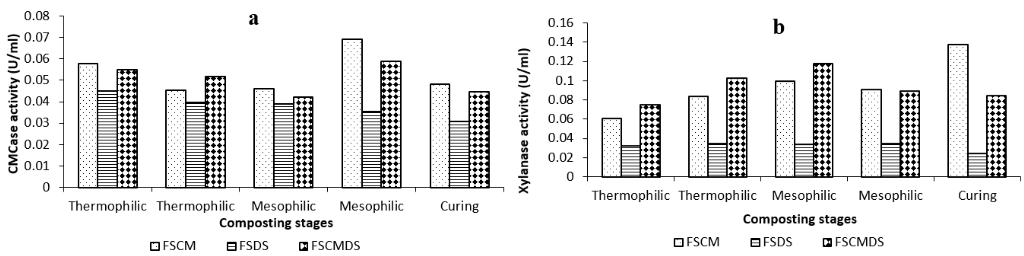

Figure 3. Changes in (a) cellulase and (b) xylanase activities during the composting of sawdust and chicken manure with and without the inoculant.
FSCM = Fresh sawdust + chicken manure, FSDS = Fresh sawdust + decomposing sawdust (0.6 m + 1.2 m), FSDCM = Fresh sawdust + decomposing sawdust (0.6 m + 1.2 m) + chicken manure.

FSCMDS followed similar trends across the stages. With an initial increase, the cellulase activity declined through the first mesophilic stage, reaching a maximum at the second mesophilic stage, followed by a final stage decline. The cellulase activities reached a maximum at 0.069 U/mL and 0.058 U/mL in FSCM and FSCMDS, respectively. However, FSDS showed a steady decline in cellulase activity throughout the stages.

The FSCM and FSCMDS exhibited rapid increase in xylanase activity until the first mesophilic stage, followed by a decrease at the second mesophilic stage. Although xylanase activities in FSCM later increased at the curring stage, those of FSCMDS remained stable. The highest xylanase activity (0.137 U/mL) in FSCM was achieved at the curring stage. However, that of FSCMDS reached a maximum activity (0.118 U/mL) at the first mesophilic stage.

The initial increase in cellulase activity could be as a result of the presence of a readily exposed cellulose matrix due to the mechanical treatment during milling. Cellulases are generally grouped into inducible and constitutive enzymes (Zhang et al., 2017). Therefore, organisms that produce constitutive cellulase might be dominant at the initial thermophilic stage. In addition, the degradation of lignocellulose during composting might not be limited to microbial activities. For example, the high temperature in combination with the organic acids released could serve as a form of pretreatment or pyrolysis, opening up the lignocellulose matrix and releasing some simple sugars. The sugars can then be utilized as an inducible substrate for cellulase production at the early thermophilic stage. The high cellulase activity obtained at the later mesophilic stage is in agreement with Wei et al. (2012), who observed an increasing cellulase activity at the later stages in wood chip-grass composting. The amorphous nature of the xylan component explains the observed continuous increase in xylanase activity at the earlier stages of the composting. This observation is juxtaposed by the high cellulase activity observed at the second mesophilic stage. It can be explained that at this stage xylanase has successfully hydrolyzed the xylan hemicellulose, thus, opening up the cellulose matrix for easy accessibility to cellulase, for hydrolysis. The removal of hemicellulose improved the accessibility of enzymes to cellulose (Kruyeniski et al., 2019). The results of this study are consistent with those of Wei et al. (2012), who reported higher hemicellulase levels at the earlier stage of composting.

SEM analysis

From our study, it appeared that the FSCM had better results in terms of physicochemical properties, microbial changes, and enzyme activities. Therefore, SEM analysis was performed to examine the surface morphologies of the raw and mature composts. Fig. 4 shows that the raw feedstock had a compact, rigid, relatively continuous surface-ordered structure, while the final compost had a discontinuous, rough, and loose structure in which some parts of the surface were missing. This shows that the action of microorganisms and their enzymes, together with various physicochemical properties during the composting process resulted in disaggregation and biodegradation of the final compost. The degradation of lignocellulose during composting is a dynamic and synergistic process involving a diverse community of microorganisms. It is a complex process that involves the combined action of various microorganisms, such as cellulolytic, hemicellulolytic and ligninolytic microbes. Each microbe contributes specific enzymes to degrade different components of plant cell walls. Cellulolytic and hemicellulolytic microbes produce cellulases (endoglucanase, exoglucanase, β-glucosidase) and hemicellulases (xylanase, mannanase) to breakdown cellulose and hemicellulose while ligninolytic microbes produce ligninolytic enzymes such

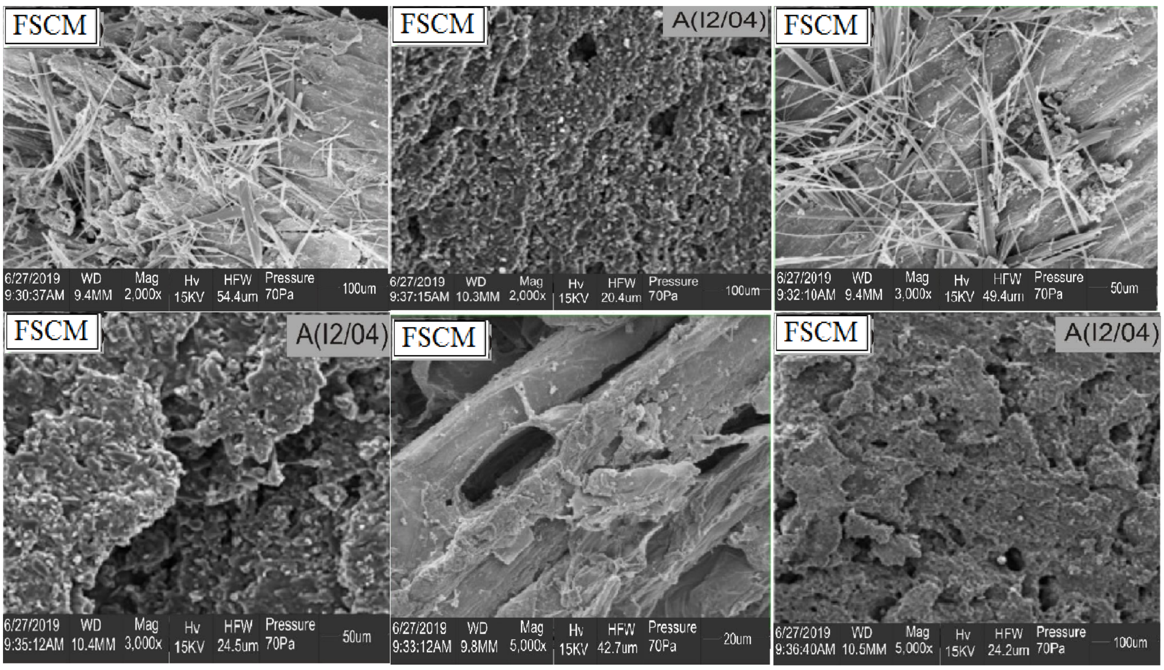

Figure 4. SEM images of raw and mature composts of saw dust-chicken manure compost formulation FSCM.

as lignin peroxidase, manganese peroxidase and laccase to degrade lignin. These enzymes act synergistically to break-down lignocellulose materials into simpler sugars and other compounds which can then be utilized by the microbes for energy and growth. The results corresponded with the FTIR analysis, which revealed structural alterations based on peak intensity variations, indicating the degradation of cellulose, hemicellulose, and lignin structures during the composting process.

FTIR spectroscopy

This method confirms the extent of decomposition of the several functional groups present in the feedstock, with the presence or absence of several absorbance bands in the functional groups indicating decomposition (Gupta and Garg, 2009). The FT-IR spectra bands of the feedstock mix and the mature compost formulations are depicted in Fig. 5. The broad peak indicating spectra band between 3700 and 3100 1/cm confirms the presence of cellulose, hemicellulose, and lignin. Compared with those of the feedstock, the intensities of the mature compost formulations decreased. Srivastava et al. (2020), reported that the decreasing intensity at 3387.8 1/cm is attributed to the decomposition of phenols and carbohydrates as a result of the reduction in OH and CH_2 structures. Similarly, Lim and Wu (2015), reported a band at 3328 1/cm correposponding to decreasing carbohydrate content in palm oil mill effluent (POME) vermicompost. The change in peak intensity at 3385 1/cm suggested the C≡C stretching vibration of nitrile. The C≡C stretching of nitriles was observed at 2329 1/cm in paper waste compost. An increasing band intensity at 1664 1/cm was observed for the mature compost formulation FSCM and FSCMDS in comparisons with FSDS and the initial feedstock. This might be attributed to an increase the in aromatic C=C groups during the composting process. Srivastava et al. (2020), reported an increase in band intensity at 1644.8 1/cm due to C=C stretching of the aromatic group in municipal solid waste vermicompost. Similarly, Al-Alawi et al. (2019), reported a decrease in maturity of green waste compost.

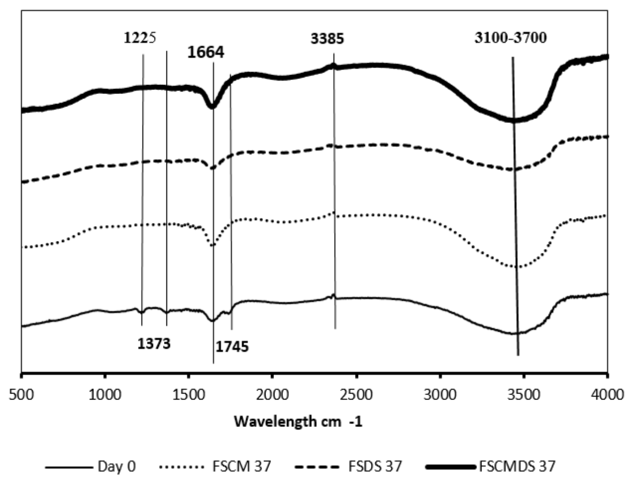

Figure 5. FTIR Analysis of the initial and mature saw dust -chicken mature compost formulations

There was a disappearing band at 1745, 1373, and 1225 1/cm in all the mature compost in comparison to the initial feedstock. The band at 1745 1/cm is attributed to the C=O stretching of hemicellulose, while the intensity peak at 1373 1/cm suggested the N-O stretching of the nitro group. A similar intensity peak was observed by Hamidu et al. (2020), although their intensity peak was observed at 1344.78 1/cm. The 1225 1/cm band could be attributed to C-O-C stretching, which could indicate the biodegradation process. The C-O-C stretching was observed by Wu et al. (2011), in MSW landfill stabilisation. A similar result was observed by Al-Alawi et al. (2019) however, the intensity was noticed at 1165 1/cm. The frequencies of the absorption bands are given in Table 4.

Plant bioassay

The plant bioassay was performed by growing Phaseolus vulgaris (cowpea) on the compost-aided soil, compost and soil only (Table 5). Leaf number and stem height were recorded on day 16 after planting. The FSCM-aided soil had a significantly greater ($p > 0.05$) leaf number (15.0 ± 1.1) and stem height (21.7 ± 1.9 cm). The stem height (17.0 ± 1.9 cm) and leaf number (11.0 ± 0.9) of the FSCMDS treatment were greater than those of the FSDS stem height (13.3 ± 0.9 cm) and leaf number (09.0 ± 0.8), which was significantly different at ($p > 0.05$). However, there was no significant difference ($p > 0.05$) in the leaf number between the FSDS treatment and the control, which was similar to the difference in stem height observed between the sample FSCM treatment and the control. Plant bioassays were also carried out on compost without aided soil. Among the three compost formulations, the FSCM sample also had the greatest number of leaves (14.0 ± 1.6) and greatest stem height (15.0 ± 1.3 cm), which were significantly higher ($p > 0.05$) than those of the FSDS, FSCMDS and the control (soil only) treatment.

However, the number of leaves produced by the FSCMDS-treated plants and the control plants did not significantly differ. It was evidenced that both samples FSCMs (soil-aided and FSCM only) improved the leaf numbers better than did the control (soil only). However, it did not improve the stem height of cowpea plants when compared with that of the control. Overall, soil-aided FSCM showed the highest growth rate of cowpea. This explains that FSCM can be used to improve organic matter, properties and also supplement nutrient deficiency in the soil. Although, sample FSCMDS also contributed nutrients to the soil as evidenced by a significant increase in leaf number over the control. However, the growth rate was lower than that of the FSCM sample. In this experiment, compost sample FSDS recorded the least growth rate.

Overall, composting without inoculum produced better results in terms of the physicochemical properties, microbial population, enzyme activities, and plant growth than composting with inoculum (decomposing sawdust). This could be because the decomposing sawdust may have gone through an improper degradation process, resulting in reduced microbial growth and activity. A proper composting process will generate an abundance of functional microor-

Table 4. Frequency of absorption during composting of sawdust-chicken manure compost formulations.

Wavenumber location (1/cm)	Vibration and assignment	References
950 – 1200	C-O bond of Polysaccharides C-O stretching of cellulose and lignin	(Barana et al., 2016) (Guo et al., 2008)
1030 – 1080	C-O stretching of polysaccharide or polysaccharide-like substances, SiO asymmetric stretch of silicate impurities	(Filip and Bielek, 2002)
1000 – 1250	C-O-C stretching, C-O covalent bonds, and C-OH, linkages are dominant in cellulose, hemicellulose, and lignin.	(Binod et al., 2012)
1417	Asymmetric C-H bending signifies a C-H stretching in cellulose and hemicellulose	(Baharuddin et al., 2010)
1630 – 1650	Attributed to amide 1 group	(Baharuddin et al., 2010)
1711 – 1740	Uronic ester and acetyl groups in hemicellulose C=O bond which is a component of various polysaccharides such as cellulose and hemicellulose.	(Alemdar and Sain, 2008); (Stewart, 1995); (Abraham et al., 2011)
2970	Attributed to aliphatic methylene groups and assigned to fat and lipid	(Grube et al., 2006)
3427 – 3451	H-bonded-OH group vibrations present in cellulose, hemicellulose, and lignin	(Kshirsagar et al., 2015); (Kazeem et al., 2017)

Table 5. Effects of soil-aided compost on *Phaseolus vulgaris* (cowpea) growth.

Sample	Leaf number*	Leaf number**	Stem height* (cm)	Stem height** (cm)
FSCM	15.0 ± 1.1^a	14.0 ± 1.6^a	21.7 ± 1.9^a	15.0 ± 1.3^a
FSDS	09.0 ± 0.8^c	03.0 ± 1.5^c	13.3 ± 0.9^c	05.0 ± 0.9^d
FSCMDS	11.0 ± 0.9^b	09.0 ± 1.7^b	17.0 ± 1.9^b	12.0 ± 0.5^c
Control***	09.0 ± 1.3^c	09.0 ± 2.0^b	21.0 ± 1.0^a	21.0 ± 1.0^b

*compost + soil, ** compost only, *** soil only Values are presented as the means of triplicate measurements ± S.D. Means with different superscripts in a row are significantly different ($p > 0.05$).

ganisms, which will subsequently promote the composting process when its product known as finished compost is used as an inoculant. It has been suggested that a successful composting process requires a balanced carbon-to-nitrogen (C/N) ratio to promote the degradation process by enhancing the microbial population (Sinha et al., 2020). In the composting process, carbon serves as both an energy source and a fundamental building block of the microbial cell mass. Nitrogen is an essential component of proteins, nucleic acids, amino acids, and enzymes for cell development and function. As a result, an optimal C/N ratio will enable the generation of diverse microbial communities with excellent functioning, hence improving the composting process. This finding is in agreement with our finding that composting with chicken manure (FSCM and FSCMDS) had a lower C/N ratio than composting without chicken manure (FSDS), indicating that chicken manure provides the N source for microbial growth and functioning thus, enhancing the organic matter degradation. In addition, the composting with chicken manure (FSCM and FSCMDS) also contains a considerable amount of nutrients (N, P, K) which promotes the *Phaseolus vulgaris* (cowpea) growth.

Composting is an essential process for organic material degradation, providing nutrients for plants, and reducing waste. This process is often improved by adding inoculants, which promote microbial activity and maturity. However, finding practical and accessible inoculant resources is not always easy and can also be costly and time-consuming. Therefore, the search for alternative sources of readily available inoculants becomes essential for sustainable compost production. One such potential source is decomposing sawdust, which can be used as a natural inoculant particularly for local or regional settings. This study showed that the use of decomposing sawdust has a positive impact on the composting process when amended with chicken manure. However, it is important to note that further improvements and optimization are needed to achieve optimal outcomes. Overall, the use of readily available inoculants such as decomposing sawdust can contribute to the sustainable composting practices and should be explored further.

4. Conclusion

Based on the findings of this study, it is concluded that inoculating compost stocks such as sawdust-chicken manure mixtures with decomposing sawdust has proven to be an effective means of producing high-quality compost for use as organic amendments to improve soil fertility status and plant performance. A comparison of the compost formulations, revealed that FSDS performed poorly due to lower microbial and lignocellulose degrading enzyme activities, resulting in inefficient degradation and low nutrient content. Monitoring of the physical and chemical parameters of the compost during composting revealed the progression of the composting process. Specifically, for C/N $\leq$ 15 in the FSCM and FSCMDS, established compost maturity and nutrient enrichment including trace or heavy metals. SEM analysis confirmed surface structure modification while FTIR revealed positive transformation in the compost. The growth characteristics of *Phaseolus vulgaris* revealed that the application of FSCM enhanced growth performance compared with other formulations. Composting sawdust-chicken manure without inoculant (non-seeding using decomposing sawdust inoculant) is enough to obtain compost of high quality with a C/N ratio of 12.62, 100% sanitization, efficient degradation, increased nutritional elements and effective soil ammendment for high growth performance of *Phaseolus vulgaris*. However, composting sawdust-chicken manure amended with decomposing sawdust (inoculant) will be equally suitable in local regions where there is a scarcity of available chicken manure.

Authors contributions

The authors confirm the study conception and design: MOK, TAS, AAE; data collection: MOK, TAS; analysis and interpretation of results: MOK, TAS, MHMZ; draft manuscript preparation: MOK, TAS, AAE, MHMZ. The results were evaluated by all authors, and the final version of the manuscript was approved.

Availability of data and materials

Data described in this manuscript are accessible upon request.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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