Co-composting of sawdust with food waste: effects of physical properties on composting process and products quality

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Abstract

Sawdust and food waste have been part of solid organic waste causing great environmental pollution. Composting is a popular utilization method of converting waste like sawdust and food waste to sanitized and stabilized soil amendment. Unfortunately, many composting systems failed due to a dearth of information as a result of little or no scientific research focused on the effects of the physical properties of composting materials on the composting process. To fill this knowledge gap, three composting experiments of food wastes mixed with sawdust at ratio 20:80, 30:70, and 40:60 and compacted to different initial bulk densities of 15, 20, and 25 kg/m^3 respectively was carried out. Physicochemical parameters monitored throughout the composting process include bulk density; porosity; particle density, temperature, moisture content; pH, and electrical conductivity (EC). The highest temperature (65.3 ^{o}C) was recorded by trial 3 while trial 1 recorded the lowest temperature (49.3 ^{0}C). A steady decrease in temperature after the thermophilic stage was observed throughout the composting process. Among trials 1, 2, and 3, the maximum pH (9.2) and EC (5.1 mS/cm) were observed in compost trial 3. Additionally, the lowest pH (5.3) and EC (1.4 mS/cm) was observed in trial 1. Moisture content ranged from 60–15%. Trial 3 had the highest percentage finest and lowest fibrosity content. A significant increase in bulk density, porosity, and particle density was observed in the three compost trials. The compost's bulk density of (25 kg/m^3) in trial 3 was observed to attained maturity and stability as compared with trials 1 and 2.

1.0 Introduction

A large amount of waste generated from agriculture and food waste from households is one of the global serious issues (Hadi et al. 2021). The rate at which solid organic waste is being generated worldwide due to the rise in population and industrialization is alarming (Wu *et al*., 2014). Many of these wastes are disposed of untreated and it has caused environmental and health challenges (Lukashe et al. 2019; Awasthi et al. 2014; Sukholthaman et al. 2016). Traditional waste disposal methods and inappropriate waste management make the case even worst in developing countries. Household wastes are mixed with other wastes and are disposed of at dumpsites without any efficient material or energy recovery (Oudal et al. 2016). Recently in Nigeria, there is an increase in demand for wood for furniture and other construction purposes, as a result, a considerable amount of sawdust from timber is generated from sawmills. Sawdust is a waste product in form of a tiny piece or powder from wood as wood is cut by hand saw or machine of different sizes (Hadi et al. 2021). South-west Nigeria alone with over 10,000 sawmills is currently processing over 500,000 logs of woods per year, with about 50–55% as waste informs of sawdust (Adegoke et al., 2014). As a result, a huge landfill of sawdust is been created at the sawmill and it poses a threat to humans and the environment. Getting rid of sawdust requires maximum operational cost, as a result, many were dumped to form sawdust piles and many were burnt on regular basis. Abdul-Halim et al., (2019) reported that improper disposal and or indiscriminate burning of biomass are responsible for depleting quality of air, contributing to an increase in greenhouse gas emissions, and significantly contributing to global warming and climate change. In addition, it has become a source of contaminant to drinking water, soil pollution (Hwang et al. 2020) and constitutes a major threat to the environment and human health. Therefore, the need for more effective waste management and reasonable plan should be adopted to overcome this environmental concern (Moh et al. 2017).

Concerning food waste, it forms a major threat globally because it increases daily due to the increase in human population and improvement in the global economy. FAO statistics report of 2020 indicated that about one-third of food produced is wasted globally (FAO, 2020) and Nigeria alone contributed about 32 million tones of wasted food (Adebayo et al., 2020). The statistics indicated that 57% are wasted during the cooking and distribution process, 30% are wasted as a leftover, 13% are on storage and disposal (FAO, 2020). Food waste is widely defined as solid or liquid matter, processed or unprocessed, and unintended or intended dump as a leftover during the processing and distribution process (FAO, 2020). However, food waste is becoming an environmental challenge that threatens man and environmental resources (land and water resources) if it is discharged into the environment without prior treatments. It may cause pollution and harmful effects on human and animal health (Ghosh et al. 2019). It is however important to find effective management of these wastes to promote the effort concerning the development of a sustainable society.

Researches has proved that organic waste products can be recycled using different technologies such as aerobic digestion, composting, fermentation, refuse-derived-fuels, and gasification (Kelleher, 2007; Mashat, 2014; Nizami et al., 2017). All these methods require the service of an expert which is an additional cost to the processing of these wastes. Composting has several advantages over other methods of recycling organic waste and it is also considered as a sustainable treatment of converting organic wastes into valuable end products. Converting waste to valuable end products through composting is eco-friendly, in addition to its cost-effectiveness, the valuable end product among others makes composting the most widely adopted method (Al-Rhumaihi et al. 2020). It is also considered the best option for recycling waste without causing environmental hazards (Chen et al. 2018; Calaby-Floody et al. 2019). Composting is gaining more attention as many of the developed nations has reported having adopted composting as a method of recycling and processing the wastes being generated in their country. For example in Europe, over 4 million tonnes of organic waste were recycled by more than 124 compost facilities. Similarly, European countries like; Holland, Spain, and France composted 24, 33, and 14% of the total waste generated in the year 2005 alone (Kelleher, 2007). Composting by-products has been extensively used as organic fertilizer to replenish loss soil nutrients (Wang et al. 2019) and as bioremediation to remove soil organic contaminants (Chen et al. 2015; Purnomo et al. 2011).

Composting is a biological process of converting organic waste into a stable and hummus-like organic product through microbial decomposition under aerobic conditions to produce a good quality organic soil conditioner (Fernandez et al., 2014; Hemidat et al. 2018; Bao et al. 2016). The composting process starts with the mixing of an organic substrate which is the prerequisite for every composting management condition (Cao et al. 2020). However, setting up good management composting system requires good knowledge about the physical properties of the substrates and the bulking agents. Knowing this could necessitate efficient maintenance and run of a composting plant. Inadequate information about the physical properties of compost material has made many composting systems fail. It is, therefore, necessary to have vital information about the physical properties of the materials involved and understand the composting system.

Composting is a biological process that needs oxygen and moisture for microbial activities (Assandri et al., 2021). The distribution of moisture, oxygen, and temperature within compost is an important factor in maintaining aerobic conditions during composting. The movement of moisture and air across the compost is greatly affected by the geometry and arrangement of the bulking agent where physical properties play a major role (Orthodoxou et al. 2015; Agnew et al. 2005). Moisture and air are required in moderate proportion during composting. Too much moisture and air could lead to excessive cooling and could prevent the compost from reaching the thermophilic condition that is necessary for optimum decomposition and sanitization of the matured compost. Also, inadequate moisture and air in the compost could result in to decrease in oxygen availability to microorganisms and heat evenly distributed across the compost matrix and this could lead to anaerobic conditions. Moisture and air transfer in the composting system are greatly controlled by the physical properties of the substrate. Good knowledge of these physical parameters is important for the analysis and process control of the composting systems.

Most of the physical properties of composting materials that attracted great attention are bulk density, porosity, and particle density. Bulk density of compost is the ratio of the mass of composting materials to the volume of the composting materials and it determines some mechanical properties of the compost such as strength, porosity, and ease of compaction (Mayur et al., 2018). The bulk density of compost determines how fast or slows the degradation of the compost. Due to this, knowing the bulk density of compost is an important requirement for designing an efficient compost system.

2.0 Theoretical Relationship Of Physical Properties In A Porous Organic Matrix

When forming a compost pile, the physical properties of the composting mixture must be taken into consideration for optimal performance of the moisture content, carbon to nitrogen ratio, and to provide a favourable condition for microorganisms (Mayur et al., 2018). Mayur et al., (2018) have identified some of the important physical parameters that affect the optimal performance of the composting process such as bulk density, moisture content and air-filled-porosity or free air space. As soon as the compost pile is formed, difficulties are often observed because the effects of some physical properties are always ignored or information about it is not available. For example, bulk density plays a crucial role in the strength and porosity of the compost pile. If the pore space gets filled with water in the presence of high moisture content, then there would be an increase in air space resistance, which results in oxygen deficit in the pile, and anaerobes started dominating aerobes. Bulk density is the ratio of the mass of compost to its volume. Its mathematical expression is kilogram per cubic meter (Kg/m^3) (Eq. 1).

$$Bdw\,() = \frac{mass\,of\,t\,he\,material}{volume\,of\,t\,he\,bin} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$BD_d = BD_W \times \frac{100 - \%moisture}{100} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Where γ_{wet} is wet bulk density (Kg m[3]).

Another physical parameter that determines the distribution of air and moisture across the compost matrix is porosity. Porosity or air-filled porosity as popularly called in compost literature can be expressed in terms of bulk density and moisture content as described in Eq. (3)

$$\text{Porosity}\ (\eta) = \left(1 - \frac{\gamma_{wet}}{p_d}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Where pd is the particle density

Many studies have been carried out on composting sawdust with food wastes or with other substrates (Jae-Han et al., 2020, Zaihua et al., 2020). These studies explained the efficiencies of unconventional bulking agents in composting food waste and end product (Jae-Han et al., 2020), about biological parameters such as oxygen uptake rate, carbon dioxide (CO_2) evolution rate, and Physico-chemical properties such as moisture content, volatile solids, C/N ratio and heavy metals (Singh and Kalamdhad, 2013a; Nayak et al, 2014). However, little scientific data exist on the best physical properties for composting sawdust with a substrate (food waste). This study was designed to investigate the effects of physical properties of composting materials on composting process during the composting of sawdust with food waste as well as to evaluate the best bulk density for composting sawdust with food waste.

3.0 Materials And Methods

3.1 Experimental materials

3.1.1 The compost bin

60 liters, low-cost, and non-biodegradable plastic containers were used in this study (Fig. 1). The plastic container was light, easy to handle and control, and was water resistant. The inner diameter of the container was 290 mm while the height was 380 mm. The filled line of 300 mm was marked from the bottom of the compost bin. Holes of 3 mm diameter separated by 10 cm was drilled on the side and bottom of the container corresponding to 10% surface porosity, this was necessary for proper aeration and the drainage of the leachate during the composting process. The bins were then placed on a wooden support to minimize heat loss.

3.1.2 Food waste and sawdust

The food wastes were collected from University of Ilorin canteens and were made up of leftover cooked rice, breads and waste vegetable. The bigger food particles were cut to smaller sizes < 1.5 cm. The sawdust was from soft tree (Malaina tree) and was packed from local sawmill. It was sieved by 5 cm aperture size sieve to obtain the same materials size. The two were then mixed together at different proportions with spade, and was then loaded into bins. Three different composting mixtures at three different initial bulk densities were formulated.

Table 2
The initial experimental conditions of each of the composting trials

	Composting mixture			
Trials	**Sawdust (%w/w)**	**Waste food (%w/w)**	**Initial moisture Content (%)**	**Initial bulk density (kg/m^3)**
1	80	20	60	15
2	70	30	60	20
3	60	40	60	25

3.2 Experimental setup and monitoring process

3.2.1 Bulk density

Equation 1 was used to measure the bulk densities of the composting experiments. The bins were filled with mixture of composting materials previously mixed at different proportions. Each bin was moderately compacted from predetermined heights of 100 mm, 150 mm and 200 mm respectively. After compaction, the procedure was repeated to filled the bin to the desire level and bulk densities. At the end of the process, each experimental trials has the initial bulk densities of 15 kg/m^3, 20 $kg/m^{3,}$ and 25 kg/m^3 respectively. The initial moisture contents of the experiments were set to 60%.

3.2.2 Physicochemical analysis during the composting period

The three composting bins were veered weekly. The maturity indexes were also measured weekly till the compost was matured. Temperature was recorded three times in a day; at 8 a.m in the morning, 3 p.m in the afternoon and 8 p.m in the night, and a Reotem analog compost thermometer was used. This was done by putting the thermometer probe to the compost at different level by means of holes drilled on the bins. Also, compost samples were oven dried at 105^0C to constant weight to ascertain its moisture content.

Samples approximately 0.050 Kg of compost were randomly picked from different part of the bin and absolutely blended to earn a 0.15 Kg weekly which was divided into three. For the purpose of pH and Electrical conductivities (EC) determinations, 0.050 Kg of the blended compost was used. The pH and EC were measured by mixing the known sample with 10 cm^3 of distilled water and then shook. A pH meter (pH-3C, Shanghai, China) was inserted to measure pH, and Electrical Conductivity (EC) was also determined using a conductivity meter (LeiCi, Shanghai, China). Method described by Wang et al., (2021a) was used to measure the total organic carbon (TOC). Total nitrogen (TN) was measured using the Kjeldahl method (Cao et al. 2018) and the ratio of TOC to TN gives the C:N ratio. The remaining 0.05 kg compost sample was used to measure the bulk density and moisture content of the sample throughout the composting period.

The free air space or porosity of the compost was measured from the bulk density and particle density of the compost mix using Eq. (3). Bulk density was measured using a plastic container whose volume is approximately 50 cm^3. The plastic container was filled to one-third height and gently tapped on the plain surface to eliminate voids; then, filled up to two-thirds and after that up to the top brim of the container. Bulk density was calculated by dividing the mass of the compost by the volume of the plastic container. A pycnometer was improvised using a plastic bottle having a screw cap to measure the particle density of the compost material. A hole of 2 mm diameter was drilled on the cap. Small plastic tubing was attached to the hole with about 30 mm length of tube projecting into the bottle when covered with a cap. The rest of the tube was bent on top of the cap and conducted excess liquid out when the bottle was filled with liquid. The lower density of compost makes distilled water unsuitable to use as displaced fluid to measure the density of the compost material; therefore, kerosene was used as reference fluid because of its lower density following the Mayur et al., (2018) method.

3.3 Analysis of the final products

The physical, biological, and chemical properties of the final compost obtained were analyzed. The chemical properties of the final compost assessed include; EC, pH, Cation exchange capacity (CEC), C:N ratio, Phosphorus, and Nitrogen contents, while the physical assessment was based on the loose bulk density, and percentage finest of the final compost. The biological assessment of the final compost was based on phytotoxicity evaluation using the Germination index (Tibu et al. 2019). Compost extracts were prepared from the final compost by mixing 20 g of air-dried compost in 10 cm^3 of distilled water. The mixture was then shook for 30 min after which was filtered using Whatman No 4 filter paper to produce compost extract which was then used in germination index tests. Tomatoes seed (*Solanum lycoperiscum*) (Viability as tested = 90%) was used for the germination index test. Whatman No 4 filter paper already moistened with an extract from compost was laid in a Petri dish and Ten (10) viable seeds of tomatoes were placed on it. A control experiment was also set up using deionized water only. The experiments were replicated thrice and were set up in the laboratory where the temperature was maintained at room temperature. After 7 days of incubation, germinated seeds were counted (Tibu et al. 2019) and the germination index (GI) was evaluated according to Eq. 4

GI (%) = $\frac{\%seedGermination \times RootLenghtofTreatment}{\%seedGermination \times RootLenghtofControl} \times 100$ …………4

Where

GI is germination index

3.4 Physical properties analysis of the final compost

3.4.1 Percentage finest determination

The percentage finest determination of the matured compost was done using a mechanical shaking method. From each of the compost, a known representative sample of dried compost was placed on a stack of 5 standard test sieves arranged on the shaker and shaken for 10 minutes. The mass (g) of compost retained on each sieve was measured and was recorded. The procedure was repeated three times for each of the samples compost. The retained compost samples on each sieve were classified into four different fraction sizes: oversize, coarse, pin, and fine. Particle size < 24 mesh (> 850 μm) were oversize, 24–60 mesh (500–850 μm) were coarse, 60–70 mesh (400–500 μm) were pin size and 70–80 mesh (177–400 μm) were classified as fine particle size.

3.4.2 Fibrosity content determination

The fibrosity content of each of the matured compost trials was measured by the method described by Boylan et al., (2009). A compost sample with Known volume and water content was saturated overnight in a concentration of 40g/L solution of sodium hexametaphosphate (Calgon) to disperse the fibers. The sample was then washed in a 150μm sieve with distilled water. The retained material on the sieve was then gently rubbed by hand and the remaining fibers with a diameter greater than 0.5 mm were removed using tweezers. This was then oven-dried at 80^{O}C to a constant mass. Percentage fiber was then calculated using Eq. (5)

$$fibrecontent(\%) = \frac{M fibre-dry}{M original-dry} \times 100$$ ……………..5

Where

M $_{fibre-dry}$ is dry mass of fibres

M $_{Original-dry}$ is the original dry specimen mass

3.5 Statistical analysis

All the experiments were repeated three times and for each sampling; the mean and standard deviation were reported in this study. All the calculations and graphical analysis were done using Microsoft excel 2010.

4.0 Results And Discussion

4.1 Characterization of the Raw materials

The composting materials have different physical and chemical properties. The moisture contents were found to be approximately 10.23% for sawdust and 64.23% for food waste. In composting experiment, the total organic carbon and nitrogen content of the materials is the nutritional characteristics of the composting materials, the ratio of the two (C:N ratio) is used to assess the nutritional balance for the microorganism. However, the C:N ratio of sawdust was 49.59, while that of food waste was 34.95. The C:N ratio of sawdust was slightly higher than that of the food waste. In addition, the two composting materials were slightly acidic with pH of 5.6 and 5.3 for sawdust and food waste respectively. The electrical conductivity of the composting materials was within the range of 7.55 dS/m for sawdust and 41.63 dS/m for food waste. The higher electrical conductivity recorded by food waste may be because of some salts present in the food materials. Fibrosity content was determined for sawdust only and was found to be 89.0%. Bulk densities for both materials were 15.12 and 10.23 Kg/m^3 for sawdust and food waste respectively.

Table 1
Basic characterization of raw materials used in the composting experiments

Parameters	Sawdust	Food waste
TN (%)	1.62 ± 0.16	1.54 ± 0.29
TOC (%)	80.34 ± 1.47	53.83 ± 0.20
C/N	49.59	34.95
pH	5.65 ± 0.11	5.36 ± 0.47
EC (dS/m)	7.55 ± 0.47	41.63 ± 0.65
Moisture content (%)	10.23 ± 0.23	64.23 ± 0.13
Fibrosity content (%)	89.0 ± 0.02	*Nd
Bulk density (Kg/m^3)	15.12 ± 0.01	10.23 ± 0.14
Nd = not determine		

4.2 Composting temperature evolution

Composting temperature is one of the key parameters of the stability index that indicate the stability and maturity of the compost (Mayur et al., 2018). Temperature affects microbial activities during composting and it also indicates process change during composting. The breaking down of complex organic compounds into simpler units is enhanced by temperature (Waqsa et al. 2018). Figure 1 shows the temperature profile of trials 1, 2, and trial 3 for different bulk densities respectively. As shown in the figures, temperature ranges and duration at each stage differ in each of the experimental trials and this could attribute to the different experimental conditions of each of the composting trials. Microbes' activities are responsible for an increase in temperature during an active composting period (Prashant et al. 2019). For it to perform at optimum, it should be provided with adequate nutrients, moisture, and oxygen. In this present study, it was observed that the temperature of the three composting trials increased rapidly from day 1 of the experiment, peaked at different days, and started cooling until they were stable and reached ambient temperature. This shows that biodegradation of organic materials through the activities of microbial has started. Jakubus (2020) recorded the same in the study of comparative compost prepared from various organic wastes based on biological and chemical parameters. In this study, each of the composting trials recorded the three temperature phases i.e mesophilic $< 45\ ^{O}C$, (heating period), thermophilic $> 45\ ^{O}C$ (high temperature period) and cooling phase $<$ $45\ ^{O}C$ (Mayur et al., 2018). The optimum temperature range to kill pathogen is 40–65 ^{O}C (Wang et al. 2021, Bao et al. 2016) and it must last for three to four days to sanitize the compost. In this study, the observed temperature ranged between 42.3^{O}C and 65.3^{O}C throughout the experimental period and this is enough to kill pathogens in the compost.

Compost trial 3 recorded the highest temperature (65.3 ^{O}C) and it lasted for more than three days. In compost trial 3, the initial bulk density was 25 Kg/m^3; therefore the physical structure of this trial allows even distribution of oxygen and moisture for microorganisms. The increase in the activities of microorganisms in this trial leads to a rapid increase in temperature. Compost trial 1 recorded the lowest temperature during the high-temperature period (49.3 ^{O}C). The lowest temperatures recorded in this trial indicate lower activities of microorganisms. In trial 1, the compost materials are closely packed together as a result of compaction, therefore, a high rate of biodegradation occurred and this led to high-temperature evolution within the compost. This shows that a bulk density of 25 Kgm^3 is favourable for temperature rise as free air space is reduced therefore more oxygen and moisture is available for microorganisms. Therefore, it may be assumed that the high bulk density corresponds to less free air space. Microorganism decomposes organic matter and heat is released, the temperature of the composting trial increases at the beginning of the composting process. With the decrease in organic matter content of the composting materials and through heat loss by ventilation and evaporation (Arias et al. 2021), the temperatures of the trial gradually decreased and reach ambient temperature. However, the best bulk density from the perspective of temperature in this study was that of experiment trial 3.

4.3 Moisture content

Estimation of moisture requirement is important for optimum productivity of composting process and one of the major factors that need to be considered in the composting system design (Hemidat et al., 2018). Moisture must flow for an adequate supply of oxygen to microorganisms for proper microbial activities. Literature reported different moisture content, for example, Liang et al. (2003) recommended moisture within the range of 70% for maximum microbial activities while Wang et al. (2021)

recommended moisture within the range of 50–60%. Moisture content greater than 60% is not recommended as it prevents oxygen from the tiny pore of the compost pile and lowers its aerobic activities (Nahm, 2005). This is supported by Looper (2002) who found that moisture content above 60% produces odour and stops temperature to rise to thermophilic during composting. Bulk density directly influenced the moisture needed for effective composting. The theoretical volume of water needed is related to the initial bulk density and air-filled porosity of the compost (Equations 1 and 2). Concerning trials 1, 2, and 3, the initial moisture contents were adjusted to the required range of 60% (Wang et al., 2021). Consistent with other reported data, this moisture range was the best to support microbial activities. Generally, the moisture content of the three compost trials decreased gradually during the composting process in the first four weeks of the composting period. This can be attributed to active microbial activities and the turning frequency of the compost (Cao et al., 2020). The change in moisture content was more pronounced in compost trial 3, followed by trial 2, and least in compost trial 1. This result is in line with the findings of Pezzola et al. (2021) in the study of the use of new parameters to optimize the composting process of different organic waste.

The moisture content of trials 2 and 3 were significantly decreased and the highest temperatures were also recorded in these trials. The decrease in moisture content in trials 2 and 3 may be due to the activities of microorganisms that consume moisture during their activities (Jae-Han et al., 2020). In trial 3 which had the highest bulk density, a maximum moisture content reduction of more than 50% of the total moisture was observed. This could be as a result of the highest bulk density of the compost (Mayur et al., 2018). During active composting, bulk density increases and eliminates or reduces the air-filled-porosity which is believed to be inaccessible to microorganisms (Mayur et al., 2018) and this leads to a decrease in porosity; as a result, less moisture would be available for microorganisms and this would reduce their activities (Makan et al., 2013). As the compost approached stability, the moisture content in all the compost trials gradually decreased to around 23.33%, 21.54%, and 18.43% in trials 1, 2, and 3 respectively. There was no significant relation between mixing ratio and moisture content, but the compost trial 3 with the highest bulk density recorded the lowest reduction of moisture content.

4.4 Evaluation of pH and electrical conductivity (EC)

4.4.1 pH

Figure 4 shows the evaluation of the pH of the composts. The pH range during the composting period is used to assess the progress of composting as it influences the microorganism growth and gaseous loss of ammonia (Hemidat et al. 2018). Variation in pH tends to occur because of chemical changes in the chemical composition of composting materials. Changes in pH were observed in the three trials throughout the composting period in this study. Many researchers have reported that the initial pH value of the mixture should range from about 6.0 to 7.0 (Chang et al., 2019; Varelas, 2019). However, the initial pH value of the compost trials after mixing in this study was slightly alkaline (6.3–6.9) which was optimum for microbial activities. This was in agreement with the finding of Abdul-Halim et al., (2019) who recorded the same range of initial pH values. As the composting was progressing, pH value varies across the composting experiment. However, after the third week, i.e during the thermophilic stage of composting pH values in the trials significantly increased. The significant increase in pH value was more pronounced in experiment trial 3. The pH increase in all the trials may be as a result of volatilization of organic acid under high temperature (Manu et al., 2019), consumption of organic acids by microorganisms, the production and accumulation of NH_4^+ and humic substances (Elkinci et al., 2019, Manu et al. 2019), and mineralization of acidic compounds such as carboxylic and phenolic group (Madejon et al. 2021) and due to the breaks down of complex amino acids and peptides with the release of NH_4^+ (Sundberg et al. 2013). The pH changes in trials 1 and 2 followed a similar pattern. After then, pH values in all the trials were then decreased. According to Wang et al., (2021), the production of NH_3 gas from the decomposition of nitrogen tends to increase the pH value in the early weeks of composting but decreases later due to the decomposition of organic acid to organic matter. At the end of the composting experiment, the pH of the three trials of this study decreased and was observed to be lower than the initial values and almost alkaline. Trial 1 with an initial bulk density of 15 Kg/m^3 showed the lowest final pH range (7.4), while trial 2 and 3 was a little bit higher than trial 1

4.4.2 Electrical conductivity of the composting trials

Electrical conductivity (EC) determination is crucial during composting as it indicates the salinity and the usability of final compost products. It also shows the number of soluble salts in the compost. An increase in EC would lead to phytoinhibitory effects (Zhou et al. 2019). The electrical conductivity greater than 4 mS/cm is considered injurious to plants (Manu et al. 2018) because the soluble salts can negatively affect seed germination. The electrical conductivity of each of the trials displays an irregular pattern throughout the composting period. It first increased then decreased and later increased at the end of the composting period. When the composting experiment was started, compost trial 3 recorded the highest EC (Fig. 4). This observation might be as a result of the highest proportion of food waste in trials 3 which leads to the buildup of soluble salt which is assumed to be as a result of food salinity or the presence of mineral salts like phosphates and NH_4^+ through the breakdown of compost materials (He et al. 2020). The initial EC of trial 3 is significantly higher than compost trials 1 (1.8 mS/cm) and 2 (1.8 mS/cm). This may be due to the highest proportion of food waste in compost trial 1. Trial 1 had the smallest proportion of food waste so it had the smallest initial EC value. Early in the third week, compost trials 1 and 2 showed a similar value of EC, except trial 3 that still maintained a higher EC value than trials 1 and 2. After the 8th week of composting, no significant reduction was observed in EC of compost trial 3. It still maintained higher EC than trials 1 and 2. However, in the early 10th week, all the compost trials had similar EC values. The final EC was below 4 mS/cm which is good for plant production (He et al., 2020).

4.5 Total Organic Carbon, Total Nitrogen, and C/N ratio

4.5.1 Total organic carbon

Organic carbon from the bulking agent is consumed by microorganisms as food for metabolic activities, this leads to degradation of organic matter by microbial activities in the presence of oxygen with the release of CO_2 gas leading to the production of organic matter, therefore, total organic carbon decreases generally during the composting process (Hadi et al. 2021). As shown in Fig. 7, TOC showed a downward trend in all the composting trials with compost trial 3 exhibiting the greatest decrease in TOC, while compost trial 1 recorded the lowest decrease in TOC. The greatest reduction in total organic carbon was observed at the high-temperature stage of the composting, and the main reason for the decrease in TOC content in compost trial 3 was because of high temperature and vigorous microbial activities recorded in this trial, so at the end of the process, TOC was lowest in this trial. In trial 2, organic carbon degradation was gradual while it was slowest in trial 1. The reason for the slowest organic matter degradation in compost trial 1 was because of the lowest temperature recorded in the trial. In compost trial 1, the composting materials are less compacted together leaving more space for air and moisture to penetrate, therefore microbial activities were slowest in this trial and as a result, the temperature was lowest in this trial compared to trials 2 and 3. At the end of the composting process, total organic carbon reduction in compost trial 1 was the least.

4.5.2 Total Nitrogen

Figure 8 shows the nitrogen variation of each of the composting trials during the composting process. Total nitrogen was first decreased in all the composting trials during the earlier stage of composting and later increased continuously till the end of the composting period. Several scholars reported similar observations in their study. For example, Yu et al. (2019) observed that nitrogen content first decreased and then increased during the study of changes in carbon, nitrogen components, and humic substances in organic-inorganic aerobic co-composting. The authors claimed that the loss in nitrogen at the early stage of composting could be attributed to volatilization (Yu et al. 2019) and due to some loss in the form of NH_3-N (Sun et al. 2017; Lu et al. 2016; Cao et al. 2020). The loss in nitrogen content at the early stage of composting could be due to the consumption of nitrogen content by microorganisms for growth and reproduction (Ren et al. 2016) and due to leaching from the compost. However, as the composting is progressing, a significant increase in nitrogen content was recorded in all the composting trials during the subsequent sampling. An increase in nitrogen maybe because of the degradation of organic carbon compounds (He et al. 2017).

4.5.3 C/N Ratio

Another important parameter for the determination of composting time, quality of the final compost, temperature, and for evaluating compost maturity is the C:N ratio. It also plays an important role in formulating the nutritional balance of a composting mixture. Carbon and nitrogen are needed by microorganisms as a source of energy for metabolic activities. A proper C:N ratio is favourable to microbial growth and production and also good for soil and plant growth (Kebibeche et al. 2019). As the composting progressed, the C/N ratio was decreased throughout the composting period in all the composting trials. A decrease in C/N ratio was highest in compost trial 3, moderate in trial 2, and lowest in compost trial 1. This may be due to variation in temperature as a result of compaction. Compost trial 1 had the lowest bulk density (15 Kg/m^3) so, the temperature was lowest in this trial and it recorded the lowest reduction in C/N ratio value. In compost trial 3, the changes in total nitrogen and organic carbon were high; therefore the reduction of C/N ratio was highest in this trial. At the end of the composting process, the highest reduction in C/N ratio was in compost trial 3 and the lowest reduction was observed in compost trial 1. This result was in line with the result of Getahum et al. (2012) in the composting of municipal solid waste.

4.6 Physical properties variation during composting

4.6.1 Bulk density, particle density, and porosity

Figure 9 shows the variation of bulk density of the compost trials throughout the composting period. The initial bulk density of the compost trials was 15 kg/m^3, 20 kg/$m^{3,}$ and 25 kg/m^3 for trials 1, 2, and 3 respectively. During the composting process, an increase in bulk density was observed in all the trials. This may be as a result of the settlement of the compost as soon as it was compacted. A similar result was reported by Zhao et al. (2011) during composting of municipal solid waste of different particle sizes. Zhao et al., (2011) reported that an increase in bulk density was a result of the decrease in particle size of the waste. During the compaction of the compost, the volume of the compost is reduced while its mass remains unchanged. The highest bulk density in this study was observed in compost trial 3, while the lowest bulk density was observed in compost trial 1. Therefore, an increase in bulk density in trial 3 may be a result of the compaction effect.

For an effective composting process, air (oxygen) must flow to achieve maximum compost performance. Bulk density, porosity, and free-air-space are interconnected and play a critical role in air movement in the compost mix (Iqbal et al., 2010). Free-air-space or air- filled-porosity as cited in literature with a minimum value of 30% and 60% maximum is required to ensure the aerobic condition (Mayur et al., 2018). Different studies reported different free air space values. For example, Ahn et al., (2008) and Ruggieri et al., (2009) reported a maximum value of 85–90% without any negative effects on compost. But in this study, a decreasing trend in porosity value was observed with maximum and minimum porosity values of 46.34% and 37.41% were observed. The minimum and maximum porosity value of 37.41% and 39.23% was recorded in compost trial 1. For trials 2, 33.64% minimum and 40.36% maximum were recorded. While 46.34% maximum and 30.67% minimum were recorded in compost trial 3.

4.7 Evaluation of Final Compost

4.7.1 Maturity and stability analysis of the matured compost

Compost maturity simply refers to the level of decomposition of the poisonous substances formed during the composting phase (Wu et al. 2000). The maturity and stability of the final compost are important for its use in agriculture. If compost is not stable, microbial activities in it can cause adverse effects and can affect plant growth since the final product will be of agricultural use. The properties of the final products obtained in this study are shown in Table 3. The final product varies in terms of its physical and chemical properties. In all, the final pH of all the compost trials was within the recommended value (6–8), with the value being close to alkaline (7.4–8.3). Total nitrogen in the compost trial 3 (1.78%) was slightly higher than trial 1 (1.14%) and 2 (1.45%). The electrical conductivity ranged between 3.15 and 2.13 dS/m, C/N ratio ranged between 10.56 and 19.59, CEC value between 13.66 and 26.27, a phosphorous value between 8.29 and 11.08 Cmol/Kg, and final moisture content values between 20.20 and 23.20%.

4.7.2 Phytotoxicity of the matured compost

The matured compost must be free of any poisonous substance before it can be use as soil organic fertilizer. Determination of the level of toxicity is important as it it gives insight into the agricultural value of the final product. The most common and economical method used to evaluate agricultural value of the final compost is the germination index method (Tibu et al. 2019). Germination index test carried out to evaluate the level of phytotoxicity of the final compost of this study using tomato seed recorded 100% in trials 1 and 2 while trials 3 recorded 90% germination. Similar observations were reported by Tibu et al. (2019). In his study of phytotoxicity, germination index between 80 and 100% was reported. The high germination index recorded in this study might be due to the presence of nutrients in adequate proportion in the final compost of each of the compost trials. Tibu et al (2019) reported that if the germination index values are greater than 80%, then the compost is phytotoxin-free and it is safe and good to use. So, in this study, all the compost trials showed germination index values greater than the limit value, and therefore considered phytotoxin-free and safe to use.

Table 3
Chemical properties of the final compost

Composting Trials	C:N	pH	EC	CEC (Cmol/Kg)	Phosphorus (Cmol/Kg)	Nitrogen (%)	Moisture content (%)
Trial 1	19.59 ± 0.25	7.8 ± 2.11	2.13 ± 0.24	13.66 ± 0.08	8.29 ± 1.52	1.14 ± 0.02	23.20
Trial 2	14.85 ± 0.10	8.3 ± 2.01	2.91 ± 0.22	22.20 ± 0.28	11.08 ± 0.81	1.45 ± 0.01	22.40
Trial 3	10.56 ± 0.20	7.4 ± 1.07	3.15 ± 0.16	26.27 ± 0.12	8.25 ± 1.44	1.78 ± 0.01	20.50

Table 4
Physical properties of the final compost

Compost trial	Finest (%)	Fibrosity (%)	Bulk density (Kgm^{-3}) Initial final
Trial 1	89.0 ± 0.01	0.5 ± 0.012	15.0 28.21 ± 0.2
Trial 2	95.0 ± 0.12	0.0 ± 0.00	20.0 37.21 ± 0.5
Trial 3	97.0 ± 0.11	0.0 ± 0.00	25.0 45.23 ± 0.3

4.8 Physical properties of the final compost

4.8.1 Finest and fibrosity content of the matured compost

The physical characteristics of the final compost were also evaluated based on the finest ratio and fibrosity content. Compost trial 3 had the highest percentage finest (97%), followed by compost trial 2 with 94% finest, and experiment trial 1 had the lowest percentage finest 89% finest. Fibrosity contents vary significantly among the experimental trials, experiment trials 3 and 2 recorded zero fibrosity while experiment trial 1 recorded 5% fibrosity content. The zero fibrosity recorded in trials 2 and 3 shows that all the sawdust in these trials were decompose totally while trial 3 contains some fiber content as a result of incomplete decomposition of the sawdust by microorganisms.

4.9 Regression analysis

The interactions between the physical parameters (bulk density, porosity, particle density, and moisture content) considered in this study were analyzed using correlation analysis (Wu et al. 2019). The graphical representation is shown in Fig. 8a - c. A strong positive correlation was found between porosity and moisture content and it exceed 0.9. The correlation between bulk density and porosity was negatively correlated (-0.942), and the highest negative correlation was between moisture content and bulk density (-0.978). The reason for the negative correlation between bulk density and porosity is that bulk density increases throughout the composting process the porosity show decreasing trend. The same thing happened between moisture contents and bulk density, as composting progressed moisture was lost and bulk density increases.

5.0 Conclusions

The study was carried out to investigate the influence of the physical properties of composting materials on composting of sawdust with food waste. For this reason, sawdust and food waste was composted in a bin at the initial bulk densities of 15, 20, and 25 kg/m^3. Physic-chemical parameters were monitored during the composting period. According to the results obtained and presented above, the three composting trials at different initial bulk densities had reached an acceptable degree of maturation and stability at the end of the composting process. The highest temperature of 65.3 ^{o} C was recorded in trial 3 with the highest bulk density and lasted for more than four days. Loss in Moisture content was more pronounced in trials 3 than in trials 1 and 2. The lowest EC was observed in trial 1 and highest in trial 3. The bulk density increases throughout the process, porosity, and moisture content decrease during the composting process. Trial 3 and 2 had the highest finest and lowest fibrosity content and trial 1 had the lowest finest and highest fibrosity content. Based on the result presented above, the best compost was produced at 25 kg/m^3 bulk density and 46.34% porosity.

Abbreviations

Nomenclature symbols

NH_4^+ ammonium ion

NH_3-N ammonia nitrogen

Abbreviations

OM Organic matter
TOC Total organic carbon
EC Electrical conductivity

GI Germination index
TN Total nitrogen

B_d Bulk density

Declarations

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Author contributions

BELLO Hadi: Conceptualization, Methodology, Data curation, Writing – original draft, Writing – review & editing. **AJAO Olamilekan Jamiu:** Conceptualization, Methodology, Investigation, Writing – original draft. **SADIKU NUSIRAT:** Writing – review & editing.

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Figures

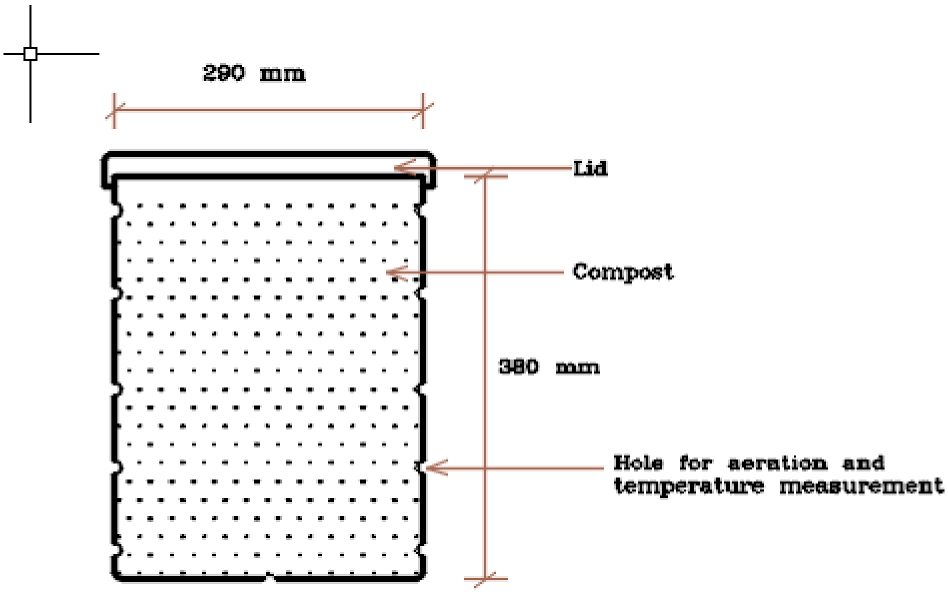

Figure 1

Schematic diagram of composting system

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Figure 2

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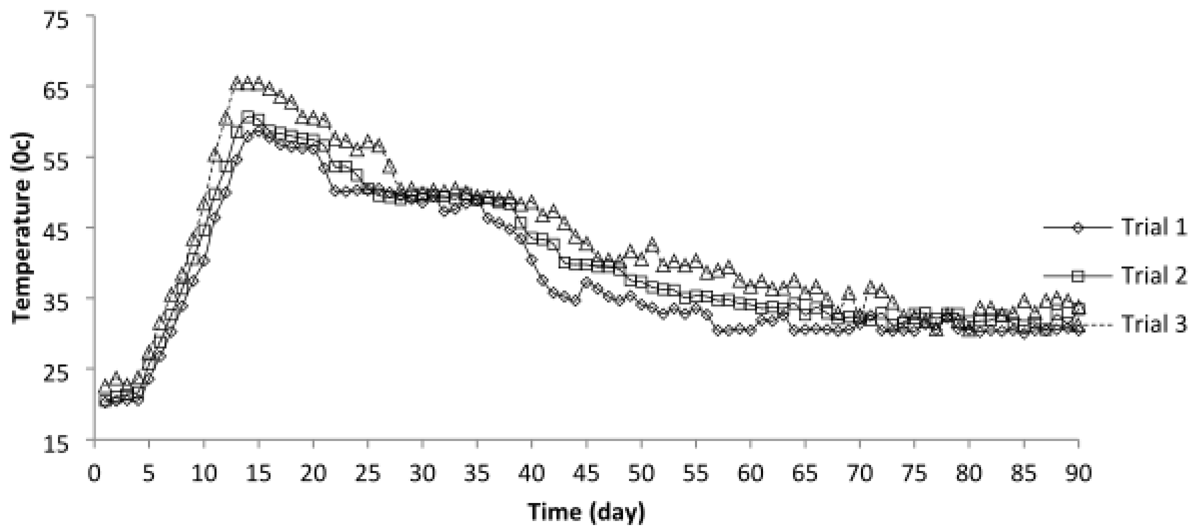

Figure 3

Variation of the temperature of the three trials during composting

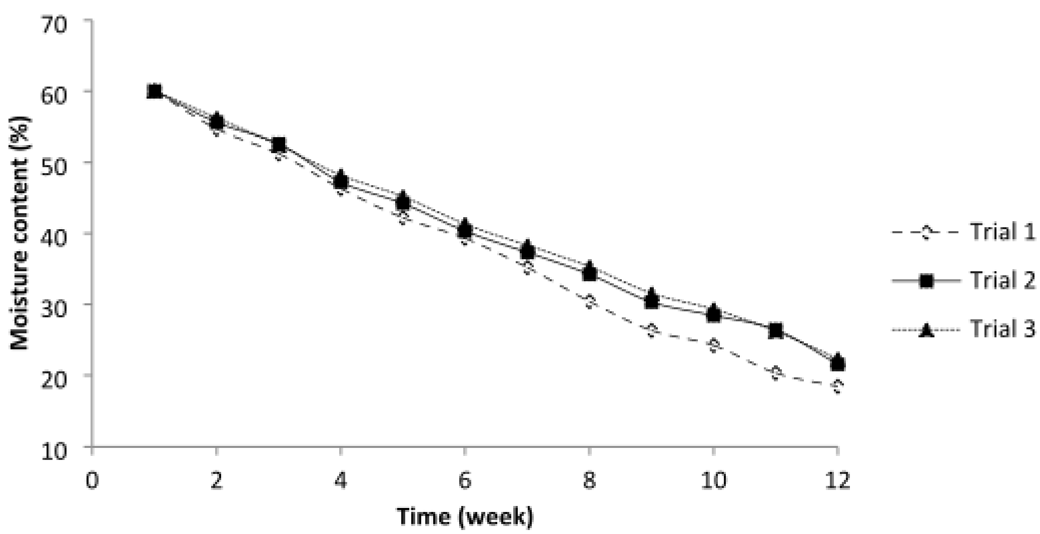

Figure 4

variation of moisture content of composting trial

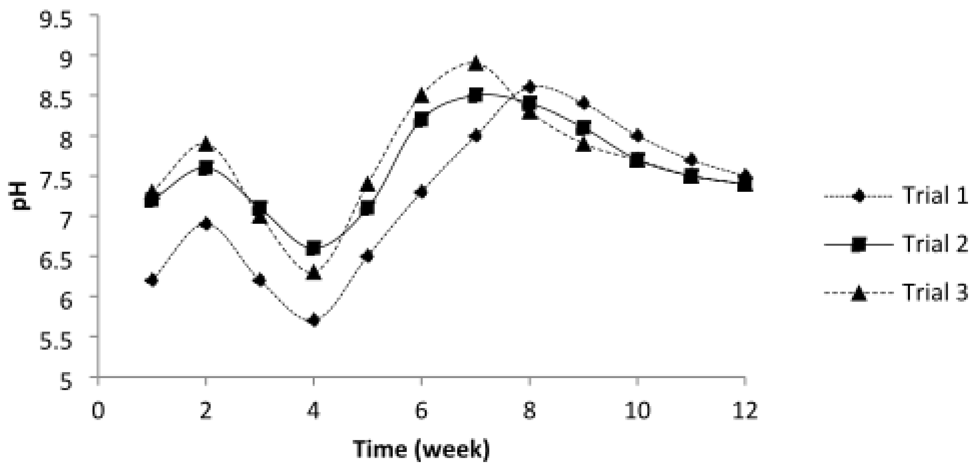

Figure 5

pH of the composting trials

Figure 6

Electrical conductivity of the composting trials

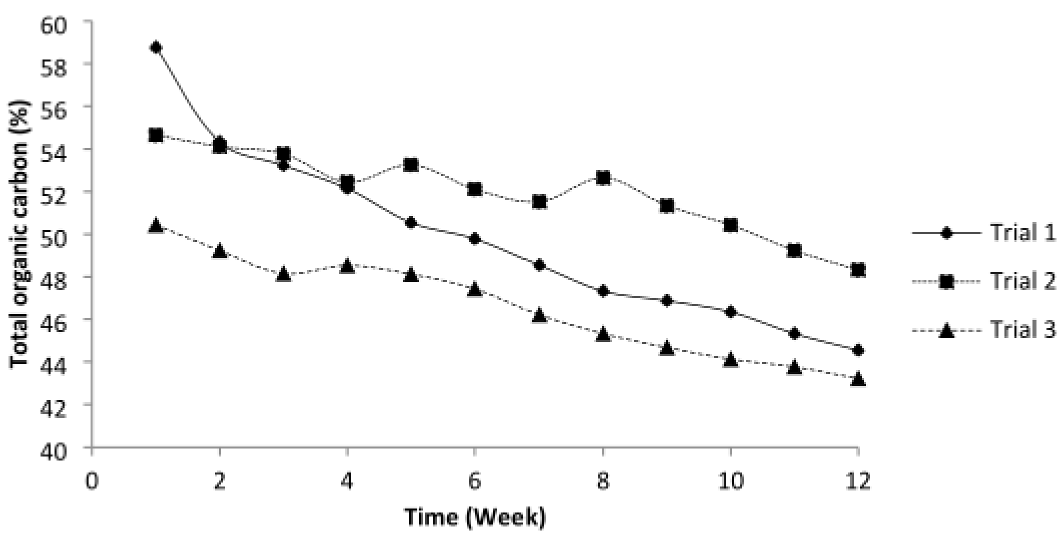

Figure 7

Total organic carbon of the composting trials

Figure 8

Total nitrogen of the composting trials

Figure 9

C:N ratio of the composting trials

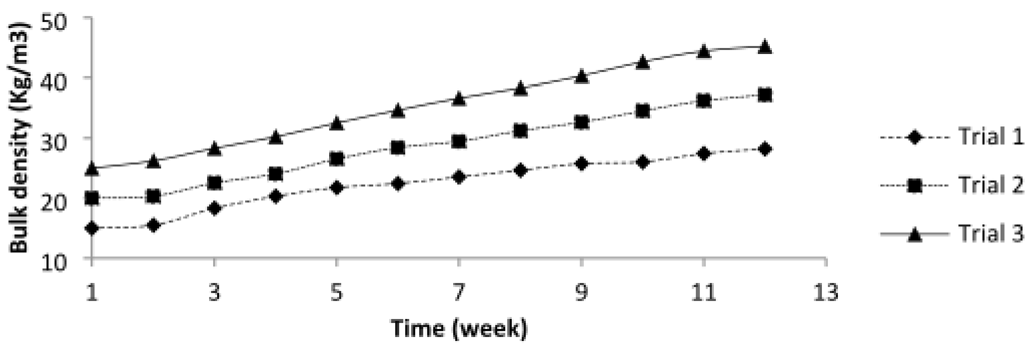

Figure 10

Fig 9 Variations of bulk densities during the composting period

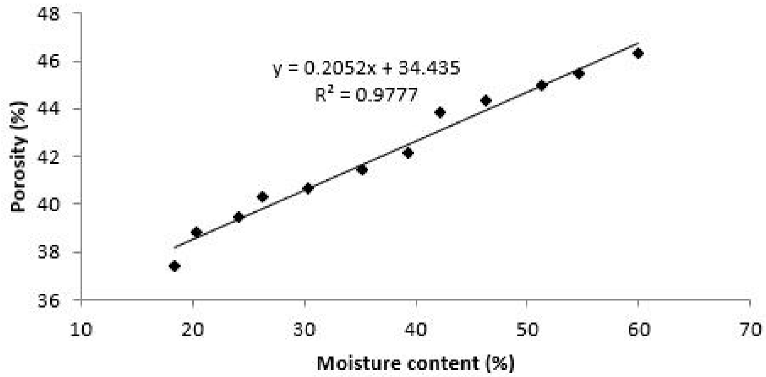

Fig 8a

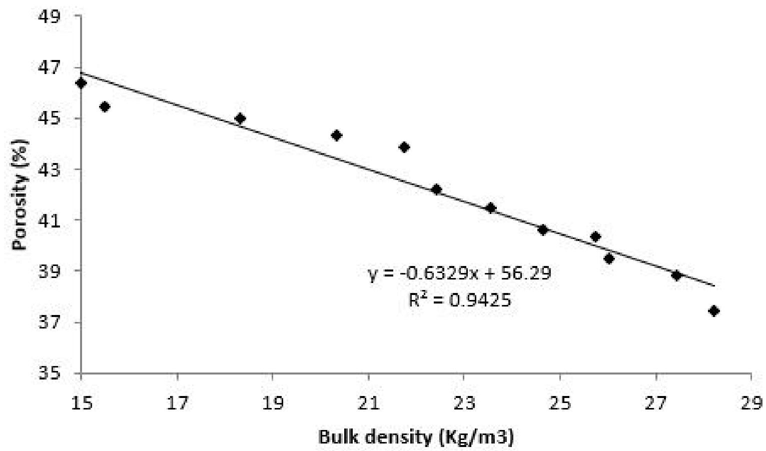

Fig 8b

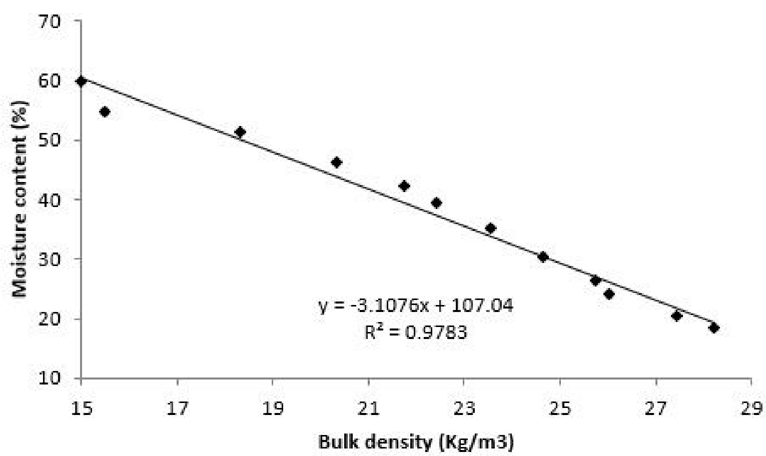

Fig 8c

Figure 11

Figure 8a – 8c correlations between a) porosity and moisture content b) porosity and bulk density c) moisture content and bulk density