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The Impact of Composted Animal Wastes and Their Associated Faecal Indicator Organisms on the Growth and Yield of Waterleaf (*Talinum triangulare* (Jacq.) Vegetable in Calabar, Nigeria

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Abstract-** This study evaluated the effects of untreated, composted, and incinerated animal wastes on physicochemical properties, microbiological safety, nutritional composition, and growth performance of Talinum triangulare. Laboratory analyses assessed moisture content, organic matter, nitrogen, pH, microbial quality, proximate composition, mineral content, and yield parameters. Results showed that untreated wastes had higher moisture content (70–85%), organic matter, and nitrogen levels, which declined after composting and incineration. Composting improved nutrient stability, whereas incineration resulted in reduced organic matter (≤18%) and nitrogen (≤0.5%) with increased alkalinity (pH 8.0–8.4). Microbiological analysis revealed that soils amended with untreated manure had the highest faecal contamination (5.30×10^5–2.10×10^6 CFU/g), including Escherichia coli, Klebsiella, Enterobacter, and Salmonella species. Composting significantly reduced microbial loads (1.50×10^3–4.23×10^3 CFU/g), while incineration recorded the lowest levels (1.2×10^1–2.0×10^1 CFU/g). PCR confirmation identified E. coli (uidA) and Salmonella (invA and hns genes) in plant samples. Composted manure produced the highest growth and yield of T. triangulare, particularly mixed manure treatments, whereas incinerated treatments showed the poorest performance. Nutritional analysis revealed improved quality of compost-treated plants, with higher crude protein content (up to 6.0%) and essential mineral accumulation. Composting provided the best balance of nutrient availability, plant productivity, nutritional enhancement, and microbial safety, demonstrating its potential as a sustainable approach for animal waste management and vegetable production.

***Keywords:** Animal Waste Treatment, Composting, Incineration, Talinum Triangulare (Waterleaf), Physicochemical Properties.*

I. INTRODUCTION

The increasing global demand for food, driven by rapid population growth, has intensified the use of synthetic fertilizers to improve agricultural productivity. It is estimated that by 2050, the world population will reach 9.1 billion, requiring approximately a 60% increase in food production (Ortez, 2022). Although inorganic fertilizers enhance crop yield, their prolonged use has been associated with soil degradation, nutrient imbalance, environmental pollution, increased soil acidity, and declining long-term soil fertility (Karimi et al., 2016; Bui & Nguyen, 2020). Furthermore, the high cost of chemical fertilizers limits their accessibility to many smallholder farmers in developing countries, highlighting the need for sustainable alternatives (Abebe & Debebe, 2019; Ullah et al., 2023). Organic fertilizers derived from agricultural wastes have emerged as environmentally friendly alternatives capable of improving soil fertility and sustaining crop productivity (Falola & Mukaila, 2022). Among the available waste management strategies, composting is considered one of the most efficient methods for converting organic wastes into stable, nutrient-rich soil amendments (Ayilara et al., 2020; Waqas et al., 2023). Compost improves soil structure, enhances water-holding capacity, increases nutrient availability, and promotes beneficial microbial activity while reducing dependence on synthetic fertilizers (Chukwu et al., 2022; Goldan et al., 2023; Ullah et al., 2023). Aerobic composting, in particular, produces mature, pathogen-reduced compost suitable for agricultural applications more rapidly than other composting methods (Mehta & Sirari, 2018; FAO, 2021).

Waterleaf (Talinum triangulare) is an important leafy vegetable widely cultivated and consumed in tropical Africa, particularly Nigeria. The crop is valued for its rapid growth, nutritional value, and medicinal properties, including anti-inflammatory, antibacterial, and antifungal activities (Oluwole et al., 2018; Oluwole et al., 2019). Optimum production depends on adequate soil fertility, making nutrient management essential for maximizing growth and yield (Oladoye & Liu, 2022). Consequently, organic manure has become an attractive alternative to inorganic fertilizers because it supplies nutrients while improving soil quality and supporting sustainable vegetable production. Despite their agronomic benefits, untreated animal wastes may contain pathogenic microorganisms capable of contaminating soil and fresh vegetables, thereby posing risks to human and environmental health (Goldan et al., 2023). Pathogens may be transferred to crops through direct contact with manure, contaminated soil particles, or uptake through plant roots (Alegbeleye et al., 2018; Burris et al., 2020; Chukwu et al., 2022). Consequently, the microbiological quality of compost has become an important consideration for safe agricultural use. Faecal indicator organisms, particularly Escherichia coli and total coliforms, are widely used to evaluate the hygienic quality of compost because their presence reflects possible faecal contamination and the effectiveness of the composting process in reducing microbial hazards (Manyi-Loh et al., 2016; Motlagh & Yang, 2019; Chukwu et al., 2022).

Animal wastes differ considerably in nutrient composition, carbon-to-nitrogen ratio, moisture content, and microbial populations, suggesting that composts prepared from different animal sources may vary in both fertilizing efficiency and microbiological quality (Goldan et al., 2023; Ullah et al., 2023). Although previous studies have demonstrated the benefits of compost application on crop growth, limited information exists on the comparative effects of composted cow dung, poultry manure, pig manure, and their mixtures on the growth and yield of waterleaf under humid tropical conditions. Furthermore, few studies have simultaneously evaluated the physicochemical characteristics of composted animal wastes, the reduction of faecal indicator organisms during composting, and their relationship with crop performance. Therefore, this study evaluated the impact of composted animal wastes and their associated faecal indicator organisms on the growth and yield of waterleaf (Talinum triangulare) in Calabar, Nigeria, to identify sustainable and microbiologically safe organic fertilizer options for vegetable production.

II. MATERIALS AND METHOD

2.1 Study Area

The study was conducted in Calabar Metropolis, Southern Nigeria, located at Latitude 4.58°N and Longitude 8.21°E, with an altitude of 62 m above sea level. The area is a tropical coastal zone within the mangrove swamp agro-ecological region, characterized by a short dry season and a prolonged rainy season (March–November). Calabar receives an annual rainfall of approximately 3,000 mm, with mean temperatures ranging from 25–28°C (Amadi et al., 2020). The city had a population of 375,196 according to the 2006 census, with subsequent growth driven by rapid urbanization (Bassey et al., 2024). Figure 2 presents the geographical location of Calabar in Nigeria.

2.2 Mapping of Experimental Site

The experimental field was laid out in a complete randomized block design in a rectangular arrangement of 10 × 8 plots, giving a total of 80 plots comprising 4 replicates × 5 rates of nitrogen × 4 nitrogen sources (compost, ash, untreated organic waste, and fertilizer). Each plot measured 1 m × 1 m, with a separation distance of 0.5 m between plots. Runoff and cross-contamination were minimized by selecting an experimental site with a low gradient and by constructing raised edges within the 0.5 m spacing between plots to prevent possible runoff during irrigation and rainfall. Standing on plots after sowing was avoided to minimize contamination through transfer via footwear (Chukwu et al., 2022).

2.3 Collection and Treatment of Animal Wastes

Animal wastes (cattle manure, poultry manure and pig manure) were collected from local animal farms within Calabar Metropolis, Nigeria, using sterile bags and transported to the experimental site for treatment. The wastes were treated using two common household methods practiced by farmers in the study area: composting and incineration (Chukwu et al., 2022).

2.4 Composting Treatment

Pit composting (PC) was used to compost the animal manure for field trials. A 9 × 9 m square pit was dug to a depth of 1.8 m. Planks were laid at the base of the pit to prevent mixing of compost with soil, and the pit was covered with a large black polythene sheet. The pit was filled with cattle manure (~146 m^3) and covered with a black nylon sheet to retain heat. Water was added to the compost three times per week (120 dm^3 per interval). The compost heap was turned manually once each week to ensure uniform decomposition. In line with common practices among local farmers, the composting process was carried out for 30 days. The same procedure was applied to poultry and pig manure (Mengistu et al., 2017).

2.5 Incineration (Burning) Treatment

The animal waste was treated by burning in a local burn barrel with an open lid. Dried animal manure was heaped inside a metal container measuring 0.6 m in diameter and 1 m in height. The material was subjected to slow thermal heating at an ambient temperature of approximately 38°C until it was completely combusted to ash. The resulting ash was allowed to cool, then collected and stored in sterile polythene bags for use as an organic amendment in the field trial within 24 hours (Chukwu et al., 2022).

2.6 Determination of physical, chemical and biological properties of organic manure

2.6.1 Physicochemical Analysis of Compost

To evaluate the various physical, chemical, and biological transformations of the compost, representative samples were collected from different points of the compost pit (bottom, surface, and center) at 10-day intervals (i.e., days 10, 20, and 30). All samples were sealed in plastic containers and transported immediately to the laboratory. Upon arrival, the samples were stored in a refrigerator at 4 °C until analysis. Physicochemical and microbial analyses were carried out at the Department of Chemistry laboratory and Department of Microbiology laboratory, University of Cross River State respectively following standard procedures.

2.6.1.1 Moisture Content

Moisture (M), which represents the water content in organic waste, was determined from the difference in sample weight before and after drying. The moisture content of the manure was determined by weighing 10 g of the sample into a crucible dish that had been previously dried at 98–100 OC, cooled in a desiccator, and weighed after reaching room temperature. The cover of the dish was loosened, and the sample was heated at 98–100 OC until a constant weight was obtained. After drying, the cover was tightened, and the dish was transferred to a desiccator, allowed to cool to room temperature, and weighed (Zobeashia et al., 2022).

$$\text{Moisture (\%)} = \frac{\Delta SB - \Delta SA}{\text{Weight of sample}} \times 100$$

ΔSB = weight of dish and sample before drying.
ΔSA = weight of dish and sample after drying.

2.6.1.2 Total Organic Matter and Organic Carbon Contents

The per cent organic matter, *P*OM (%), and organic carbon (C), *P*OC (%), in the waste were determined by a modification of the Springer and Klee method (Chukwu et al., 2021). Dried samples were ground and oxidized by the addition of 20 ml of 2N $K_2Cr_2O_7$ and 26 ml of concentrated H_2SO_4 at 160 ± 2 °C, and manually titrated to determine excess dichromate. The value of *P*OC was calculated as;

$$P_{OC} = \frac{(A - B) \times F \times K}{W}$$

Where;

A is the volume of $FeSO_4$ solution (ml) used in titrating excess $K_2Cr_2O_7$ of the sample, *B* is the volume of $FeSO_4$ solution (ml) used in titrating excess $K_2Cr_2O_7$ of the blank analysis, *F* is the correction factor from daily titration of K2Cr2O7 solution with FeSO4 (1.30), K is a constant given by the dilution and equivalent C content (0.003 x 100), and W is the weight of the sample (g). The value of POM was then calculated from POC as

$$P_{OM} = 0.35 + 1.80 \times P_{OC}$$

2.6.1.3 Total Nitrogen (TN)

Total nitrogen (TN) was determined using the Kjeldahl method (Asri et al., 2020). Dried compost samples were ground to pass through a 2-mm sieve prior to analysis. For the determination of total nitrogen, the samples were digested using concentrated H_2SO_4 in the presence of a catalyst mixture in a Kjeldahl flask. Subsequently, the nitrogen content in the digest was determined through steam distillation followed by titration (Mengistu et al., 2017; Asri et al., 2020).

2.6.1.4 Total Solid

The total solid content of the substrate was determined by drying a known volume of the substrate in a pre-weighed crucible dish at 105 °C in a hot air oven for one hour. After which, it was left to cool at room temperature in a desiccator and weighed (Zobeashia et al., 2022). The TS was computed using the following formula:

$$TS = \frac{(M_1 - M_2)}{V}$$

Where;

M1: mass of crucible dish after drying at 105 °C (mg), M2: mass of initial crucible dish (mg) V: Volume of sample (L)

2.6.1.5 Volatile Solid

Volatile solids are the amount of solid that volatilizes when heated at 550 °C. It was estimated by burning the total solid at 550°C for about 2 hours in a muffle furnace. The crucible was taken out and allowed to cool in a desiccator and then weighed (Zobeashia et al., 2022). The VS was determined using the formula:

$$VS = \frac{(M_1 - M_3)}{V}$$

Where

M1: mass of crucible dish after drying at 105 OC (mg), M3: Mass of crucible dish after ignition at 550 OC (mg), V: Volume of sample (L)

2.6.1.6 Dry Matter

Twenty (20 g) of organic waste was dried at 110 OC to constant mass (24 hours). The percentage dry matter content was measured from the weight of the sample before and after drying:

$$P_{dm} = \frac{(W_{dw} + W_c)}{((W_{fw} + W_c) - W_c)} \times 100$$

Where;

Wdw, Wc and Wfw are the weights of the dried sample, container and undried sample, respectively (all in g).

2.6.1.7 Determination of Temperature and pH

The pH of animal wastes was determined according to the AOAC (2012) method. Air-dried samples were sieved, and 30 g was mixed with 30 ml distilled water to form a slurry. The mixture was allowed to stand for 1 h with intermittent stirring. After temperature adjustment and calibration of the pH meter, the electrode was inserted into the slurry, and pH readings were recorded to the nearest tenth (Anigbo et al., 2021).

2.7 Compost Phytotoxicity Test

Compost phytotoxicity was determined using a modified seed germination test (Mengistu et al., 2017). A 10 g portion of the screened compost sample was shaken with 100 ml of distilled water for one hour. The suspension was then centrifuged at 3000 rpm for 15 minutes, and the supernatant was filtered using Whatman No. 42 filter paper.

Whatman No. 2 filter paper was placed in sterilized Petri dishes and moistened with 9 ml of the extract. Thirty waterleaf seeds (Talinum triangulare Jacq.) were placed on the filter paper. Distilled water (9 ml) was used as the control, and all experiments were conducted in triplicate. The Petri dishes were kept in the dark at room temperature for 5 days. At the end of the incubation period, the germination index (GI) was calculated using the appropriate formula.

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$$\text{Germination Index (\%)} = \frac{\text{Seed germination (\%)} \times \text{Root elongation (\%)}}{100}$$

2.8 Faecal Coliform Analysis

The determination of faecal coliforms in the initial raw materials and compost samples was carried out following the method described by Mengistu et al. (2017). Under aseptic conditions, 10 g of each sample (untreated and treated wastes) were weighed and homogenized in 90 ml of sterile distilled water to obtain an initial suspension. The mixture was thoroughly agitated to ensure uniform distribution of microorganisms. Serial dilutions of the suspension were then prepared up to 10^{-6}.

An aliquot of 0.1 ml from each dilution was inoculated, in triplicate, onto Eosin Methylene Blue (EMB) agar plates. The inoculated plates were incubated at 44 °C for 24 hours. Following incubation, distinct colonies were counted, and the faecal coliform population was expressed as $\log_{10}$ colony-forming units per gram ($\log_{10}$ CFU/g) of fresh sample. The mean values for each treatment were calculated and recorded.

2.9 Soil Amendment and Cultivation of Waterleaf

Organic fertilizers (compost, ash, and untreated wastes) were incorporated into the plough layer at a depth of 15–25 cm, while NPK fertilizer served as the control. Talinum triangulare seeds obtained from the Cross River State Agricultural Input Supply were sown at a depth of 1.27 cm. Plots were irrigated every 2–3 days, weeded manually, and monitored until maturity. Growth parameters, including plant height, leaf diameter, leaf length, leaf number, and dry biomass, were measured to evaluate treatment effects.

2.10 Data Analysis

Data were analyzed using SPSS version 20. Microbial counts of compost samples were transformed into logarithmic values. Field measurement data were analyzed to determine the reduction of faecal indicator organisms (FIOs). Spearman's correlation analysis was used to assess the relationship between microbiological and physicochemical parameters. Significant differences between the mean values of waterleaf growth parameters were determined using one-way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test at a significance level of $p< 0.05$.

III. RESULT

3.1.1 Moisture Content

Moisture content varied considerably among animal waste types and treatment methods (Table 1). Untreated wastes recorded the highest moisture levels, with pig slurry showing the highest range (80–85%), followed by cow dung (78–82%) and poultry droppings (70–75%). Mixed untreated wastes showed comparable moisture values (77–83%). Composting substantially reduced moisture content across all treatments, with values ranging from 40–55%, while incineration resulted in the lowest moisture levels (4–10%), reflecting extensive dehydration during thermal processing. These findings indicate that composting improves moisture stabilization, producing materials with more suitable physicochemical characteristics for agricultural application.

Table 1. Moisture Content (%) of Animal Wastes under Different Treatment Methods

Treatment	Untreated (%)	Composted (%)	Incinerated (%)
Cow dung	78–82	45–50	5–8
Poultry droppings	70–75	40–45	4–7
Pig slurry	80–85	50–55	6–10
Cow dung + Pig slurry	79–83	47–52	5–8
Pig slurry + Poultry droppings	78–82	45–50	5–8
Poultry droppings + Cow dung	77–81	44–49	5–7
Cow dung + Poultry droppings + Pig slurry	78–82	46–51	6–9

3.1.2 Organic Matter and Organic Carbon Content

Organic matter (OM) and organic carbon (OC) contents varied according to waste type and treatment method (Table 2). Untreated wastes recorded the highest OM and OC values, with pig slurry and cow dung showing the highest organic content (87–90% OM and 51–54% OC). Composting resulted in moderate reductions, with composted materials retaining 60–70% OM and 35–40% OC due to microbial decomposition and carbon mineralization. Incineration caused substantial losses of organic components, reducing OM to 12–18% and OC to 7–10%. Mixed waste treatments followed a similar pattern, with composted combinations maintaining higher organic content than incinerated wastes.

Table 2. Organic Matter and Organic Carbon Content (%) of Animal Wastes under Different Treatment Methods

Treatment	Untreated OM (%)	Untreated OC (%)	Composted OM (%)	Composted OC (%)	Incinerated OM (%)	Incinerated OC (%)
Cow dung	88–90	51–53	65–70	38–40	15–18	9–10
Poultry droppings	85–88	50–52	60–65	35–37	12–15	7–9
Pig slurry	87–90	51–54	62–67	36–39	13–16	7–10
Cow dung + Pig slurry	88	51	65	38	15	9
Pig slurry + Poultry droppings	87	50	63	37	14	8
Poultry droppings + Cow dung	86	49	61	36	12	7
Cow dung + Poultry droppings + Pig slurry	87	50	64	38	13	8

3.1.3 Total Nitrogen Content

Total nitrogen (TN) content varied among animal wastes and treatment methods (Table 3). Untreated wastes recorded the highest nitrogen levels, with poultry droppings showing the greatest content (3.0–3.3%), followed by pig slurry (2.7–3.0%) and cow dung (2.5–2.8%). Mixed waste treatments showed comparable nitrogen values, with the combined cow dung, poultry droppings, and pig slurry treatment recording among the highest levels (2.8–3.1%). Composting resulted in moderate nitrogen reductions, with treated wastes retaining 1.8–2.3% nitrogen, indicating stabilization and conservation of nutrients during decomposition. In contrast, incineration caused substantial nitrogen loss, reducing levels to 0.2–0.5%, reflecting volatilization of nitrogen compounds during thermal processing. Overall, composting preserved more nitrogen than incineration, making it a more suitable treatment method for nutrient recovery and agricultural application.

Table 3. Total Nitrogen Content (%) of Animal Wastes under Different Treatment Methods

Treatment	Untreated (%)	Composted (%)	Incinerated (%)
Cow dung	2.5–2.8	1.8–2.1	0.2–0.4
Poultry droppings	3.0–3.3	2.0–2.3	0.3–0.5
Pig slurry	2.7–3.0	1.9–2.2	0.2–0.4
Cow dung + Pig slurry	2.6–2.9	1.9–2.2	0.2–0.4
Pig slurry + Poultry droppings	2.8–3.1	2.0–2.3	0.3–0.5
Poultry droppings + Cow dung	2.7–3.0	1.9–2.2	0.2–0.4
Cow dung + Poultry droppings + Pig slurry	2.8–3.1	2.0–2.3	0.3–0.5

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3.1.4 Total Solids, Volatile Solids and Dry Matter

Total solids (TS), volatile solids (VS), and dry matter (DM) contents varied according to treatment method (Table 4). Untreated wastes recorded the lowest TS and DM values (17–23%), reflecting their high moisture content. Composting increased TS and DM levels to 45–52% due to moisture loss and organic matter stabilization during decomposition. Incineration produced the highest TS and DM values (90–95%) as a result of complete dehydration and concentration of mineral residues.

In contrast, volatile solids decreased following treatment, indicating progressive degradation and combustion of organic fractions. Untreated wastes showed higher VS values (15–19%), which declined moderately after composting (38–54%) and markedly after incineration (10–15%). Similar trends were observed in mixed waste treatments, demonstrating that composting promotes stabilization of organic materials, while incineration removes most volatile organic components.

Table 4. Total Solids, Volatile Solids and Dry Matter Content (%) of Animal Wastes under Different Treatment Methods

Treatment	Untreated TS/DM (%)	Composted TS/DM (%)	Incinerated TS/DM (%)	Untreated VS (%)	Composted VS (%)	Incinerated VS (%)
Cow dung	17–21	48–52	91–95	15–18	40–54	12–15
Poultry droppings	18–22	45–50	90–94	16–19	38–42	10–14
Pig slurry	18–22	46–50	92–95	15–18	40–43	12–15
Cow dung + Pig slurry	17–22	47–52	91–94	—	—	—
Pig slurry + Poultry droppings	18–23	45–50	90–94	—	—	—
Poultry droppings + Cow dung	17–21	46–50	91–94	—	—	—
Cow dung + Poultry droppings + Pig slurry	18–23	46–51	91–95	—	—	—

3.1.5 pH and Temperature

The pH and temperature of animal wastes varied significantly with treatment method (Table 5). Untreated wastes exhibited slightly acidic to neutral pH values (6.2–6.8) and ambient temperatures (24–28°C). Composting increased pH values to neutral or slightly alkaline conditions (7.0–7.8) and elevated temperatures to 40–55°C, indicating active microbial decomposition and thermophilic activity. Incineration produced the highest temperatures (85–100°C) and strongly alkaline pH values (8.0–8.4), resulting from the formation of alkaline ash residues.

Similar patterns were observed in mixed waste treatments, where composting enhanced stabilization through increased temperature and pH, while incineration caused greater alkalinity due to mineral concentration after combustion. These findings demonstrate that treatment methods strongly

influence the physicochemical properties of animal wastes, with composting providing conditions favourable for nutrient stabilization and agricultural application.

Table 5. pH and Temperature of Animal Wastes under Different Treatment Methods

Treatment	Untreated pH	Composted pH	Incinerated pH	Untreated Temperature (°C)	Composted Temperature (°C)	Incinerated Temperature (°C)
Cow dung	6.5–6.8	7.2–7.8	8.0–8.2	25–28	45–55	90–100
Poultry	6.2–6.7	7.0–7.6	8.0–8.3	25–27	40–45	85–95

droppings						
Pig slurry	6.3–6.8	7.2–7.7	8.1–8.4	24–27	45–55	90–100
Cow dung + Pig slurry	6.4–6.8	7.2–7.8	8.0–8.2	25–28	45–55	90–100
Pig slurry + Poultry droppings	6.3–6.7	7.1–7.7	8.1–8.3	24–27	45–55	90–100
Poultry droppings + Cow dung	6.3–6.8	7.1–7.6	8.0–8.2	25–28	45–55	90–100
Cow dung + Poultry droppings + Pig slurry	6.3–6.8	7.2–7.8	8.1–8.4	25–28	45–55	90–100

3.1.6 Compost Phytotoxicity Assessment of Talinum triangulare

Compost extracts significantly influenced seed germination, root elongation, and germination index (GI) of *Talinum triangulare* compared with the control (Table 6). Germination percentage ranged from 85–100% among compost treatments, while the control recorded the lowest germination (70%). The highest germination (100%), root length (5.2 cm), and germination index (100%) were observed in the combined cow dung + poultry droppings + pig slurry compost extract, indicating improved nutrient balance and absence of phytotoxic compounds.

Pig slurry compost extract recorded the lowest performance among compost treatments, with 85% germination, 4.2 cm root length, and 85% GI, possibly due to residual salts or ammonia compounds. Overall, compost extracts enhanced seed germination and root development compared with distilled water, demonstrating the maturity and suitability of the composted materials for agricultural application.

Table 6. Seed Germination, Root Elongation and Germination Index of *Talinum triangulare* under Compost Extract Treatments

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Table 6. Seed Germination, Root Elongation and Germination Index of Talinum triangulare under Compost Extract Treatments

Treatment	Seeds Sown	Seeds Germinated	Germination (%)	Root Length (cm)	Germination Index (%)
Cow dung extract	20	18	90	4.5	90

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Poultry droppings extract	20	19	95	5.0	95
Pig slurry extract	20	17	85	4.2	85
Cow dung + Pig slurry extract	20	19	95	4.8	92
Pig slurry + Poultry droppings extract	20	18	90	4.6	88
Poultry droppings + Cow dung extract	20	19	95	4.9	93
Cow dung + Poultry droppings + Pig slurry extract	20	20	100	5.2	100
Control (distilled water)	20	14	70	3.2	70

3.2 Faecal Indicator Organisms in Animal Waste Compost

3.2.1 Faecal Coliform Load in Untreated, Composted and Incinerated Animal Wastes

Faecal coliform counts varied considerably among the different animal waste treatments (Table 3). Untreated animal wastes recorded the highest faecal coliform loads, ranging from 5.30×10^5 to 2.10×10^6 CFU/g. Among the untreated samples, the combined cow dung, poultry droppings, and pig slurry treatment recorded the highest mean faecal coliform count (2.10×10^6 CFU/g), followed by pig slurry and poultry droppings (1.97×10^6 CFU/g) and cow dung and pig slurry (1.77×10^6 CFU/g). Untreated cow dung recorded the lowest faecal coliform count (5.30×10^5 CFU/g).

Composting substantially reduced faecal coliform populations compared with untreated wastes. Mean counts in composted samples ranged from 1.50×10^3 to 4.23×10^3 CFU/g, with composted cow dung recording the lowest count (1.50×10^3 CFU/g) and composted cow dung + poultry droppings + pig slurry recording the highest (4.23×10^3 CFU/g). The reduction observed following composting suggests that microbial competition, increased temperature during decomposition, and compost stabilization contributed to the elimination of faecal indicator organisms.

Incineration resulted in the greatest reduction of faecal coliforms, with counts ranging from 1.20×10^1 to 2.00×10^1 CFU/g. Incinerated poultry droppings recorded the lowest mean count (1.20×10^1 CFU/g), while the mixed incinerated wastes showed slightly higher values (2.00×10^1 CFU/g). These findings demonstrate that thermal treatment was more effective than composting in reducing faecal contamination of animal wastes.

Table 7: Faecal Coliform Counts in Untreated, Composted and Incinerated Animal Wastes

Treatment group	Mean Faecal Coliform Count Range (CFU/g)
Untreated animal wastes	$5.30 \times 10^5 – 2.10 \times 10^6$
Composted animal wastes	$1.50 \times 10^3 – 4.23 \times 10^3$
Incinerated animal wastes	$1.20 \times 10^1 – 2.00 \times 10^1$

Treatment group Mean Faecal Coliform Count Range (CFU/g)
Untreated animal wastes $5.30 \times 10^5 – 2.10 \times 10^6$
Composted animal wastes $1.50 \times 10^3 – 4.23 \times 10^3$
Incinerated animal wastes $1.20 \times 10^1 – 2.00 \times 10^1$

3.2.2 Occurrence of Faecal Indicator Organisms in Animal Waste Treatments

The distribution of faecal indicator organisms recovered from the different animal waste treatments is presented in Table 4. The identified organisms included Escherichia coli, Klebsiella spp., Enterobacter spp., and Citrobacter spp., while Salmonella spp. was recovered only from some untreated mixed waste samples.

Untreated animal wastes showed the highest diversity and frequency of faecal indicator organisms. Escherichia coli was predominant in untreated cow dung (33.3%) and mixed cow dung, poultry droppings, and pig slurry (25.9%), whereas Klebsiella spp. showed higher occurrence in untreated poultry droppings (45.5%) and pig-based waste mixtures (41.7–46.7%). The high prevalence of these organisms reflects the microbial burden associated with fresh animal excreta.

Following composting, the frequency and diversity of faecal indicator organisms decreased. E. coli remained the dominant organism in composted cow dung (33.3%), poultry droppings (37.5%) and mixed compost (40%). However, organisms such as Enterobacter spp. and Citrobacter spp. were also recovered, suggesting their ability to persist during organic waste decomposition.

Incinerated animal wastes showed minimal recovery of faecal indicator organisms. The few organisms detected included Klebsiella spp., Citrobacter spp., Enterobacter spp., and E. coli, indicating effective microbial destruction following exposure to high temperatures.

Table 8: Overall Distribution of Faecal Indicator Organisms Among Treatment Groups

Treatment group	Predominant faecal indicator organisms
Untreated wastes	*E. coli*, *Klebsiella* spp., *Enterobacter* spp., *Citrobacter* spp., *Salmonella* spp.
Composted wastes	*E. coli*, *Enterobacter* spp., *Citrobacter* spp., *Klebsiella* spp.
Incinerated wastes	*Klebsiella* spp., *Citrobacter* spp., *Enterobacter* spp., *E. coli*

3.3 Effects of Animal Waste Treatment Methods and Seasonal Variation on the Growth and Yield of Talinum triangulare

3.3.1 Growth Performance of Talinum triangulare Under Different Animal Waste Treatments

Growth and yield parameters of Talinum triangulare varied among animal waste treatments and seasons (Tables 5 and 6). All treatments showed progressive increases in plant growth from week one to week four; however, plants amended with animal wastes consistently performed better than the untreated control.

During the dry season, the control treatment recorded the lowest growth performance, with final values of 45.67 leaves, 16.92 cm plant height, 4.27 cm leaf diameter, 7.89 cm leaf length, 15.45 cm stem height, and 0.77 cm stem girth at week four. In comparison, poultry manure produced the highest growth response, recording 63.67 leaves, 23.83 cm plant height, 5.21 cm leaf diameter, 9.45 cm leaf length, 20.30 cm stem height, and 1.15 cm stem girth. Among combined manure treatments, cow dung + poultry droppings + pig manure showed improved growth performance, indicating enhanced nutrient availability from mixed organic amendments.

Similar growth trends were observed during the rainy season, although plants generally exhibited greater growth compared with the dry season. The control recorded final values of 55.10 leaves, 17.45 cm plant height, 4.40 cm leaf diameter, 8.14 cm leaf length, 15.93 cm stem height, and 0.77 cm stem girth. Poultry manure treatment again produced the highest growth, with final values of 78.00 leaves, 24.20 cm plant height, 5.72 cm leaf diameter, 10.78 cm leaf length, 21.45 cm stem height, and 1.25 cm stem girth. Mixed manure treatments also improved plant development, with the cow dung + poultry droppings + pig manure combination showing superior performance compared with individual cow dung and pig manure treatments. The higher growth observed under poultry manure and mixed manure applications may be associated with improved nutrient availability, particularly nitrogen and phosphorus, which enhance vegetative growth, leaf expansion, and biomass production.

Overall, seasonal variation influenced plant performance, with rainy season cultivation producing higher growth values than dry season cultivation across most treatments. This may be attributed to improved soil moisture availability during the rainy period, which facilitates nutrient uptake and metabolic activities required for plant development.

Table 9: Growth Parameters of Talinum triangulare Under Different Untreated Animal Waste Treatments During Dry and Rainy Seasons

Treatment	Season	Leaves (No.)	Plant Height (cm)	Leaf Diameter (cm)	Leaf Length (cm)	Stem Height (cm)	Stem Girth (cm)
Control	Dry	45.67	16.92	4.27	7.89	15.45	0.77
Control	Rainy	55.10	17.45	4.40	8.14	15.93	0.77
Pig manure	Dry	45.20	19.73	4.80	8.32	17.71	1.10
Pig manure	Rainy	62.24	20.35	4.95	8.58	18.26	1.15
Cow dung	Dry	41.13	19.47	4.15	7.59	16.78	0.90
Cow dung	Rainy	41.32	20.46	4.07	7.59	17.27	0.90
Poultry manure	Dry	63.67	23.83	5.21	9.45	20.30	1.15
Poultry manure	Rainy	78.00	24.20	5.72	10.78	21.45	1.25
Mixed manure treatments	Dry/Rainy	Improved growth	Improved growth	Improved growth	Improved growth	Improved growth	Improved growth

3.3.2 Effect of Compost Application and Seasonal Variation on the Growth and Yield of Talinum triangulare

The effects of composted animal manure applications on the growth and yield performance of Talinum triangulare during dry and rainy seasons are presented in Tables 6 and 7. All compost treatments enhanced plant growth compared with the untreated control, with progressive increases observed in leaf production, plant height, leaf development, stem height, and stem girth throughout the four-week growth period.

During the dry season, compost-amended plants showed superior growth performance compared with the control. The control treatment recorded the lowest final growth values, with 38.67 leaves, 17.53 cm plant height, 3.98 cm leaf diameter, 6.90 cm leaf length, 15.13 cm stem height, and 0.79 cm stem girth at week four. Among single compost treatments, poultry manure produced the highest growth response, recording 69.00 leaves, 23.73 cm plant height, 5.40 cm leaf diameter, 9.88 cm leaf length, 20.53 cm stem height, and 1.37 cm stem girth.

Combined compost treatments produced greater improvements than individual manure applications. The cow dung + poultry droppings + pig manure treatment recorded the highest overall growth during the dry season, with 79.67 leaves, 26.57 cm plant height, 6.08 cm leaf diameter, 10.87 cm leaf length, 22.10 cm stem height, and 1.60 cm stem girth. Other combined treatments, including cow dung + pig manure and poultry droppings + pig manure, also demonstrated improved growth compared with single manure treatments.

A similar trend was observed during the rainy season, with compost-amended treatments producing higher growth values than the control. The control treatment recorded the lowest final growth values, including 37.67 leaves, 18.47 cm plant height, 3.90 cm leaf diameter, 6.87 cm leaf length, 15.17 cm stem height, and 0.66 cm stem girth. Among individual compost treatments, poultry manure produced improved growth, reaching 74.33 leaves, 26.33 cm plant height, 5.67 cm leaf diameter, 10.70 cm leaf length, 21.70 cm stem height, and 1.48 cm stem girth.

The combined cow dung + poultry droppings + pig manure treatment consistently produced the highest growth performance during the rainy season, recording 82.67 leaves, 27.60 cm plant height, 6.18 cm leaf diameter, 11.20 cm leaf length, 23.17 cm

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stem height, and 1.60 cm stem girth. These findings indicate that mixed compost applications provided a more favourable nutrient balance for vegetative development compared with single manure treatments.

Overall, seasonal variation influenced plant performance, with rainy season cultivation generally producing higher growth responses than dry season cultivation. The improved performance under combined compost treatments may be attributed to enhanced nutrient availability, improved soil structure, increased microbial activity, and gradual nutrient release during compost decomposition. The superior growth observed with cow dung + poultry droppings + pig manure suggests that integrating different animal wastes produces a more balanced organic amendment capable of supporting optimum growth and yield of Talinum triangulare.

Table 10: Growth Parameters of Talinum triangulare Under Compost Treatments During Dry and Rainy Seasons

Treatment	Season	Leaves (No.)	Plant Height (cm)	Leaf Diameter (cm)	Leaf Length (cm)	Stem Height (cm)	Stem Girth (cm)
Control	Dry	38.67	17.53	3.98	6.90	15.13	0.79
Control	Rainy	37.67	18.47	3.90	6.87	15.17	0.66
Pig manure	Dry	63.33	22.12	5.08	9.24	19.55	1.26
Pig manure	Rainy	72.33	26.00	5.60	10.57	21.73	1.46
Cow dung	Dry	56.67	20.97	4.78	8.67	18.33	1.18
Cow dung	Rainy	66.00	24.10	5.18	10.00	20.87	1.34
Poultry manure	Dry	69.00	23.73	5.40	9.88	20.53	1.37
Poultry manure	Rainy	74.33	26.33	5.67	10.70	21.70	1.48
Cow + poultry + pig compost	Dry	79.67	26.57	6.08	10.87	22.10	1.60
Cow + poultry + pig compost	Rainy	82.67	27.60	6.18	11.20	23.17	1.60

3.3.3 Effect of Incinerated Animal Waste (Ash) Application and Seasonal Variation on the Growth and Yield of Talinum triangulare

The effect of incinerated animal waste (ash) application on the growth and yield performance of Talinum triangulare during dry and rainy seasons is presented in Tables 8 and 9. Growth parameters increased progressively from week one to week four across all treatments; however, plants grown with incinerated manure amendments generally exhibited improved growth compared with the untreated control.

During the dry season, the control treatment recorded the lowest growth performance, with final values of 24.33 leaves, 13.57 cm plant height, 4.13 cm leaf diameter, 5.67 cm leaf length, 11.83 cm stem height, and 0.60 cm stem girth at week four. Application of incinerated animal wastes enhanced plant development, with poultry manure producing improved growth among single treatments, recording 30.67 leaves, 14.73 cm plant height, 4.63 cm leaf diameter, 5.93 cm leaf length, 12.10 cm stem height, and 0.61 cm stem girth.

Combined ash treatments showed better performance than individual treatments. The cow dung + poultry droppings + pig manure ash treatment produced the highest growth response during the dry season, with 33.00 leaves, 15.07 cm plant height, 5.05 cm leaf diameter, 5.93 cm leaf length, 12.93 cm stem height, and 0.66 cm stem girth. Similarly, pig + poultry manure ash and cow + pig manure ash treatments also recorded higher growth values compared with single ash applications.

During the rainy season, a similar pattern was observed, with all incinerated manure treatments producing higher growth values than the control. The control recorded final values of 32.00 leaves, 15.03

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cm plant height, 3.83 cm leaf diameter, 5.48 cm leaf length, 12.83 cm stem height, and 0.62 cm stem girth. Among individual treatments, poultry manure ash showed improved growth, reaching 34.00 leaves, 16.30 cm plant height, 5.23 cm leaf diameter, 6.23 cm leaf length, 13.43 cm stem height, and 0.66 cm stem girth.

The combined cow dung + poultry droppings + pig manure ash treatment produced the highest overall performance during the rainy season, recording 36.00 leaves, 15.93 cm plant height, 5.20 cm leaf diameter, 6.00 cm leaf length, 13.07 cm stem height, and 0.71 cm stem girth.

Overall, rainy season cultivation resulted in slightly improved growth compared with the dry season, indicating the influence of moisture availability on nutrient uptake and plant development. Although incinerated manure treatments produced lower growth responses compared with composted manure applications, they consistently improved plant performance compared with the untreated control. The positive effect of ash application may be associated with increased availability of mineral nutrients such as potassium, calcium, and phosphorus released during combustion.

The superior performance of combined ash treatments suggests that blending different animal waste sources provides a wider nutrient spectrum, supporting better vegetative growth of Talinum triangulare.

Table 11: Growth Parameters of Talinum triangulare Under Incinerated Animal Waste Treatments During Dry and Rainy Seasons

Treatment	Season	Leaves (No.)	Plant Height (cm)	Leaf Diameter (cm)	Leaf Length (cm)	Stem Height (cm)	Stem Girth (cm)
Control	Dry	24.33	13.57	4.13	5.67	11.83	0.60
Control	Rainy	32.00	15.03	3.83	5.48	12.83	0.62
Pig manure ash	Dry	29.67	14.37	4.33	5.87	12.27	0.61
Pig manure ash	Rainy	33.00	15.50	4.57	5.89	12.97	0.69
Cow dung ash	Dry	27.00	13.87	4.22	5.67	11.60	0.59
Cow dung ash	Rainy	32.00	14.87	4.49	5.77	12.47	0.63
Poultry manure ash	Dry	30.67	14.73	4.63	5.93	12.10	0.61
Poultry manure ash	Rainy	34.00	16.30	5.23	6.23	13.43	0.66
Cow + poultry + pig ash	Dry	33.00	15.07	5.05	5.93	12.93	0.66
Cow + poultry + pig ash	Rainy	36.00	15.93	5.20	6.00	13.07	0.71

3.4 Faecal Indicator Organisms in Talinum triangulare Cultivated with Untreated Animal Wastes

Faecal coliforms were detected in all Talinum triangulare samples cultivated with untreated animal wastes, indicating faecal contamination associated with the application of untreated manure. The mean faecal coliform counts varied among treatments, with the lowest count recorded in plants grown with untreated cow dung ($2.55 \pm 0.12 \times 10^3$ CFU/g) and the highest in plants treated with a combination of cow dung, poultry droppings, and pig slurry ($8.77 \pm 0.46 \times 10^3$ CFU/g).

Among the single manure treatments, untreated pig slurry and poultry droppings recorded higher microbial loads compared with cow dung. Combined manure treatments generally showed increased faecal coliform counts compared with individual manure applications, with cow dung + poultry droppings + pig slurry showing the highest contamination level. Escherichia coli was the most frequently isolated

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organism across most treatments, followed by Enterobacter spp., Klebsiella spp., Salmonella sp., Proteus sp., and Citrobacter sp. The occurrence of these organisms suggests potential public health risks associated with the consumption of vegetables cultivated with untreated animal wastes.

Table 12: Faecal Coliform Counts and Predominant Faecal Indicator Organisms in Talinum triangulare Cultivated with Untreated Animal Wastes

Treatment	Faecal coliform count ($\times 10^3$ CFU/g) Mean ± SD	Predominant isolated organisms (% occurrence)
Untreated cow dung	2.55 ± 0.12	*E. coli* (50), *Enterobacter* sp. (25), *Klebsiella* sp. (25)
Untreated poultry droppings	4.88 ± 0.24	*E. coli* (40), *Salmonella* sp. (40), *Klebsiella* sp. (20)
Untreated pig slurry	6.12 ± 0.24	*E. coli* (40), *Enterobacter* sp. (40), *Proteus* sp. (20)
Cow dung + pig slurry	7.32 ± 0.32	*E. coli* (40), *Enterobacter* sp. (20), *Proteus* sp. (20), *Citrobacter* sp. (20)
Pig slurry + poultry droppings	8.00 ± 0.40	*Salmonella* sp. (40), *E. coli* (20), *Klebsiella* sp. (20), *Proteus* sp. (20)
Cow dung + poultry droppings	7.08 ± 0.39	*E. coli* (40), *Klebsiella* sp. (40), *Enterobacter* sp. (20)
Cow dung + poultry droppings + pig slurry	8.77 ± 0.46	*E. coli* (50), *Klebsiella* sp. (16.7), *Enterobacter* sp. (16.7), *Proteus* sp. (16.7)

3.4.1 Faecal Indicator Organisms in Talinum triangulare Cultivated with Untreated and Treated Animal Wastes

Faecal indicator organisms were detected in Talinum triangulare cultivated with all manure treatments; however, microbial loads varied considerably depending on the treatment applied. Untreated animal wastes recorded the highest faecal coliform counts, ranging from $2.55 \pm 0.12 \times 10^3$ CFU/g in plants grown with untreated cow dung to $8.77 \pm 0.46 \times 10^3$ CFU/g in plants cultivated with untreated cow dung, poultry droppings, and pig slurry. The predominant organisms recovered from untreated manure treatments included Escherichia coli, Salmonella sp., Enterobacter sp., Klebsiella sp., Proteus sp., and Citrobacter sp., with E. coli being the most frequently isolated organism.

Composting significantly reduced faecal contamination compared with untreated manure applications. Faecal coliform counts in composted manure treatments ranged from $1.10 \pm 0.10 \times 10^3$ CFU/g to $1.95 \pm 0.29 \times 10^3$ CFU/g. E. coli remained the predominant organism recovered from composted

treatments, while Enterobacter sp., Klebsiella sp., and Citrobacter sp. were detected at lower frequencies.

Incinerated manure treatments recorded the lowest microbial loads, with faecal coliform counts ranging from 4×10^2 CFU/g to 7×10^2 CFU/g. Only residual organisms, mainly Enterobacter sp. and Klebsiella sp., were detected. The lowest contamination level was observed in plants cultivated with incinerated cow dung, poultry droppings, and pig slurry, which recorded a mean faecal coliform count of $6.5 \pm 0.50 \times 10^2$ CFU/g. Overall, composting and incineration substantially reduced faecal indicator organisms compared with the use of untreated animal wastes, with incineration demonstrating the greatest reduction in microbial contamination.

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Table 13: Faecal Coliform Counts and Predominant Faecal Indicator Organisms Recovered from Talinum triangulare Cultivated with Untreated and Treated Animal Wastes

Manure Treatment	Faecal Coliform Count (Mean ± SD)	Predominant Organisms Detected	Percentage Occurrence (%)
Untreated cow dung	2.55 ± 0.12 $\times 10^3$ CFU/g	*E. coli*, *Enterobacter* sp., *Klebsiella* sp.	50, 25, 25
Untreated poultry droppings	4.88 ± 0.24 $\times 10^3$ CFU/g	*E. coli*, *Salmonella* sp., *Klebsiella* sp.	40, 40, 20
Untreated pig slurry	6.12 ± 0.24 $\times 10^3$ CFU/g	*E. coli*, *Enterobacter* sp., *Proteus* sp.	40, 40, 20
Untreated cow dung + pig slurry	7.32 ± 0.32 $\times 10^3$ CFU/g	*E. coli*, *Enterobacter* sp., *Proteus* sp., *Citrobacter* sp.	40, 20, 20, 20
Untreated pig slurry + poultry droppings	8.00 ± 0.40 $\times 10^3$ CFU/g	*Salmonella* sp., *E. coli*, *Klebsiella* sp., *Proteus* sp.	40, 20, 20, 20
Untreated cow dung + poultry droppings	7.08 ± 0.39 $\times 10^3$ CFU/g	*E. coli*, *Klebsiella* sp., *Enterobacter* sp.	40, 40, 20
Untreated cow dung + poultry droppings + pig slurry	8.77 ± 0.46 $\times 10^3$ CFU/g	*E. coli*, *Klebsiella* sp., *Enterobacter* sp., *Proteus* sp.	50, 16.7, 16.7, 16.7
Composted cow dung	1.47 ± 0.31 $\times 10^3$ CFU/g	*E. coli*, *Enterobacter* sp.	66.7, 33.3
Composted poultry droppings	1.83 ± 0.30 $\times 10^3$ CFU/g	*E. coli*, *Enterobacter* sp., *Klebsiella* sp.	50, 25, 25
Composted pig slurry	1.20 ± 0.20 $\times 10^3$ CFU/g	*E. coli*, *Enterobacter* sp.	50, 50
Composted mixed manure treatments	1.10–1.95 $\times 10^3$ CFU/g	*E. coli*, *Enterobacter* sp., *Klebsiella* sp., *Citrobacter* sp.	25–66.7
Incinerated manure treatments	4–7 $\times 10^2$ CFU/g	*Enterobacter* sp., *Klebsiella* sp.	50–100

4.4.3 Molecular Characterization of Selected Faecal Indicator Organisms

4.4.3.1 PCR Amplification of the uidA Gene for Escherichia coli

PCR targeting the uidA gene (β-glucuronidase), a species-specific molecular marker for Escherichia coli, yielding an ~147 bp amplicon, was performed on eight representative E. coli isolates recovered from untreated animal wastes and Waterleaf samples.

Gel electrophoresis of the PCR products revealed that all eight isolates produced clear, distinct ~147 bp amplicons, corresponding to the band obtained with the positive control. No amplification was observed in the negative control, confirming the specificity of the assay and the successful molecular confirmation of E. coli isolates.

Table 14: PCR Results for the uidA Gene in E. coli Isolates

Sample Source	Number of Isolates Tested	Positive Amplification (*uidA*)	Negative Control	Positive Control
Untreated Cow Dung	2	2	0	1
Untreated Poultry Droppings	2	2	0	1
Untreated Pig Slurry	2	2	0	1
Waterleaf grown with untreated wastes	2	2	0	1

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4.4.3.2 PCR Amplification of the invA Gene for Salmonella sp.

PCR targeting the invA gene (invasion gene A), a highly conserved virulence gene specific to Salmonella sp., producing an amplicon size of ~346 bp, was performed on three representative Salmonella spp. isolates obtained from untreated poultry droppings and Waterleaf samples.

Gel electrophoresis of the PCR products showed that all three isolates produced the expected ~346 bp amplicon, corresponding to the invA gene. Both positive and negative controls performed as expected, confirming the specificity and reliability of the PCR assay for molecular confirmation of Salmonella sp.

Table 15: PCR Results for invA Gene in Salmonella sp. Isolates

Sample Source	Number of Isolates Tested	Positive Amplification (*invA*)	Negative Control	Positive Control
Untreated Poultry Droppings	2	2	0	1
Waterleaf grown with untreated wastes	1	1	0	1

4.4.3.3 PCR Amplification of the hns Gene for Salmonella sp.

PCR targeting the hns gene (histone-like nucleoid structuring gene), a conserved regulatory gene commonly used for molecular confirmation of Salmonella sp., yielding an amplicon size of ~290 bp, was performed on the same Salmonella sp. isolates as described above.

Gel electrophoresis of the PCR products revealed that all three isolates produced distinct amplicons at ~290 bp, corresponding to the hns gene. Both positive and negative controls showed the expected results, further confirming the identity of the Salmonella sp. isolates.

Table 16: PCR Results for hns Gene in Salmonella sp. Isolates

Sample Source	No. of Isolates Tested	Positive Amplification (*hns*)	Negative Control	Positive Control
Untreated Poultry Droppings	2	2	0	1
Waterleaf grown with untreated wastes	1	1	0	1

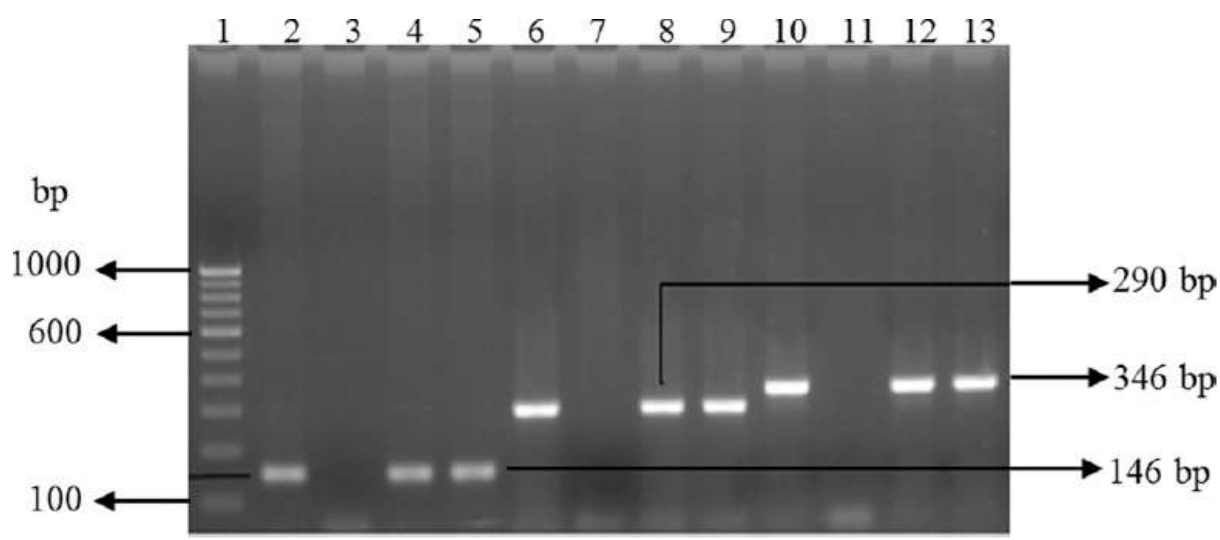

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Figure 1: Gel electrophoresis showing PCR amplification of target genes in Escherichia coli and Salmonella spp. isolates from untreated animal wastes and Waterleaf. Lane 1: 100 bp DNA ladder, Lane 2: uidA positive control for E. coli (~147 bp), Lane 3: uidA negative control (E. coli), Lanes 4–6: uidA gene-positive E. coli isolates (~147 bp), Lane 7: invA positive control for Salmonella spp. (~346 bp), Lane 8: invA negative control (Salmonella spp.), Lanes 9–10: invA gene-positive Salmonella spp. isolates (~346 bp), Lane 11: hns positive control for Salmonella spp. (~290 bp), Lane 12: hns negative control (Salmonella spp.), Lane 13: hns gene-positive Salmonella spp. isolate (~290 bp)

3.4.2 Effect of Treatment Methods on the Nutritional Composition of Talinum triangulare

3.4.2.1 Proximate Composition of Talinum triangulare under Different Manure Treatment Methods

The proximate composition of Talinum triangulare cultivated with untreated, composted, and incinerated animal wastes is presented in Table 3.4.2. The nutritional composition varied according to manure treatment methods. Moisture content ranged from 82.5% to 86.0%, with the highest values recorded in composted combined manure treatments, particularly composted poultry droppings + pig slurry and composted cow dung + poultry droppings + pig slurry (86.0%), while the lowest moisture content was observed in incinerated cow dung (82.5%).

Ash content ranged from 9.8% to 13.0%, with higher values generally observed in composted treatments, especially combined manure applications. Crude protein content varied from 3.5% to 6.0%, with composted cow dung + poultry droppings + pig slurry recording the highest protein value (6.0%), whereas incinerated cow dung recorded the lowest (3.5%). Crude fibre and crude fat contents ranged from 2.5–3.5% and 0.50–0.95%, respectively, with composted treatments showing comparatively higher values. Carbohydrate content ranged from 0.0% to 1.6%, with higher values mainly observed in untreated and incinerated treatments.

Overall, composted manure treatments enhanced the nutritional quality of T. triangulare, particularly with respect to protein, mineral accumulation, and fibre content, while incineration generally resulted in reduced nutrient composition.

Table 17: Proximate Composition (%) of Talinum triangulare under Different Manure Treatment Methods

Treatment	Moisture (%)	Ash (%)	Crude Protein (%)	Crude Fibre (%)	Crude Fat (%)	Carbohydrate (%)
Untreated manure	83.0–85.0	10.1–13.0	3.8–5.5	2.5–3.3	0.50–0.90	0.0–1.6
Composted manure	84.0–86.0	11.0–13.0	4.6–6.0	2.9–3.5	0.78–0.95	0.0–0.72
Incinerated manure	82.5–83.5	9.8–11.0	3.5–4.9	2.5–3.5	0.15–0.80	0.20–1.50

3.4.2.2 Mineral Composition of Talinum triangulare under Different Manure Treatment Methods

The mineral composition of Talinum triangulare cultivated with different manure treatment methods is presented in Table 3.4.3. Mineral concentrations varied among treatments, with composted manure generally producing higher mineral accumulation compared with untreated and incinerated treatments.

Calcium concentration ranged from 130–165 mg/100 g, magnesium from 48–60 mg/100 g, potassium from 225–280 mg/100 g, iron from 3.8–5.5 mg/100 g, phosphorus from 43–58 mg/100 g, and sodium from 27–35 mg/100 g. The highest mineral concentrations were recorded in composted cow dung + poultry droppings + pig slurry, which showed the highest values for calcium (165 mg/100 g), magnesium (60 mg/100 g), potassium (280 mg/100 g), iron (5.5 mg/100 g), phosphorus (58 mg/100 g), and sodium (35 mg/100 g).

In comparison, incinerated treatments generally showed reduced mineral concentrations, particularly

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in cow dung-based treatments. These findings indicate that composting improved nutrient availability and mineral uptake by T. triangulare, while incineration reduced the availability of some essential minerals.

Table 18: Mineral Composition (mg/100 g) of Talinum triangulare under Different Manure Treatment Methods

Treatment	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Iron (Fe)	Phosphorus (P)	Sodium (Na)
Untreated manure	135–155	50–57	230–270	4.0–5.0	45–55	28–33
Composted manure	145–165	53–60	250–280	4.5–5.5	50–58	30–35
Incinerated manure	130–150	48–55	225–260	3.8–5.0	43–52	27–32

3.5 Comparative Effects of Different Animal Waste Treatments (Poultry, Cow, and Pig) on the Growth and Yield of Talinum triangulare During dry and Rainy seasons

3.5.1: Yield of Talinum triangulare in dry and rainy seasons using pig manure in organic, compost, and incinerated forms.

The yield performance of Talinum triangulare cultivated with pig manure under organic, composted, and incinerated treatments during dry and rainy seasons is presented in Table 4.86. Compost treatment consistently produced the highest yield across all months, with total yield of 407 (43.1%), followed by organic manure with 350 (37.1%), while incinerated manure recorded the lowest yield of 186 (19.7%). Compost manure produced a 16.3% higher yield than organic manure and more than twice the yield obtained with incinerated manure, indicating improved nutrient availability and fertilizer efficiency after composting.

Fresh pig manure showed moderate performance, whereas incinerated manure produced the lowest yield due to the loss of organic matter and nitrogen during thermal processing, which reduces nutrient availability for plant growth. Seasonal variation was also observed, with rainy season cultivation producing higher yields (502; 53.2%) compared with the dry season (441; 46.8%), likely due to improved moisture availability and enhanced nutrient uptake.

Table 19: Yield of Talinum triangulare by seasons using pig manure in organic, compost, and incinerated forms.

Season	Months	Organic	Compost	Incinerated	Monthly Total (% of Grand Total)
Dry season	Jan	40 (30.8%)	62 (47.7%)	28 (21.5%)	130 (13.8%)
	Feb	62 (39.0%)	66 (41.5%)	31 (19.5%)	159 (16.9%)
	Mar	62 (40.8%)	62 (40.8%)	28 (18.4%)	152 (16.1%)
Rainy season	May	62 (37.8%)	70 (42.7%)	32 (19.5%)	164 (17.4%)
	June	62 (36.9%)	73 (43.5%)	33 (19.6%)	168 (17.8%)
	July	62 (36.5%)	74 (43.5%)	34 (20.0%)	170 (18.0%)
Total		350 (37.1%)	407 (43.1%)	186 (19.7%)	943 (100%)

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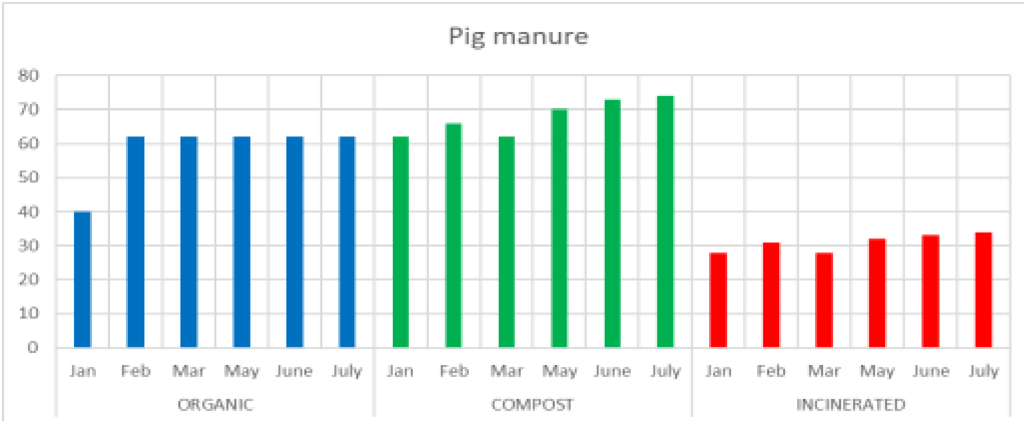

Figure 2: Yield of Talinum triangulare by seasons using pig manure treatment

3.5.2 Yield of Talinum triangulare in dry and rainy seasons using cow dung manure in organic, compost, and incinerated forms.

The yield of Talinum triangulare cultivated with cow dung manure under organic, compost, and incinerated treatments during dry and rainy seasons is presented in Table 4.87. Compost manure consistently produced the highest yield across all months, with a total yield of 368 (46.4% of grand total), followed by organic manure with 247 (31.1%), while incinerated cow dung recorded the lowest yield of 179 (22.6%). Compost application increased yield by 49% compared with organic manure and 106% compared with incinerated manure, indicating improved nutrient availability and fertilizer efficiency after composting. Organic cow dung produced moderate yields but was less effective than composted manure, likely due to slower nutrient release and potential nutrient losses. Incinerated cow dung showed the poorest performance, which may be attributed to the destruction of organic matter and volatilization of essential nutrients, particularly nitrogen, during combustion.

Seasonal variation showed higher yields during the rainy season, which contributed 417 (52.5%) of the total yield compared with 377 (47.5%) recorded in the dry season. The improved rainy-season performance may be linked to increased soil moisture, enhanced nutrient mineralization, and better plant nutrient uptake. Overall, composted cow dung proved to be the most effective treatment for improving the yield of T. triangulare.

Table 20: Yield of Talinum triangulare by seasons using cow dung in organic, compost, and incinerated forms.

Season	Months	ORGANIC	COMPOST	INCINERATED	Monthly Total (% of Grand Total)
Dry season	Jan	42 (34.7%)	52 (43.0%)	27 (22.3%)	121 (15.2%)
	Feb	41 (31.5%)	60 (46.2%)	29 (22.3%)	130 (16.4%)
	Mar	41 (32.5%)	58 (46.0%)	27 (21.4%)	126 (15.9%)
Rainy season	May	41 (29.9%)	65 (47.4%)	31 (22.6%)	137 (17.3%)
	June	41 (29.5%)	66 (47.5%)	32 (23.0%)	139 (17.5%)
	July	41 (29.1%)	67 (47.5%)	33 (23.4%)	141 (17.8%)
Total		247 (31.1%)	368 (46.4%)	179 (22.6%)	794 (100%)

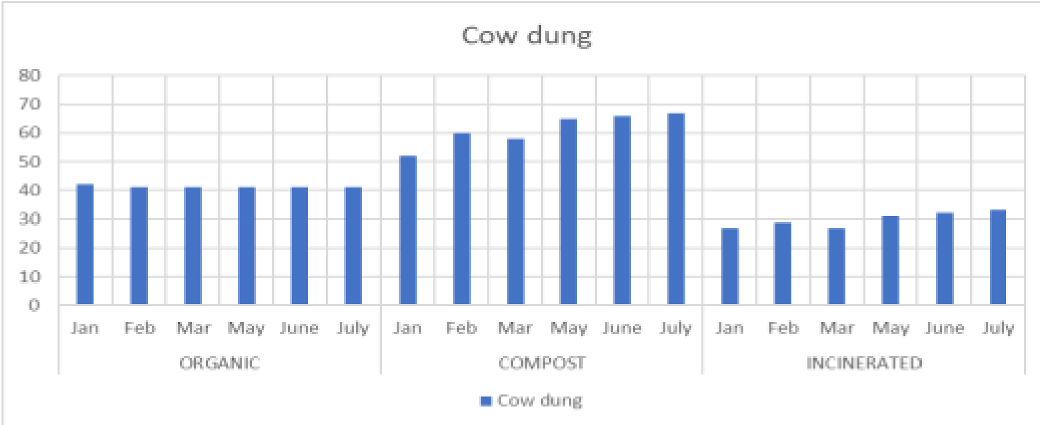

Figure 3: Yield of Talinum triangulare by seasons using cow dung treatment

3.5.3. The yield of T triangulare in dry and rainy seasons using Poultry manure in organic, compost and incinerated form.

The yield of Talinum triangulare cultivated with poultry manure under organic, compost, and incinerated treatments is presented in Table 4.88. Compost manure produced the highest overall yield (430; 36.7% of grand total), closely followed by organic poultry manure (425; 36.3%), while incinerated poultry manure recorded the lowest yield (194; 16.6%). Compost and organic treatments consistently outperformed incinerated manure, indicating that biological nutrient release from untreated and composted poultry manure enhanced plant productivity, whereas incineration reduced fertilizer efficiency through loss of organic matter and nitrogen. Overall, composted poultry manure demonstrated the best performance, although organic poultry manure showed comparable yield potential.

Table 21: Yield of Talinum triangulare by seasons using poultry manure in organic, compost, and incinerated forms.

Season	Months	Organic	Compost	Incinerated	Monthly Total (% of Grand Total)
Dry season	Jan	35 (26.9%)	65 (50.0%)	30 (23.1%)	130 (11.1%)
	Feb	78 (42.9%)	72 (39.6%)	32 (17.6%)	182 (15.5%)
	Mar	78 (43.8%)	70 (39.3%)	30 (16.9%)	178 (15.2%)
Rainy season	May	78 (42.6%)	72 (39.3%)	33 (18.0%)	183 (15.6%)
	June	78 (41.7%)	75 (40.1%)	34 (18.2%)	187 (16.0%)
	July	78 (41.3%)	76 (40.2%)	35 (18.5%)	189 (16.1%)
Total		425 (36.3%)	430 (36.7%)	194 (16.6%)	1172 (100%)

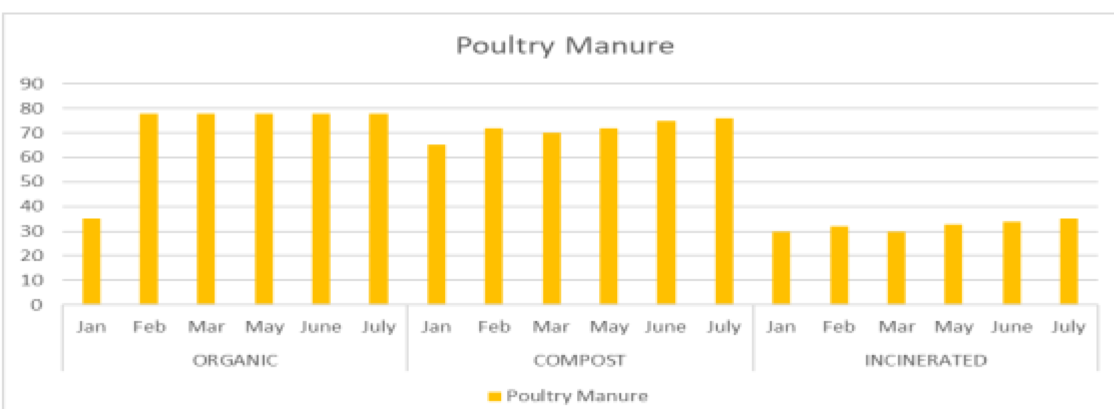

Figure 4: Yield of Talinum triangulare by seasons using poultry manure treatment

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3.5.4. The yield of T. triangulare in dry and rainy season using Cow dung and Pig manure in organic, compost and incinerated form.

The yield of Talinum triangulare cultivated with cow and pig manure under organic, compost, and incinerated treatments is presented in Table 4.89. Compost manure produced the highest overall yield (411; 49.9% of grand total), followed by organic manure (234; 28.4%) and incinerated manure (183; 22.2%). Compost treatment consistently enhanced yield across all months, indicating improved nutrient availability and stabilization of organic matter. In contrast, incinerated manure recorded lower productivity, likely due to the loss of organic nutrients during combustion. Overall, composted cow and pig manure demonstrated superior fertilizer efficiency for improving T. triangulare yield.

Table 22: Yield of Talinum triangulare by seasons using cow dung and pig manure in organic, compost, and incinerated forms.

Season	Months	Organic	Compost	Incinerated	Monthly Total (% of Grand Total)
Dry season	Jan	39 (30.0%)	62 (47.7%)	29 (22.3%)	130 (15.8%)
	Feb	39 (28.1%)	68 (48.9%)	32 (23.0%)	139 (16.9%)
	Mar	39 (29.1%)	67 (50.0%)	28 (20.9%)	134 (16.3%)
Rainy season	May	39 (27.7%)	70 (49.6%)	32 (22.7%)	141 (17.1%)
	June	39 (27.9%)	71 (50.7%)	30 (21.4%)	140 (17.0%)
	July	39 (27.1%)	73 (50.7%)	32 (22.2%)	144 (17.5%)
Total		234 (28.4%)	411 (49.9%)	183 (22.2%)	828 (100%)

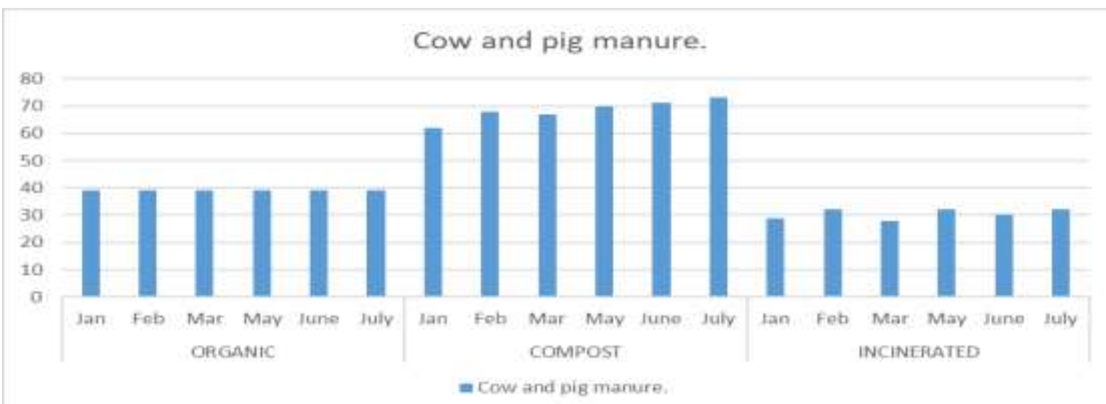

Figure 5: Yield of Talinum triangulare by seasons using cow dung and pig manure treatment

3.5.5. The yield of T. triangulare in dry and rainy season using Pig and Poultry manures in organic, compost and incinerated form.

The yield of Talinum triangulare cultivated with pig and chicken manure under organic, compost, and incinerated treatments is presented in Table 4.90. Compost manure produced the highest overall yield (441; 46.6% of grand total), followed by organic manure (264; 27.9%), while incinerated manure recorded the lowest yield (200; 21.1%).

Table 23: Yield of Talinum triangulare by seasons using pig and poultry manures in organic, compost, and incinerated forms.

Season	Months	Organic	Compost	Incinerated	Monthly Total (% of Grand Total)
Dry season	Jan	44 (29.9%)	72 (49.0%)	31 (21.1%)	147 (15.5%)
	Feb	44 (28.6%)	76 (49.4%)	34 (22.1%)	154 (16.3%)

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	Mar	44 (29.9%)	72 (49.0%)	31 (21.1%)	147 (15.5%)
Rainy season	May	44 (28.9%)	74 (48.7%)	34 (22.4%)	152 (16.0%)
	June	44 (28.4%)	76 (49.0%)	35 (22.6%)	155 (16.4%)
	July	44 (29.3%)	71 (47.3%)	35 (23.3%)	150 (15.8%)
Total		264 (27.9%)	441 (46.6%)	200 (21.1%)	947 (100%)

Figure 6: Yield of Talinum triangulare by seasons using pig and poultry manures treatment

3.5.6. The yield of T. triangulare in dry and rainy season using Poultry and Cow manure in organic, compost and incinerated form.

The yield of Talinum triangulare cultivated with chicken manure and cow dung under organic, compost, and incinerated treatments is presented in Table 4.91. Compost manure recorded the highest overall yield (439; 46.1% of grand total), followed by organic manure (252; 26.4%), while incinerated manure produced the lowest yield (197; 20.7%).

Table 24: Yield of Talinum triangulare by seasons using poultry and cow manure in organic, compost, and incinerated forms.

Season	Months	Organic	Compost	Incinerated	Monthly Total (% of Grand Total)
Dry season	Jan	42 (30.0%)	68 (48.6%)	30 (21.4%)	140 (14.7%)
	Feb	42 (28.2%)	74 (49.7%)	33 (22.1%)	149 (15.6%)
	Mar	42 (28.4%)	73 (49.3%)	33 (22.3%)	148 (15.5%)
Rainy season	May	42 (28.4%)	73 (49.3%)	33 (22.3%)	148 (15.5%)
	June	42 (28.0%)	75 (50.0%)	33 (22.0%)	150 (15.7%)
	July	42 (27.5%)	76 (49.7%)	35 (22.9%)	153 (16.0%)
Total		252 (26.4%)	439 (46.1%)	197 (20.7%)	953 (100%)

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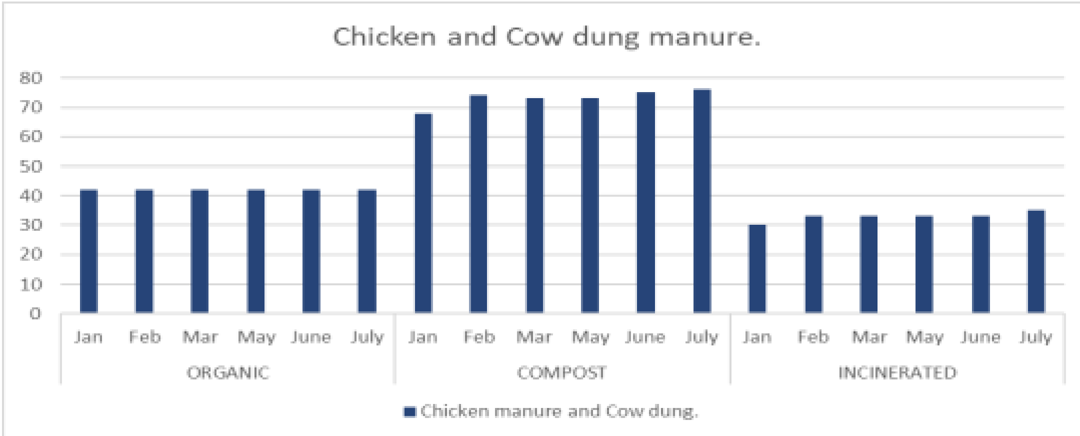

Figure 7: Yield of Talinum triangulare by seasons using poultry and cow manure treatment

4.6.7. The yield of T. triangulare in dry and rainy season using Cow, Chicken and Pig dung manure in organic, compost and incinerated form.

The yield of Talinum triangulare cultivated with cow, chicken, and pig manure under organic, compost, and incinerated treatments is presented in Table 4.92. Compost manure produced the highest overall yield (487; 45.0% of grand total), followed by organic manure (288; 26.6%), while incinerated manure recorded the lowest yield (210; 19.4%).

Table 25: Yield of Talinum triangulare by seasons using cow, poultry and pig manure in organic, compost, and incinerated forms.

Season	Months	Organic	Compost	Incinerated	Monthly Total (% of Grand Total)
Dry season	Jan	48 (30.2%)	78 (49.1%)	33 (20.8%)	159 (14.6%)
	Feb	48 (29.4%)	80 (49.1%)	35 (21.5%)	163 (15.0%)
	Mar	48 (29.3%)	81 (49.4%)	35 (21.3%)	164 (15.1%)
Rainy season	May	48 (29.1%)	82 (49.7%)	35 (21.2%)	165 (15.2%)
	June	48 (28.7%)	83 (49.7%)	36 (21.6%)	167 (15.3%)
	July	48 (28.7%)	83 (49.7%)	36 (21.6%)	167 (15.3%)
Total		288 (26.6%)	487 (45.0%)	210 (19.4%)	1084 (100%)

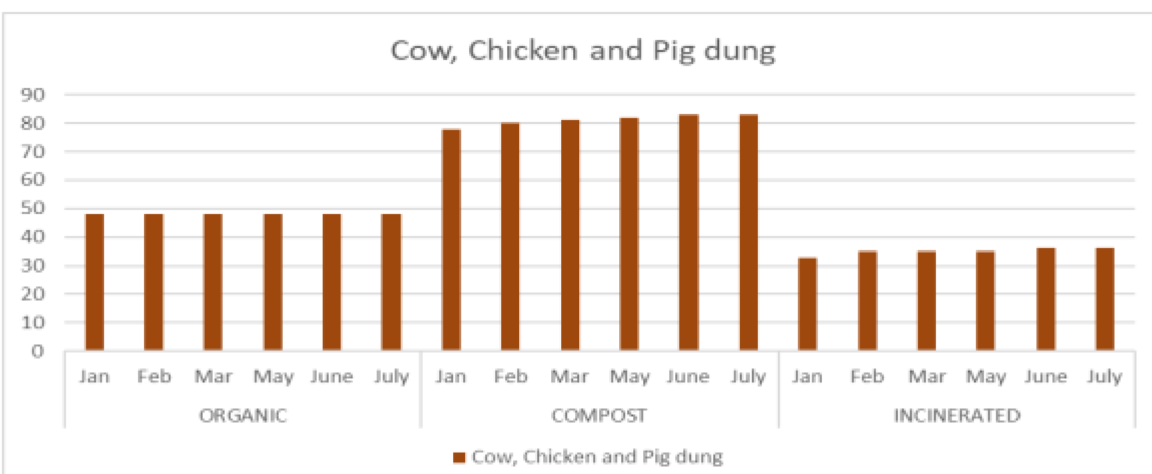

Figure 7: Yield of Talinum triangulare by seasons using cow, poultry and pig manure treatment

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IV. DISCUSSION

The findings of this study demonstrate that treatment methods significantly influenced the physicochemical properties, microbiological safety, nutritional composition, and agronomic performance of animal wastes and Talinum triangulare. Untreated animal wastes showed high moisture content (80–85%), consistent with reports of fresh livestock manure containing 70–90% moisture due to high water retention capacity (Jahan et al., 2022). High moisture limits oxygen diffusion and slows aerobic decomposition. Following composting, moisture content declined substantially (~40–55%), reflecting microbial degradation, heat generation, and evaporation during the thermophilic phase (Roy et al., 2024). Conversely, incineration resulted in very low moisture content (4–10%), confirming dehydration and conversion of organic materials into dry ash, although this reduces biological activity and soil amendment potential (Pajura, 2024).

Untreated wastes exhibited high organic matter (OM) and organic carbon (OC), reflecting abundant undecomposed organic substrates. Composting reduced OM and OC through microbial mineralization and carbon loss as CO_2, consistent with recent composting studies (Noor et al., 2024). Incineration caused marked depletion of organic fractions due to combustion, resulting in mineral ash with reduced soil-conditioning capacity (Pajura, 2024). The improved carbon retention observed in composted mixed wastes agrees with findings that co-composting enhances substrate balance and compost stability (Domene et al., 2025).

Nitrogen content was highest in untreated poultry manure, reflecting the naturally high nitrogen concentration of poultry wastes (Domene et al., 2025). Composting reduced nitrogen levels due to ammonia volatilization and leaching losses, while improving nutrient stabilization. Similar nitrogen losses during composting have been reported by Li and Li (2015). Incineration resulted in severe nitrogen depletion due to volatilization of nitrogenous compounds during combustion, consistent with observations by Shan et al. (2021). Co-composting improved nitrogen conservation by optimizing the carbon-to-nitrogen ratio and reducing nutrient losses (Noor et al., 2024).

The increase in total solids and dry matter after composting indicates stabilization and reduction of water content, while reductions in volatile solids demonstrate degradation of biodegradable organic fractions (Jahan et al., 2022; Pajura, 2024). Composting also shifted pH from slightly acidic conditions in untreated wastes (6.2–6.8) to neutral or mildly alkaline conditions (7.0–7.8), which is favourable for plant growth (Jahan et al., 2022). The thermophilic temperatures observed during composting (40–55°C) support effective microbial degradation and pathogen reduction (Roy et al., 2024). High germination indices recorded in composted treatments indicate improved maturity and reduced phytotoxicity, supporting previous findings that mature compost enhances seed germination and plant development (Domene et al., 2025).

Microbiological analysis revealed substantial differences among treatment methods. Untreated wastes showed the highest faecal coliform loads, with pig slurry and poultry manure recording greater contamination than cow dung. Mixed manure combinations further increased microbial loads, reflecting additive microbial contributions from multiple waste sources. Similar high levels of faecal indicators in untreated livestock manure have been reported in Nigeria, highlighting the risk of pathogen transmission when raw manure is applied directly to crops (Chukwu et al., 2022).

Composting significantly reduced faecal coliform populations by approximately 2–3 log reductions. This reduction is associated with thermophilic conditions that promote the inactivation of Escherichia coli and other enteric bacteria (Manga et al., 2020). However, the persistence of low-level coliforms in some composted treatments indicates the importance of adequate compost maturity, temperature monitoring, and management practices (Huang et al., 2005). Incineration achieved the greatest microbial reduction, producing near-negligible faecal coliform levels due to thermal destruction of bacterial cells. However, the loss of organic matter during combustion reduces the agronomic value of the resulting ash (Guo et al., 2023).

The transfer of faecal indicator organisms to Talinum triangulare was strongly influenced by manure treatment. Vegetables grown with untreated manure recorded the highest contamination levels, with E. coli, Klebsiella, Enterobacter, Proteus, and Salmonella detected. The dominance of E. coli reflects its abundance in animal gastrointestinal tracts and its suitability as a faecal contamination indicator. Detection of Salmonella in poultry manure treatments is particularly important because of its association with foodborne illness linked to contaminated vegetables (Bai et al., 2020). Similar manure-to-crop transmission of faecal organisms has been reported in leafy vegetables grown with untreated animal wastes (Chukwu et al., 2022).

Composted manure treatments showed lower microbial contamination, with simplified bacterial diversity dominated mainly by E. coli, Enterobacter, and Klebsiella. This agrees with reports that compost maturity reduces microbial diversity and pathogen survival (Xue et al., 2022). Although incinerated treatments recorded the lowest contamination levels, the detection of residual organisms indicates that complete elimination of microbial risks requires proper handling and prevention of post-treatment contamination (Berg et al., 2020).

Nutritional analysis showed that composted manure treatments significantly improved the proximate composition of T. triangulare. Composted combined manure treatments, particularly cow dung + poultry droppings + pig slurry, produced the highest crude protein, fibre, fat, and mineral contents. Increased protein content under composted treatments reflects improved nitrogen availability and uptake, consistent with previous studies on leafy vegetables grown with composted organic manure (Ojeniyi et al., 2018; Adekiya et al., 2020). In contrast, reduced protein values in incinerated treatments resulted from nitrogen losses during combustion (Zhang et al., 2021).

Mineral composition followed a similar trend, with composted treatments showing higher calcium, magnesium, potassium, iron, and phosphorus concentrations. Composting enhances nutrient mineralization and improves nutrient availability through increased microbial activity and soil nutrient retention (Agegnehu et al., 2016). Poultry-based composts showed particularly high mineral concentrations due to the nutrient richness of poultry manure (Ezekiel et al., 2020). Conversely, incinerated treatments showed reduced nutrient availability because of organic matter loss and poor nutrient solubility (Zhang et al., 2021).

Growth and yield parameters of T. triangulare were significantly improved by organic amendments compared with control treatments. Composted combined manure, particularly cow dung + poultry droppings + pig slurry, produced the highest vegetative performance, reflecting improved nutrient balance, soil structure, and microbial activity. Similar benefits of compost application on vegetable productivity have been reported (Agegnehu et al., 2016; Adekiya et al., 2020). Poultry manure showed superior performance among single manure treatments due to its high nitrogen content and rapid nutrient release (Adekiya et al., 2019).

Seasonal variation also influenced plant performance, with higher growth during the rainy season due to improved soil moisture, nutrient mobility, and microbial activity. Similar observations have been reported in tropical agricultural systems where moisture availability influences nutrient uptake efficiency (Nziguheba et al., 2016).

Composting was identified as the most effective treatment strategy, achieving a balance between microbial safety, nutrient conservation, and crop productivity. Combined compost treatments provided the best outcomes due to improved nutrient synergy, while poultry manure was the most effective single manure source. Untreated manure increased contamination risks, whereas incineration provided microbial safety at the expense of nutrient quality and agronomic performance.

V. CONCLUSION

This study demonstrates that the treatment method of animal waste significantly influences its effectiveness, safety, and impact on the growth, yield, and nutritional quality of Talinum triangulare. Among all methods evaluated, composting proved to be the most effective. Composting improved the physicochemical properties of animal wastes, enhanced nutrient availability, and significantly reduced faecal contamination, making it both agronomically beneficial and relatively safe. In contrast, untreated wastes, although nutrient-rich, posed health risks due to high microbial loads, while incineration, despite eliminating pathogens, reduced nutrient content and overall soil fertility value. Composted manures, particularly combined mixtures of cow dung, poultry droppings, and pig slurry, consistently produced the highest plant growth, yield, and nutritional quality. Poultry manure also stood out as the most effective single source due to its high nutrient content. Seasonal variation further influenced results, with better performance observed during the rainy season. The findings confirm that composted, combined organic wastes offer the best balance of productivity, safety, and sustainability, making them the most suitable option for improving the cultivation of Talinum triangulare.

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