



# Enhancement of agricultural productivity through application of compost produced using rice husks (*Oryza sativa*) and water fern (*Azolla pinnata*)

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## Original Research

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## Abstract:

**Purpose:** Composting agro-wastes enhances plant growth with minimal health and environmental threats. Thus, this study focused on the potential of composting rice husk (*Oryza sativa*) with water fern plants (*Azolla*) to increase agricultural productivity with minimal health and environmental pollutions.

**Method:** The study employed laboratory experimentation and analysis. In experimental design the Minitab software was used to design these experiments whereby two factors were considered which are the particle size (2 mm, 3 mm and 4 mm) and mixing ratio (1:3; 1:1; 3:1 and 4:0; 0:4). Fifteen (15) wood compartments with dimensions of 30 cm × 30 cm × 35 cm each cube of maximum carrying capacity of 5 kg were developed.

**Results:** The results for physical and chemical properties of feedstock's showed that rice husks contained 8.55% of Moisture Content, pH (6.15), total organic carbon (46.1%), ash content (20.6%),  $PO_4^{3-}$  (2475 mg/kg), K (5042 mg/kg), Na (1490.4 mg/kg), total nitrogen (0.735%) and Carbon to Nitrogen ratio (34.21). *Azolla* contained Moisture Content (93.48%), pH (6.73), TOC (42.67%), TN (3.255%), C/N ratio (13.02%),  $PO_4^{3-}$ , (4262.5mg/kg), K (1268 mg/kg), and Na (7379.52 mg/kg). The composting made using samples with particle size of < 2 mm were observed to support the growth of *Amaranthus spinous* quickly with the average growth rate of 0.9572 cm/day than other compost produced with particles size of 3 mm and 4 mm.

**Conclusion:** This study shows that there is a potential of composting rice husks with *Azolla* for nutrient resource recovery to support crop productivity.

**Keywords:** Biofertilizer; Composting; Feed stocks; Nutrients; Resource recovery; Waste management

## 1. Introduction

In Tanzania it is estimated that over 80% of the population engages in agricultural production, and half (1/2) of the national income and three quarters (3/4) of goods export in the country is contributed by agricultural sector (Leonard and Riwa, 2023). Though the sector employs a large population of Tanzania, its contribution to national GDP has been decreasing from 29.0 percent in 2015 to 26.6 percent in 2019. The decrease is attributed by structural transformation of economic activities, shifting of rural population to urban areas and challenges facing the practice and production in the agricultural sector. The agricultural sector in Tanzania

is faced by several challenges including low productivity of land/low fertility, labour and production inputs, over dependence on rain-fed agriculture, inadequate investment in agricultural training, research and extension services, inadequate capital for accessing agricultural technologies and others (Mng'ong'o et al., 2021). Inadequate investment in agricultural training, research and technology development have resulted in low productivity and capacity in agro-processing, poor quality of crop produced, post-harvest loss, environmental degradation due to poor cultivation systems and inappropriate application of agro-chemicals and fertilizers (Suvi et al., 2021). The Agricultural Sector Development Programme Phase II (ASDP II) (2017) indicated

that Tanzania applies low amount of fertilizer about 8 – 10 kg of fertilizer/per hectare in the farmlands compared to other countries like Malawi which applies 27 kg per hectare. The low application of fertilizer is contributed by several factors including inadequate capacity to purchase inorganic fertilizer, low technology for production of organic fertilizer, limited knowledge to understand the required amount of fertilizer and other. This calls for different stakeholders to take part in addressing agricultural challenges including research and development in production of organic fertilizer since Tanzania is blessed with adequate resources for production of organic fertilizer such as rice husks.

Rice is regularly consumed and is considered as an important crop for food security for over half of the world's population (Seleiman et al., 2022; Isimikalu et al., 2023) and is expected that by 2030, rice production at a global scale will increase to 567 million tonnes (Mohidem et al., 2022). It is grown on every continent except Antarctica and the extent of paddy cultivation covers about 1% of the earth's surface and is ranked as the second to wheat in terms of cultivation area and production (Seleiman et al., 2022; Leonard and Riwa, 2023). Production of rice is dominated by Asia where rice is the only food crop that can be grown during the rainy season in the waterlogged rice paddies (Bandumula, 2018). The consumption of rice in African continent is also expected to increase driven by population growth, dietary changes and crop production on the existing arable land (Mohidem et al., 2022; Balasubramanian et al., 2007).

In Tanzania, 18% of the households are engaged in rice production (Joseph, 2013) which is the second most grown food and commercial crop after maize, in the country (Leonard and Riwa, 2023). It is further estimated that 99% of the rice in the country is produced by smallholder farmers with farm sizes ranging between 0.5 to 3 hectares (Joseph, 2013; Wilson and Lewis, 2015). Rice husks are a key byproduct associated with rice production which is not considered to be of economic value to millers (Isimikalu et al., 2023; Njogu et al., 2015; Khan et al., 2012). The worldwide annual rice husk output is about 134 million tons, out of which 97% of the husks is produced in the developing countries (Abubakar, 2016). In Tanzania, it is common to find piles of rice husks around rice milling machines, left uncollected, indicating that majority of the population have no alternative of utilizing such resources which ultimately causes environmental pollution. According to Bakari et al. (2023) rice husks produced in Tanzania is more than 3.2 million metric tons per year. Rice husks (RHs) are produced in large quantities over millions of tons worldwide and only small quantities of rice husks are recovered through composting, briquette production (Wilson and Lewis, 2015), biogas production (Okeh et al., 2014), and animal feeds (Aondoaver, 2014). In most cases, farmers and business men are interested with rice grains, leaving behind rice husks at the milling machines which at the end of the day undergoes open burning which is not environmentally friendly. This calls a need of establishing affordable and beneficial technologies of utilizing such agro wastes.

Various studies suggest that composting agro industrial

waste have potential of recovering resources which can be used for agricultural production (Seleiman et al., 2022; Thiyageshwari et al., 2018; Khan et al., 2012). Materials with lignin and cellulose can be degraded economically through inoculating with lignocellulolytic microorganism (Thiyageshwari et al., 2018) and produce compost suitable for plant growth. A study done by Kumar et al. (2009) and Gao et al. (2018) indicated that rice husks contains 35 – 40% cellulose, 15 – 20% hemicellulose and 20 – 25% lignin and azolla contains 28.23 – 29.51% cellulose, 10.82 – 11.4% hemicellulose and 7.82 – 8.32% lignin (Gupta et al., 2018). Typical compositions of rice husks and azolla indicate their potential for resource recovery (Gupta et al., 2018; Gao et al., 2018). Nevertheless, despite of the potential of composting these materials for resource recovery, they are haphazardly left on the environment causing environmental and health risks (Seleiman et al., 2022).

Today, the world is witnessing the demand of food due to population growth and land degradation (Isimikalu et al., 2023; Aondoaver, 2014). The most common practice has been to use synthetic fertilizers to improve the degraded soil (Seleiman et al., 2022) which ultimately causes health and environmental pollution. A study done by Seleiman et al. (2022) revealed that *azolla* plant can be composted and enhance plant growth. Thus, there is a need of establishing proper way of handling and recovering these resources which are not easily decomposed due to the presence of lignin as complex chemical structure providing strength and makes rice husks highly resistant to microbial degradation (Thiyageshwari et al., 2018).

Therefore, this study intended to assess the potential of active composting technology for production of compost using rice husk mixed with *azolla* for the purpose of recovering organic manure and recycling important nutrients for agricultural production while solving environmental, health and social-economic problems triggered by poor management of rice husks. The compost made from agro waste are considered to be environmentally friendly, raw materials are readily available and the technology can be adopted by small and large-scale farmers and hence increase crop productivity towards meeting sustainable development goal 1 and 2 (No poverty and Hunger to all) by 2030. In addition, composting of rice husks provides an alternative way of managing this biomass (Isimikalu et al., 2023) which is currently unutilized in Tanzania and sometimes regarded as waste burnt and add up to greenhouse gases which also result into substantial loss of nutrients such as nitrogen and sulphur (Isimikalu et al., 2023).

## 2. Materials and methods

### Feedstocks and its preparation

The feedstock's used in this study were rice husks (*Oryza sativa*) collected from milling machines located in Tandale ward, Kinondoni district while *azolla* (*azolla pinnata*) were collected at Mtongani area located in Temeke municipal in Dar es Salaam region. These areas were selected for feedstock collection due to their abundances in the study area. All feedstock after collection into sacks of 20 kg plastic bags from respective collection sites were transported

to Ardhi University for preparations and experimentation. Rice husks were weighted by using Salter universal hanging scale with capacity of 200 kg. The rice husk (*Oryza sativa*) was sieved to different particle size of 2 mm, 3 mm and 4 mm since small particle size (< 4 mm) provides a large surface area for microbial decomposition, and then collected into the sacks for temporary storage before the mixing process took place.

### Preparation of feedstock composting ratios

The five-mixing ratio of different weights for azolla and rice husks were established and named as sample R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub>, and R<sub>5</sub> where the last two ratios were used as control as shown in Table 1. The two controls namely R<sub>4</sub> and R<sub>5</sub> included only rice husks (*Oryza sativa*) and *azolla* (water fern plants) respectively. The composting processes were conducted naturally by regulating only moisture content to be between 40% – 60%.

**Table 1.** Composting ratio between *azolla*, water fern plant (A) and Rice husk, *Oryza sativa* (B).

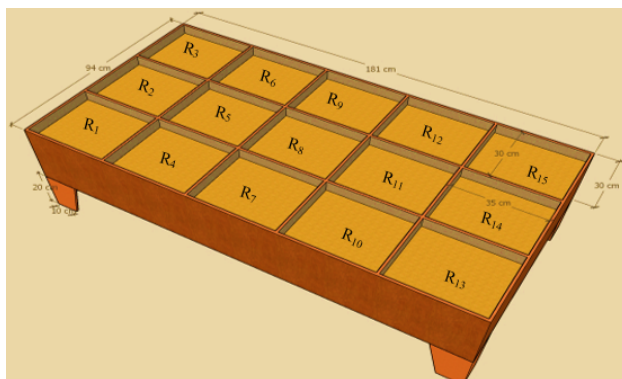
Sample	Ratio (A:B) kg	(A:B) g
R <sub>1</sub>	3:1	3000:1000
R <sub>2</sub>	1:1	2000:2000
R <sub>3</sub>	1:3	500:1500
R <sub>4</sub>	0:4	0:4000
R <sub>5</sub>	4:0	4000:0

### Methodology

Fifteen (15) wood compartments were developed and used with dimensions of 30 × 30 × 35 cm (height, width and length) for single compartment, respectively, and maximum carrying capacity of 5 kg per each cube as shown in Fig. 1.

### Mixing process

In feedstock preparation, mixing ratio comprised of three runs where by two runs comprised five ratios and one had three mixing ratios. The first run included the particle size of 2 mm of rice husk with a mixing ratio namely R<sub>5</sub>, R<sub>8</sub>, R<sub>9</sub>, R<sub>12</sub> and R<sub>13</sub>. The second run was particle size of 3 mm of rice husks with a mixing ratio namely R<sub>1</sub>, R<sub>2</sub> and R<sub>7</sub>, the third run was particle size of 4 mm with a mixing ratio of



**Figure 1.** A 3D view structure of wood bin composting system with its dimensions.

R<sub>3</sub>, R<sub>4</sub>, R<sub>6</sub>, R<sub>10</sub> and R<sub>11</sub> and the remained two mixed ratios were for controls.

### Laboratory analysis

The quality of compost produced from rice husk mixed with azolla was established by analyzing their physiochemical and biological properties which included temperature, moisture content, pH, electric conductivity, potassium (K), total nitrogen (TN), phosphates (PO<sub>4</sub><sup>3-</sup>), total organic carbon (TOC), heavy metals (Cu, Pb, Zn and Cd) and C:N ratio.

### Moisture content (MC)

Moisture content was calculated using equation (1) (AOAC, 2000);

$$MC(\%) = \frac{(W_2 - W_1) - (W_3 - W_1)}{(W_2 - W_1)} \quad (1)$$

where by  $W_1$  weight of the crucible in gram,  $W_2$  is weight of the crucible with wet sample in gram (g) and  $W_3$  is weight of the crucible with sample after drying at 105 °C.

### Organic matter content (OM)

Organic matter content was determined by loss on ignition method described by AOAC (2000) as given in equation (2).

$$\%OM = \frac{(W_3 - W_1) - (W_4 - W_1)}{(W_3 - W_1)} \times 100 \quad (2)$$

where;  $-W_1$  represents the weight of empty crucible in gram,  $W_2$  is weight of the crucible with wet sample in gram,  $W_3$  is weight of the crucible with sample after drying at 105 °C and  $W_4$  represents weight of the ash with crucible after drying up to 562 °C in an oven.

### Total nitrogen

Total nitrogen was determined by using a Kjeldahl Nitrogen test as described by AOAC (2000). The percentage of Total Nitrogen was calculated using equation (3).

$$\%TN = \frac{[(a - b) \times N \times 1.4 \times MC]}{WS} \quad (3)$$

whereby; N- normality of standard H<sub>2</sub>SO<sub>4</sub> used,  $a$ - volume (mL) of H<sub>2</sub>SO<sub>4</sub> required to titrate the sample to color change,  $b$ - volume in (mL) of 0.05N H<sub>2</sub>SO<sub>4</sub> required to titrate of blank to color change,  $WS$ - sample dry weight in grams,  $MC$ - Moisture Content and 1.4 (weight of nitrogen in gram) =  $14 \times 10^{-3} \times 100\%$  (14 is the atomic mass of N).

### Potassium (K) and heavy metals

Potassium and heavy metals were determined in the feedstock materials by using Atomic Absorption Spectrophotometer. The concentrations were converted mathematically from mg/L to mg/kg using equation (4).

$$\text{Conc} \left( \frac{\text{mg}}{\text{kg}} \right) = \text{Conc} \left( \frac{\text{mg}}{\text{L}} \right) \times \frac{V \text{ in L}}{WS} \quad (4)$$

whereby; volume (V) in L = 0.002 L of aqua regia + 0.01 L of distilled water

Weight of sample (WS) = 0.51 g = 0.00051 kg

$$\text{Conc} \left( \frac{\text{mg}}{\text{kg}} \right) = \frac{\text{mg}}{\text{L}} \times \frac{(0.002\text{L} + 0.01)}{0.00051\text{kg}} = 24 \frac{\text{L}}{\text{kg}}$$

### Determination of performance of compost produced in plant growth

The performance was determined based on the plant growth rate. During the germination and growth of *Amaranthus spinosus*, the heights of stem and leaves were established using a mathematical ruler, widths of leaves and the number of leaves in *Amaranthus spinosus* to evaluate the average daily growth rate. The measurement was recorded from 1<sup>st</sup> day, 4<sup>th</sup>, 8<sup>th</sup>, 12<sup>th</sup> to 18<sup>th</sup>. The experimental setup had four plots which included selected three compost based on C/N ratio of compost in each particle size namely, 2 mm (Plot 1 – P1), 3 mm (Plot 2 – P2) and 4 mm (Plot 3 – P3) and control (Plot 4 – P4) which had no compost. Plot 1 included compost from R<sub>12</sub>, Plot 2 from R<sub>1</sub> and three from R<sub>10</sub> while plot 4 did not include compost. Selected of compost based on C/N ratio was based on the similar C/N ratio in all particle sizes which meet the recommended standard of C/N ratio ranging from 20:1 to 30:1. This range promotes healthy plant growth and preventing nutrient imbalances or deficiencies. Mathematically the growth rate was calculated by taking the average change in height of the stem to its time taken to grow.

$$\text{Growth rate} = \frac{\Delta \text{Height of steam (cm)}}{\Delta \text{Time (day)}}$$

### Statistical analysis

Analysis of variance (ANOVA) and Pearson correlation was carried out where P values ( $p < 0.05$ ) were considered to present significant differences. Also, descriptive analysis was conducted using Excel Microsoft version 10.1 to establish means and standard deviations of analytical results.

## 3. Results and discussion

The physical and chemical properties of feedstock's material are presented in Table 2. The initial composition of

the raw material used for composting helped to monitor the parameters essential for microbial decomposition during the composting process and helped to forecast the quality of the compost produced. The findings revealed that Water fern plant had high moisture content of 93.48% compared to 8.55% of rice husks while EC was 4.16 mS/cm in water fern plant compared to 1.76 mS/cm in rice husks. The moisture content results are somehow in alignment or slightly less than that presented by Bhaskaran and Kannapan (2015), and Brand et al. (2017), respectively as indicated in Table 2. Ash content was 20.6% in rice husks compared to 9.86% in the water fern plant. The obtained ash contents for rice husk was almost the same as what was obtained but for *azolla* was different from what obtained by Bhaskaran and Kannapan (2015). Phosphate concentration was 4262.5 mg/kg compared to 2475 mg/kg while potassium concentration was 5042 mg/kg in rice husks compared to 1268 mg/kg in fern plant. The C/N ratio was 34.21 in rice husks compared to 13.02 in fern plant indicating that materials chosen for composting had Carbon and Nitrogen content of different magnitude. These results were different from the findings from other studies as indicated in Table 2. The difference might be attributed to the environmental conditions where the plants were grown which affect the distribution of chemicals.

### Heavy metal contamination in raw feedstock materials

The results of heavy metal concentrations in feedstock are presented in Table 3. During composting process, the concentration of heavy metals in feedstock remains the same except for the water-soluble metals, thus increasing their concentration in compost. Depending on the plant species, the soil type and the quality of the compost applied to the soil, accumulation of heavy metals in plant may lead to plant toxicity and decrease plant growth (Dubey et al., 2018). The

**Table 2.** Initial composition of feedstock materials before compost production as characterized in terms of physical and chemical composition.

Parameters	Physical composition of feedstocks material		Results from other studies
	Water fern plant ( <i>azolla</i> )	Rice husks ( <i>Oryza sativa</i> )	
Moisture contents (%)	93.48	8.55	AZP: 92.25 (Bhaskaran and Kannapan, 2015), RHs: 8 – 12 (Brand et al., 2017).
pH	6.73	6.15	AZP: 6.9 – 8.5 ± 1.3 (Chandra et al., 2012).
E.C (mS/cm)	4.16	1.76	AZP: 8.4 ± 0.2 (Chandra et al., 2012).
Total organic carbon (%)	42.67	46.10	RHs: 28.23 (Misra et al., 2003).
Organic matter (%)	73.02	79.40	AZP: 82.65 ± 0.01 (Pillai et al., 2002).
Ash content (%)	9.86	20.60	RHs: 20 – 29 (Bronzeoaket al., 2000), AZP: 2 (Bhaskaran and Kannapan, 2015).
Phosphate (mg/Kg)	4262.5	2475	AZP: 50 – 120 mg/kg (Kleinman et al., 2004).
Potassium (K) (mg/Kg)	1268	5042	AZP: 0 – 2 – 4.5% (Singh et al., 1977).
Total nitrogen TN (%)	3.255	0.735	RHs: 0.31 (Thiyageshwari et al., 2018), AZP: 3.22 ± 0.55 (Costa et al., 1999).
C/N ratio	13.02	34.21	25 : 1 – 30 : 1 (Mohammad et al., 2004).

**Table 3.** Heavy metal concentration in feedstock material before composting.

Parameters	Measured values (mg/kg)		Recommended values (mg/kg) by European (EU) heavy metals standard	Remarks
	in water fern plants	Rice husks ( <i>Oryza Sativa</i> ) feedstock		
Copper (Cu)	6.05 ± 0.01	8.93 ± 0.128	70	Accepted
Lead (Pb)	9.70 ± 0.001	9.07 ± 0.072	45	Accepted
Zinc (Zn)	80.06 ± 0.02	53.62 ± 0.1	200	Accepted
Cadmium (Cd)	12.41 ± 0.1	0.29 ± 0.01	0.7	Not accepted
Chromium (Cr)	< DL (< 0.01)	< DL (< 0.01)	70	Accepted

presence of heavy metal in soil results into the production of free radicals and reactive oxygen species in plant cells which alters metabolism, growth and biomass yield (Goyal et al., 2020). Hence, it is important to establish the concentration of heavy metals in feedstock used in composting to make sure that the compost is free from heavy metal contamination.

Except cadmium concentration in water fern plant which was in the range of  $12.41 \pm 0.1$  mg/kg greater than 0.7 mg/kg recommended values by European heavy metal standards, the rest of analyzed metals, i.e. copper, lead, zinc and chromium were within the recommended standards as shown in Table 3, giving the assurance that the quality of compost is expected to have no heavy metals for user's safety.

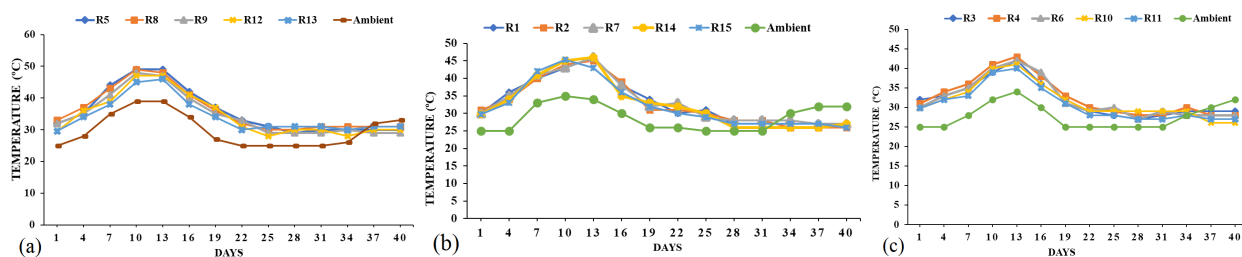
## Temperature

For the 40<sup>th</sup> days of composting process, the mesophilic phase of temperature ranged from 25 – 40 °C, the lowest temperature was observed in the first days of composting process for all 15<sup>th</sup> composted ratios as described in Fig. 2 (a), (b) and (c). In the thermophilic phase of temperature, over 40 was observed in most of the composted ratios except in samples R<sub>5</sub>, R<sub>8</sub>, R<sub>9</sub>, R<sub>12</sub> and R<sub>13</sub> as described in Fig. 2 (a) which attained a peak temperature of 49 °C in 10<sup>th</sup>, 11<sup>th</sup>, 12<sup>th</sup> and 13<sup>th</sup> day of composting process. The peak thermophilic temperature of 45 °C was observed in 10<sup>th</sup> day for ratios R<sub>1</sub>, R<sub>2</sub>, R<sub>14</sub>, and R<sub>15</sub> in Fig. 2 (b) and 44 °C in R<sub>1</sub>, R<sub>4</sub>, R<sub>6</sub>, and R<sub>10</sub> as described in Fig. 2 (c). Cooling phase of temperature 25 – 40 °C was observed on the average from the 16<sup>th</sup> day of all composted ratios during the

composting process to 40<sup>th</sup> day, as described in all figures. The acclimation stage of microorganisms was responsible for the lowest temperature at the beginning, as a portion of energy was utilized to maintain microbial activity while the rest contributed to the increasing temperature within the pile during the composting process (Xie et al., 2017). The microbial decomposition process is affected by temperature and also results in increased temperature which is given out as heat and also lowers moisture content which was utilized by microorganisms in their metabolic activities.

Smaller particles provide large surface area for microorganism to attach enable fast decomposition rate and release more heat to the compost pile evenly and to withstand excessive drying at the surfaces. Yang et al. (2019) describes the particle size with > 3 cm can result into excess aeration which will contribute to dropping the temperature and lastly slowing down the composting process. High temperature is essential for destruction of pathogenic organisms at 55 °C and undesirable weed seeds at critical point of elimination is 62 °C (Nengwu, 2007).

A drop in temperature in the compost pile before material stabilization can mean that the pile is becoming anaerobic and should be aerated (Zein et al., 2015). The temperature pile depends on pile size, the ambient (surrounding) temperature, the moisture content and the degree of aeration (Sarkar et al., 2015). Although small particle size increase surface area available for microbes to attack, so reducing the particle size of feedstock material can catalyze the composting process as observed in composted ratios R<sub>5</sub>, R<sub>8</sub>, R<sub>9</sub>, R<sub>11</sub> and R<sub>13</sub> which were reached early to mature compost. Also, reduction in the size of materials reduces the volume



**Figure 2.** (a) In-situ temperature variation during bin-composting process by considering rice husks with the particle size of < 2 mm. (b) In-situ temperature variation during bin-composting process by considering rice husks with the particle size of < 3 mm. (c) In-situ temperature variation during bin-composting process by considering rice husks with the particle size of < 4 mm.

of the compost pile hence saving space in bin compost system as described by Shishvan and Asghari (2018). The inability of the process to reach the peak temperature of 55 °C among the composted ratios might have been influenced by differences in the quality of feedstock among ratios composted, frequency of turning, the addition of water for maintaining optimal moisture content ranging between 40–60% and other environmental condition as described by Misra et al. (2003).

### Moisture content

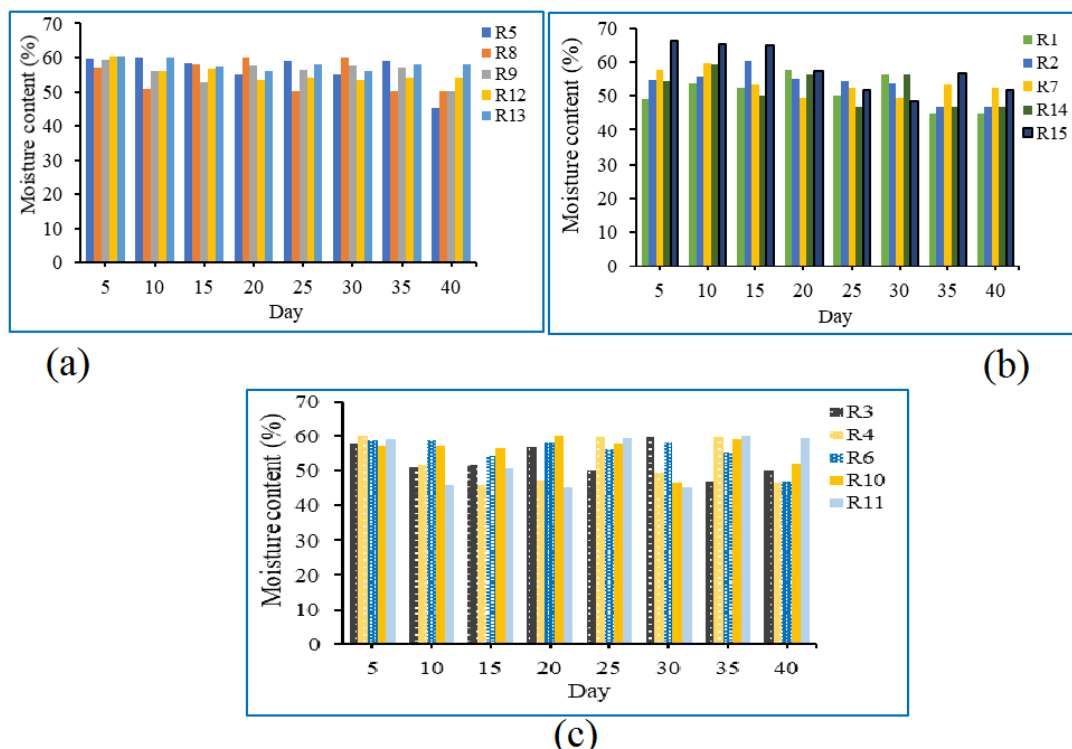
Moisture content dropped in composting ratios with the particle size of 2 mm during day 5 and day 10 when the temperature was 49 °C whereby in R<sub>9</sub> it dropped from (59.2% to 56.2%), R<sub>8</sub> (57% to 50.8%), R<sub>12</sub> (60.3% to 56%) and R<sub>13</sub> (60.4% to 60%). At the temperature of 45 °C, R<sub>15</sub> dropped from (66% to 65%) which had rice husks with particle size of 3 mm. Also, at temperature of 44 °C the moisture content dropped in sample R<sub>3</sub> which contained rice husks of particle size of 4 mm from 57.8% to 51.2%, R<sub>4</sub> (60.1% to 51.7%) and R<sub>11</sub> (59.3% to 46.2%). The correlation analysis indicated that the variation in the moisture content between 40 to 60% has an effect on the interior of the pile. From the analysis, a coefficient value  $r > 0.7$  was obtained indicating that there was a significant positive correlation between the MC and the Temperature in the interior of the pile. The heat stored within the pile is dependent on the moisture content of the composting feedstock's material.

Sample R<sub>15</sub> which is a control was observed to have higher moisture content above recommended range with moisture content of 66% and 64% in 5<sup>th</sup> and 10<sup>th</sup> day as shown in Fig. 3 (b) respectively. The habitat where feedstocks were

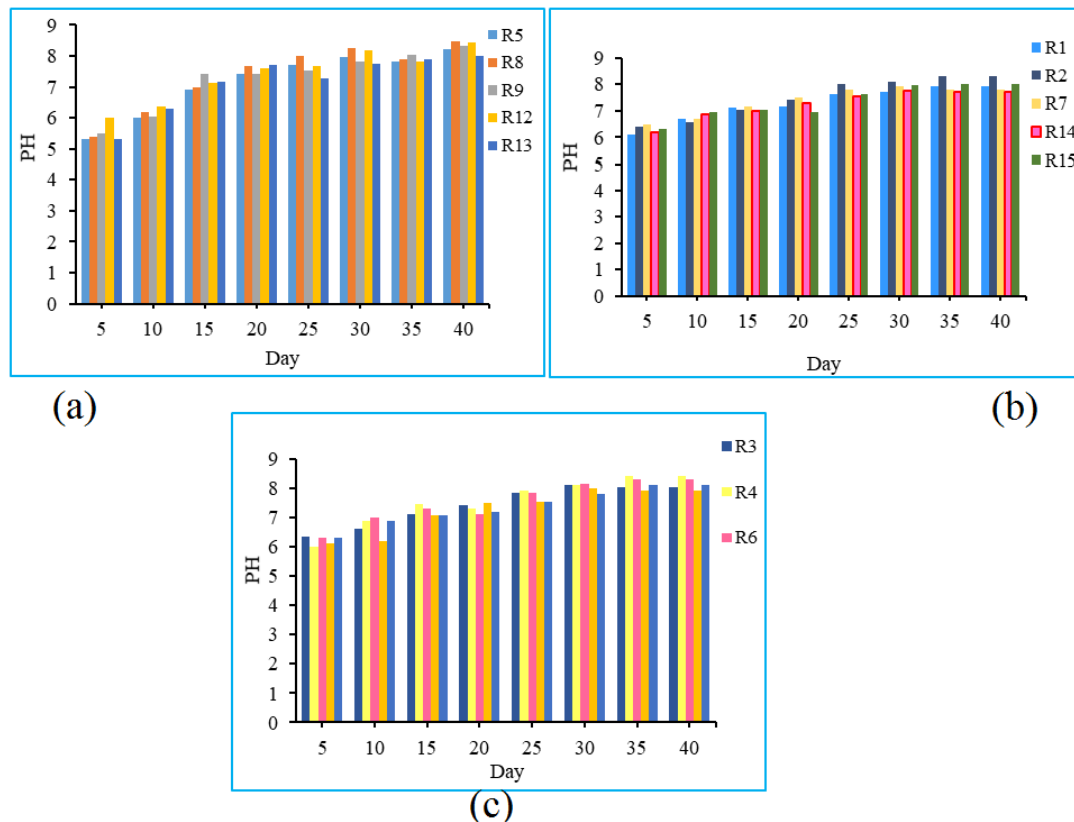
collected might contribute to much higher moisture content because *azolla* (water fern plant) is an aquatic species growing in fresh water in tropical, sub-tropical and warm-temperature region as described by Kollah et al. (2016). The lowest moisture content was 44.35% observed in sample R<sub>11</sub> at 20<sup>th</sup> and 30<sup>th</sup> days as presented in Fig. 3 (c). Generally, the moisture content was within recommended standard of 40–60%. Matured compost generally has moisture contents between 35–45% as reported by Leslie et al. (2022). During the 40<sup>th</sup> day the highest pH of 8.4 was observed in samples R<sub>8</sub> and R<sub>12</sub> as illustrated in Fig. 4 (a) and the lowest pH of 5.36 was observed in R<sub>5</sub>. Monitoring of pH is important since it may affect the rate of decomposition and decrease the growth of microorganisms. Vázquez et al. (2015) described that the optimum pH for microbial activities should range between 5.5 to 8 and mature composts usually have pH-values ranging from 7 to 8. This indicates that during the composting process, the pH values ranged within the recommended optimal level to all twelve composted ratios as illustrated in Figs. 4 (a), 4 (b) and 4 (c) except in R<sub>5</sub>, R<sub>8</sub>, and R<sub>13</sub> on 5<sup>th</sup> which were 5.36, 5.45, and 5.40 respectively as described in Fig. 4a and this is possibly due to decomposition of soluble compounds such as sugars which produce organic acids and hence decrease pH value Hemidat (2018).

### Microbial results

From the 1<sup>st</sup> day to the 14<sup>th</sup> day, a population of microbes was observed to increase as the temperature increased in composted ratios. The rice husks composted with the particle size of < 2 mm at the peak temperature of 49 °C, the number of microbes was observed to increase from



**Figure 3.** Moisture content variation during in-composting process by considering rice husks with the particle size of < 2 mm, < 3 mm and < 4 mm as described (a), (b), (c) respectively.



**Figure 4.** The ranges of pH measured on 5<sup>th</sup>, 10<sup>th</sup>, 15<sup>th</sup>, 20<sup>th</sup>, 25<sup>th</sup>, 30<sup>th</sup>, 35<sup>th</sup> and 40<sup>th</sup> days of composting process by considering rice husks with the particle size of < 2 mm, < 3 mm and < 4 mm as labelled in (a), (b), (c) respectively.

( $48 \times 10^6$  Count/100 mL to  $140 \times 10^6$  Count/100 mL) in R<sub>5</sub>, R<sub>8</sub> the number of microbes ranged from  $44 \times 10^6$  Count/100 mL to  $92 \times 10^6$  Count/100 mL, R<sub>9</sub> from  $49 \times 10^6$  Count/100 mL to  $136 \times 10^6$  Count/100 mL, R<sub>12</sub> from  $50 \times 10^6$  Count/100 mL to  $110 \times 10^6$  Count/100 mL and R<sub>13</sub> from  $45 \times 10^6$  Count/100 mL to  $70 \times 10^6$  Count/100 mL.

At temperature of 45 °C the mass of microbes was observed to increase in R<sub>1</sub> from  $39 \times 10^6$  Count/100 mL to  $93 \times 10^6$  Count/100 mL, R<sub>2</sub> from  $30 \times 10^6$  Count/100 mL to  $85 \times 10^6$  Count/100 mL, R<sub>7</sub> from  $36 \times 10^6$  Count/100 mL to  $64 \times 10^6$  Count/100 mL, R<sub>14</sub> from  $22 \times 10^6$  Count/100 mL to  $61 \times 10^6$  Count/100 mL, R<sub>15</sub> from  $34 \times 10^6$  Count/100 mL to  $84 \times 10^6$  Count/100 mL by considering the samples contained rice husk with the particle size of < 3 mm.

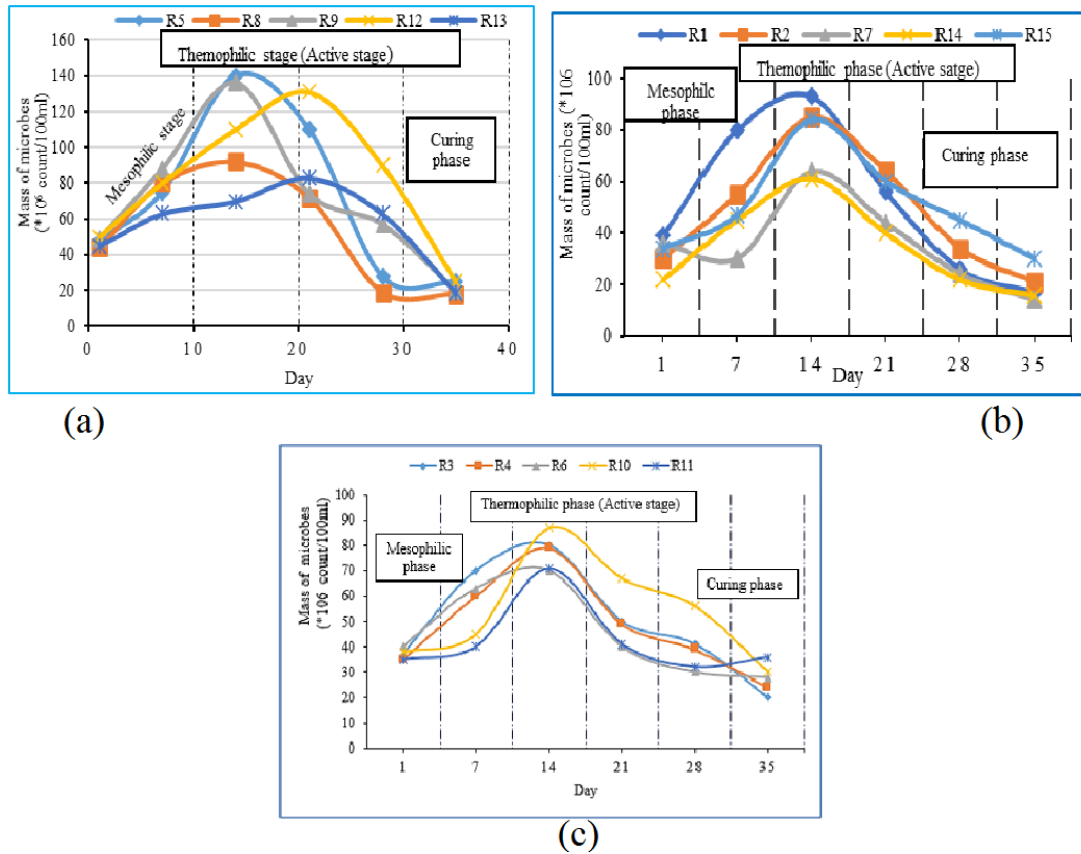
At temperature of 44 °C the number of microbes were observed to rise in R<sub>3</sub> from  $37 \times 10^6$  Count/100 mL to  $80 \times 10^6$  Count/100 mL, R<sub>4</sub> from  $35 \times 10^6$  Count/100 mL to  $79 \times 10^6$  Count/100 mL, R<sub>6</sub> from  $40 \times 10^6$  Count/100 mL to  $70 \times 10^6$  Count/100 mL, R<sub>10</sub> from  $38 \times 10^6$  Count/100 mL to  $87 \times 10^6$  Count/100 mL and R<sub>11</sub> from  $35 \times 10^6$  Count/100 mL to  $75 \times 10^6$  Count/100 mL as composted ratios with the particle size of < 4 mm respectively.

The statistical analysis of the correlation analysis indicated a coefficient value of  $r > 0.7$  which implied that there was a strong positive correlation between the mass or population/number of microbes and temperature in the interior pile. This association showed that when the number of microbes increases decomposition rate increases and a high amount of heat is given out which contributes to the rise of the inner

temperature of the pile (Aondoaver, 2014). This was also justified by Sarkar et al. (2015) who narrated that the heat liberated within the pile during the decomposition process is dependent on the population of microbe's act on composting feedstock's material during the process.

At the mesophilic phase (1<sup>st</sup> phase), mesophilic bacteria and fungi were acclimatized to new environment and started to grow rapidly to all composted ratios as described in Fig. 5 (a, b and c), whereby lowest population observed was  $18 \times 10^6$  Count/100 mL from sample R<sub>8</sub> in 35<sup>th</sup> day as illustrated in Fig. 5 (a) and the highest was  $140 \times 10^6$  count/100 mL observed in 14<sup>th</sup> from R<sub>5</sub>. This phase the microorganisms use carbon and nitrogen as the sources of energy and protein to generate heat (Pilar et al., 2015). The decomposition of soluble compounds such as sugars, produces organic acids hence would result pH to drop to about 4 or 4.5.

In the thermophilic phase, a mixed population of thermophilic bacteria and most heated tolerant fungi contribute in the breakdown of protein, fat, hemicelluloses and celluloses. The microorganisms that advance at average temperatures as mesophilic microorganisms are replaced by those that grow at greater temperatures which are thermophilic bacteria which increased in 14<sup>th</sup> day to all composted ratio but the higher microbial concentration was observed in sample R<sub>5</sub> and R<sub>9</sub> as shown in Fig. 5 (a) which were  $140 \times 10^6$  Count/100 mL and  $136 \times 10^6$  Count/100 mL respectively. In the curing stage all composted ratios were observed to have small population of microbes hence slow degradation of lignin and other highly resistant compounds which may led into the formation of a resistant organic mixture



**Figure 5.** The variation in number of microbes’ compost sample ratios on 1<sup>st</sup>, 7<sup>th</sup>, 14<sup>th</sup>, 21<sup>st</sup>, 28<sup>th</sup> and 35<sup>th</sup> days of composting process by rice husks with the particle size of < 2 mm, < 3 mm and < 4 mm as labelled in a, b, c respectively.

remained called a matured co-compost (Bernal et al., 2017).

**Color of the compost during the composting period**

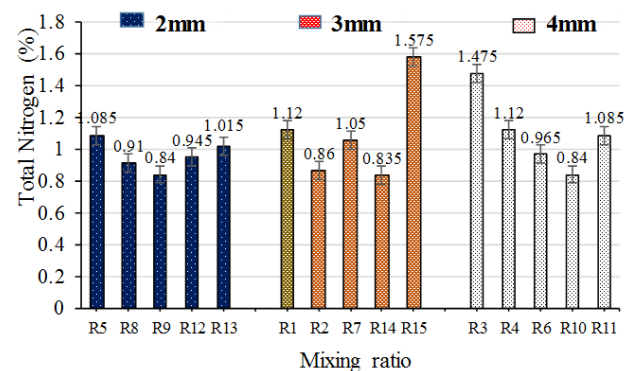
The color of the compost was observed to alternate from the initial mixer with a distinctive color of brown like appearance of Rice Husks feedstock and green color of the azolla plant to a common dark brown color for all composting ratios containing a rice husks with the particle size of 2 mm, 3 mm and 4 mm which were R<sub>3</sub>, R<sub>4</sub>, R<sub>5</sub>, R<sub>7</sub>, R<sub>8</sub>, R<sub>9</sub>, R<sub>11</sub>, R<sub>12</sub> and R<sub>13</sub>, R<sub>15</sub> except in ratios R<sub>1</sub>, R<sub>2</sub>, R<sub>6</sub>, R<sub>10</sub>, R<sub>11</sub> and R<sub>14</sub> materials which were light brown as shown in Fig. 6 (a and b). Such findings coincide with the findings reported by Leslie et al. (2022) and Zein et al. (2015) who indicated that matured compost’s colour is dark brown, with a non-offensive, earthy aroma.



**Figure 6.** Color of initial feedstock’s material and color of final co-compost respectively.

**Characteristics of matured compost**

The result showed that the highest total nitrogen was 1.575% in ratio R<sub>15</sub> while the lowest was 0.835% in R<sub>14</sub> as shown in Fig. 7. The highest percentage of nitrogen in R<sub>15</sub> was probably influenced by the quality of the feedstock’s material and the lower total nitrogen in ratio R<sub>14</sub> which is a control composting with rice husks (*Oryza sativa*) only, which could be a result of low total nitrogen in rice husks. The typical range of TN in compost is 1.0 – 3.0% and if the total nitrogen in compost is around 0.6% or less it indicates that there is a chance for nitrogen immobilization and compost of over 3% total nitrogen is usually found to be in immature compost (Costa et al., 1999). Therefore, the compost produced had



**Figure 7.** Total Nitrogen content of matured compost in all composting bin.

nitrogen content within the recommended range except for the control sample of rice husks.

**C/N ratio**

The highest value of C/N ratio of 38.61 was observed in sample R<sub>2</sub> and the lowest value was 21.65 in R<sub>3</sub>. The higher C/N ratio in R<sub>2</sub> was the result of a higher %TC which was 38.6 and low %TN of 0.86. The EPA specifies that the C/N ratio of the compost must be below 25. Therefore all samples of the rice husks with particle size of < 2 mm were observed to have a suitable ratio for compost production as described by Golabi et al. (2004) that the suitable co-compost should have the C/N ratio of 25:1; 30:1. Also samples with < 3 mm from sample R<sub>1</sub>, R<sub>7</sub> and R<sub>14</sub> were within the ranges except for composted ratio R<sub>2</sub> which was found to be above the recommended limits. Furthermore, R<sub>15</sub> and all composted samples with the rice husk of particle size of < 4 mm were not within the range of 25 to 30 as recommended by EPA. The reason for the higher C/N ratio above the limit may be caused by the slow rate of microbial decomposition resulting from the balance of material in terms of quality. A study done by Aondoaver (2014) found out the CN of rice husks at its stage of decomposition was 13:1. C/N ratio provides indication or the ripening of mature compost, therefore R<sub>1</sub>, R<sub>2</sub> and R<sub>5</sub> are suitable ratio for compost production using azolla plants and rice husks as shown in Fig. 8.

**Practical applications of compost produced from azolla and rice husks**

**Plant growth rate**

The heights of stem and leaves, widths of leaves, and number of leaves of *Amaranthus spinosus* plots 1, 2, 3 and 4 were observed to transform, increase and extended over time as described in Fig. 9 concerning their measurements as recorded in Table 4, the width of leaves and stem, plant heights and number of leaves were observed to increase and extended from 1<sup>st</sup> to 18<sup>th</sup> day as described in Fig. 10. During monitoring of *Amaranthus spinosus* growth, it was evident that after two weeks, vegetables grown with compost from *azolla* and rice husks exhibited different heights of stem and leaves, width of leaves and number of leaves. Cultivated

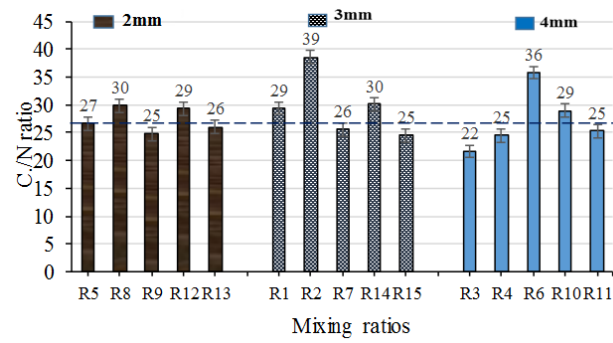


Figure 8. C/N ratio of matured compost in all composting ratio bin.

vegetables with compost shows better growth compared to those under control plot (Barus et al., 2023; Saha et al., 2003). The study conducted by Saha et al. (2003), indicated that the maximum palatability and yield by *Amaranthus* is obtained at 25 days after sowing the seed. Therefore, observation can be done to observe effective seed germination and yield indication after two weeks from the planting day. The capability of plots 1, 2 and 3 to allow the growth of *Amaranthus spinosus* at the rate of 0.9572 cm/day was probably contributed by the quality of compost ratios applied in each plot. This was justified by the regression analysis indicated in Fig. 9 which revealed the r-square of 0.96 which implies that there was significant plant growth as the day's increased.

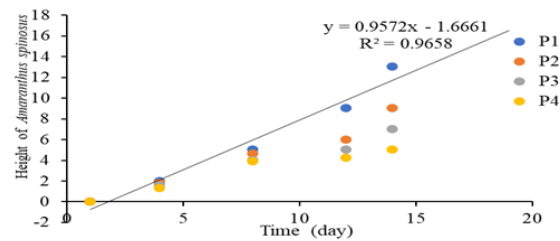


Figure 9. The relationship between height of *Amaranthus spinosus* and monitoring time (days).

Table 4. Growth rate for *Amaranthus spinosus* by measured length, widths and heights in each plot.

Day	Plot1				Plot 2				Plot 3				Plot 4 (control)			
	Hs	Ll	Wl	No.i	Hs	Ll	Wl	No.i	Hs	Ll	Wl	No.i	Hs	Ll	Wl	No.i
	cm	cm	cm		cm	cm	cm		cm	cm	cm		cm	cm	cm	
1	0	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0	0	0	0
4	2	0.8	0.4	2	1.8	0.6	0.4	2	1.6	0.4	0.3	2	1.3	0.5	0.4	2
8	5	1.3	1	3	4.6	1.9	1.2	3	4	0.9	0.8	2	3.9	0.8	0.9	2
12	9	2.8	1.5	7	6	2.7	1.5	6	5	2	1.3	4	4.2	1.2	1	3
14	13	3	2.1	8	9	3	1.8	6	7	2.2	1.7	5	5	1.2	1.4	4
18	15	4	2.4	10	12	4	2.1	8	9	2.9	2.4	6	6	1.9	1.8	5

Whereby Hs- height of stem, Ll- length of leave, Wl- width of leaves and No. i- number of leaves.



Figure 10. *Amaranthus spinosus* on 5<sup>th</sup> and 14<sup>th</sup> day in plot 1, 2, 3 and 4.

#### 4. Conclusion

This study successfully assessed the potential of composting rice husks (*Oryza sativa*) with *azolla* (water fern plant) for agricultural productivity. During the bin composting the rice husks with the particle size 2 mm obtained the highest temperature (49 °C) compared to other particle sizes including 3 mm (45 °C) and 4 mm (44 °C) while 45 °C in the thermophilic phase. Compost produced as a result of composting *azolla* (water fern plant) and rice husks (*Oryza sativa*) can be used for fertilizing the soil due to the nutritional properties observed by improving the soil structure and texture. The composting made using samples with particle size of < 2 mm were observed to support the growth of *Amaranthus spinosus* quickly with the growth rate of 0.9572 cm/day than other compost produced with particles size of 3 mm and 4 mm. It is the right time to use agro-waste products in improving plant growth as such technology is simple and can be used at a small scale and large scale supporting agricultural productivity. This research recommends further research to determine the heavy metal concentration in the feedstock's material before composts to avoid adverse effects on plant tissues when they may accumulate within manufactured compost before applied into the field for agricultural productivity. Also, follow ups study should establish full characteristics of rice husks and *azolla* including cellulose, hemicellulose and lignin and compare with typical reported values from other literatures.

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#### Authors contributions

The authors confirm the study conception and design: Leonard, L.S; conceptualization, data analysis, interpretation of results and manuscript preparations; Chacha, N; conceptualization, data analysis, interpretation and manuscript preparations; Kingshashu, A.Y; experimental set up and data collection and manuscript preparations. The results were evaluated by all authors and the final version of the manuscript was approved.

#### Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

#### Conflict of interests

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

#### References

- Abubakar AU (2016) Negerian rice husk ash (rha) in cement, concrete and mortar: A review. 1–30. DOI: <https://doi.org/10.13140/RG.2.1.2861.2242>.
- AOAC (2000) Official methods of analysis. 17th ed. *The Association of Official Analytical Chemists, Gaithersburg, MD, USA*.
- Aondoover TA (2014) Comparative assessment of the nutrient value of compost rice husks and NPK branded inorganic fertilizers *Sci J Agri Resear Manag* 274:1–4. DOI: <https://doi.org/10.7237/sjarm/274>.
- Bakari R, Kivevele T, Masawa SM, Huang X, Jande YA (2023) Assessment of rice husk biomass from different agro-ecological zones of Tanzania for biofuels feasibility via supercritical water gasification. *Biomass Bioenergy* 173:106771. DOI: <https://doi.org/10.1016/j.biombioe.2023.106771>.
- Balasubramanian V, Sie M, Hijmans RJ, Otsuka K (2007) Increasing rice production in sub-saharan Africa: Challenges and opportunities. *Adv Agron* 94:55–133. DOI: [https://doi.org/10.1016/S0065-2113\(06\)94002-4](https://doi.org/10.1016/S0065-2113(06)94002-4).
- Bandumula N (2018) Rice production in Asia: Key to global food security. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* 88:1323–1328. DOI: <https://doi.org/10.1007/s40011-017-0867-7>.

- Barus JRr, Ernawati RE, Wardani N, Pujiharti Y, Suretno N, Slameto S (2023) Improvement in soil properties and soil water content due to the application of rice husk biochar and straw compost in tropical upland. *Int J Recycl Org Waste Agricult* 12 (1): 85–95. DOI: <https://doi.org/10.30486/ijrowa.2022.1942099.1355>.
- Bernal B, Megonigal JP, Mozdzer TJ (2017) An invasive wetland grass primes deep soil carbon pools. *Glob Chang Biol* 23 (5): 2104–2116. DOI: <https://doi.org/10.1111/gcb.13539>.
- Bhaskaran SK, Kannapan P (2015) Nutritional composition of four different species of azolla. *Euro J Exp Bio* 5 (3): 6–12.
- Brand MA, Jacinto RC, Antunes R, Cunha AB da (2017) Production of briquettes as a tool to optimize the use of waste from rice cultivation and industrial processing. *Renew Ener* 111:116–123. DOI: <https://doi.org/10.1016/j.renene.2017.03.084>.
- Chandra S, Chatterjee P, Dey P, Bhattacharya S (2012) Evaluation of in vitro anti-inflammatory activity of coffee against the denaturation of protein. *Asian Pac J Trop Biomed* 2 (1): 178–180. DOI: [https://doi.org/10.1016/S2221-1691\(12\)60154-3](https://doi.org/10.1016/S2221-1691(12)60154-3).
- Costa ML, Santos MC, Carrapiço F (1999) Biomass characterization of azolla filiculoides grown in natural ecosystems and wastewater. *Hydrobiologia* 415:323–327. DOI: <https://doi.org/10.1023/A:1003824426183>.
- Dubey S, Shri M, Gupta A, Rani V, Chakrabarty D (2018) Toxicity and detoxification of heavy metals during plant growth and metabolism. *Environ Chemis Let* 16:1169–1192. DOI: <https://doi.org/10.1007/s10311-018-0741-8>.
- Gao Y, Guo X, Liu Y, Fang Z, Zhang M, Zhang R, You L, Li T, Liu RH (2018) A full utilization of rice husk to evaluate phytochemical bioactivities and prepare cellulose nanocrystals. *Sci Rep* 8 (1): 10482. DOI: <https://doi.org/10.1038/s41598-018-27635-3>.
- Golabi MH, Denney MJ, Lyekar CI (2004) Use of composted organic wastes as alternative to synthetic fertilizers for enhancing crop productivity and agricultural sustainability on the tropical island of Guam. *13<sup>th</sup> International Soil Conservation Organisation Conference (ISCO). Conserving Soil and Water for Society: Sharing Solutions*, 1–6.
- Goyal D, Yadav A, Prasad M, Singh TB, Shrivastav P, Ali A, Mishra S (2020) Effect of heavy metals on plant growth: An Overview. In: *Contaminants in Agriculture*. Springer, 79–101. DOI: <https://doi.org/10.1007/978-3-030-41552-5-4>.
- Gupta K, Chandra R, Dey D, Mondal G, Shinde KP (2018) Study of chemical composition and mineral content of sun dried azolla pinnata. *J Pharmacognosy Phytochemistry* 7 (6): 1214–1216.
- Hemidat S (2018) Monitoring of composting process parameters: A case study in Jordan. *Waste and Biomass Valorization* 9 (3): 2257–2274. DOI: <https://doi.org/10.1007/s12649-018-0197-x>.
- Isimikalu T, Olaniyan J, Affinnih K, Muhammed O, Adede AC, Jibril A, Atteh E, Yusuf S, Ezekiel TJ (2023) Rice husk biochar and inorganic fertilizer amendment combination improved the yield of upland rice in typical soils of Southern Guinea Savannah of Nigeria. *Int J Recycl Org Waste Agricult* 12 (3): 441–456. DOI: <https://doi.org/10.30486/ijrowa.2022.1951012.1409>.
- Joseph MM (2013) An analysis of use of good agricultural practices in rice production: a case study of Bagamoyo and Dakawa areas, Tanzania. *Dissertation. Jomo Kenyatta University of Agriculture and Technology*
- Khan R, Ahmad I, Khan AN (2012) Reduction in environmental problems using rice-husk ash in concrete. *Constr Buil Mater* 30:360–365. DOI: <https://doi.org/10.1016/j.conbuildmat.2011.11.028>.
- Kleinman PJA, Sharpley AN, Veith TL, Maguire RO, Vadas PA (2004) Evaluation of phosphorus transport in surface runoff from packed soil boxes. *J Environ Qual* 33:1413–1423. DOI: <https://doi.org/10.2134/jeq2004.1413>.
- Kollah B, Patra AK, Mohanty SR (2016) Aquatic microphylla *Azolla*: a perspective paradigm for sustainable agriculture, environment and global climate change. *Environ Sci Pollu Resear Int* 23:4358–69. DOI: <https://doi.org/10.1007/s11356-015-5857-9>.
- Kumar P, Barrett DM, Delwiche MJ, Stroeve P (2009) Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. *Indus Engine Chem Resear* 48:3713–3729.
- Leonard LS, Riwa EG (2023) Bioaccumulation of trace elements in paddy soil, paddy plants and rice grains from irrigation schemes, Morogoro-Tanzania. *Ethiop J Sci Technol* 16 (1): 29–49. DOI: <https://doi.org/10.4314/ejst.v16i1.3>.
- Leslie RS, Rynk CR, Bonhotal JBB, Tera SA, Nichols LH (2022) Compost characteristics and quality. The composting handbook, A how to why manual for farm, municipal, institutional and commercial composters. DOI: <https://doi.org/10.1016/C2019-0-05417-9>.
- Misra RV, Roy RN, Hiraoka H (2003) On-farm composting methods. *UN-FAO. Rome, Italy*
- Mng'ong'o M, Munishi LK, Ndakidemi PA, Blake W, Comber S, Thomas H, Hutchinson TH (2021) Toxic metals in East African agroecosystems: Key risks for sustainable food production. *J Environ Manag* 294:1–16. DOI: <https://doi.org/10.1016/j.jenvman.2021.112973>.
- Mohidem NA, Hashim N, Shamsudin R, CheMan H (2022) Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture* 12 (6): 741. DOI: <https://doi.org/10.3390/agriculture12060741>.
- Nengwu Z (2007) Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. *Bioresour Technol* 98:9–13. DOI: <https://doi.org/10.1016/j.biortech.2005.12.003>.
- Njogu P, Kinyua R, Muthoni P, Nemoto Y (2015) Thermal gasification of rice husks from rice growing areas in Mwea, Embu County, Kenya. *Smart Grid Renew Ener* 6:113–119. DOI: <https://doi.org/10.4236/sgre.2015.65010>.
- Okeh O, Chukwudi O, Frederick O (2014) Biogas production from rice husks generated from various rice mills in Ebonyi State, Nigeria. *Renew Energy* 62:204–208. DOI: <https://doi.org/10.1016/j.renene.2013.07.006>.
- Pilar R, Martínez M, Pantoja A (2015) Farmer's compost handbook. *FAO. Santiago, Chile*
- Pillai PK, Premlatha S, Rajamony S (2002) Azolla-A sustainable feed substitute for livestock. *LEISA India* 4 (1): 15–16. DOI: <https://doi.org/10.1177/0970846420010405>.
- Saha SR, Uddin MN, Rahman MA, Sharifuzzaman SM, Habib AA (2003) Growth and harvestable maturity of red amaranth at different sowing dates (No. AVRDC Trainee Publication). *Asian J Plant Sci* 2:431–433. DOI: <https://doi.org/10.3923/ajps.2003.431.433>.
- Sarkar S, Pal S, Chanda S (2015) Optimization of a vegetable waste composting process with a significant thermophilic phase. *Procedia Environm Sci* 35:435–440. DOI: <https://doi.org/10.1016/j.proenv.2016.07.026>.
- Seleiman MF, Elshayb OM, Nada AM, El-leithy SA, Baz L, Alhammad BA, Mahdi AHA (2022) Azolla compost as an approach for enhancing growth, productivity and nutrient uptake of *Oryza sativa* L. *Agronomy* 12:1–15. DOI: <https://doi.org/10.3390/agronomy12020416>.
- Shishvan SS, Asghari A (2018) Effects of particle shape and size distribution on particle size-dependent strength in metal matrix composites. *Scientia Iranica* 24:1091–1099. DOI: <https://doi.org/10.24200/sci.2017.4091>.
- Singh L, Singh N, Shrivastava MP, Gupta AK (1977) Characteristics and utilization of vegetable types of pigeonpeas (*Cajanus cajan* (L.) Millsp.). *Ind J Nutri Diet* 14:8–10.
- Suvi WT, Shimelis H, Laing M (2021) Farmers' perceptions, production constraints and variety preferences of rice in Tanzania. *J Crop Improv* 35 (1): 51–68. DOI: <https://doi.org/10.1080/15427528.2020.1795771>.

- Thiyageshwari S, Gayathri P, Krishnamoorthy R (2018) Exploration of rice husk compost as an alternate organic manure to enhance the productivity of blackgram in typic haplustalf and typic rhodustalf.
- Vázquez MA, Sen R, Soto M (2015) Physico-chemical and biological characteristics of compost from decentralised composting programmes. *Bioresour Technol* 198:520–532. DOI: <https://doi.org/10.1016/j.biortech.2015.09.034>.
- Wilson RT, Lewis I (2015) The rice value chain in Tanzania. A report from the southern highlands food systems programme. *The Food and Agriculture Organization of the United Nations, Rome*.
- Xie XY, Zhao Y, Sun QH, Wang XQ, Cui HY, Zhang X, Wei ZM (2017) A novel method for contributing to composting start-up at low temperature by inoculating cold-adapted microbial consortium. *Bioresour Technol* 238:39–47. DOI: <https://doi.org/10.1016/j.biortech.2017.04.036>.
- Yang Z, Ge Y, Zhang Xa, Shangguan B, Zhang Y, Wang Y (2019) Effect of particle size on current-carrying friction and wear properties of copper-graphite composites by spark plasma sintering. *Materials* 12 (17): 1–12. DOI: <https://doi.org/10.3390/ma12172825>.
- Zein AE, Seif H, Gooda E (2015) Moisture content and thermal balance during composting of fish, banana mulch & municipal solid wastes. *European Sci J* 11:169–187.