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THE EVALUATION OF COMPOSTED FOOD WASTE EFFECTS IN CONSERVING AND ENHANCING GROWTH PERFORMANCE OF *AZOLLA PINNATA*

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Abstract

*Compost has a significant conservation benefit for soils by increasing organic matter levels and enhancing soil fertility, thus positively influencing plant growth. This study aims to evaluate the impacts of utilizing different types of composted food waste to improve the growth performance of Azolla Pinnata. Composting mixed food waste (MFW), vegetable waste (VW), and fruit waste (FW) was conducted using the Takakura Composting Method, incorporating effective microorganisms (EM). Analysis of pH, temperature, moisture content, nutrient content (TN, TP, K), and heavy metal concentrations were done throughout the 30-day composting process. The Germination Index (GI) and Compost Quality Index (CQI) were employed to evaluate compost quality and phytotoxicity levels. Results demonstrated that all composted food waste samples met the criteria for high-quality compost, except for slight residual phytotoxicity observed in FW (*GI of 79.3%*). Notably, the integration of Azolla Pinnata with composted food waste significantly influenced the growth performance (biomass, relative growth rate and doubling time), with the most substantial enhancements of doubling time achieved using MFW treatments (1.94 days), followed by FW (2.02 days) and VW (2.07 days). This research underscores the potential for Azolla Pinnata integrated with composted food waste as a chemical-free fertilizer, offering promise for conservation efforts and sustainable agricultural practices.*

***Keywords**: Compost; Organic fertilizer; Food waste; Vegetable waste; Fruit waste; Azolla Pinnata; Growth*

Introduction

The rapid acceleration of global population growth and urbanization has resulted in an ever-increasing production of organic waste, predominantly food waste. According to recent documentation, over 1.3 billion tons of food waste are generated globally on an annual basis [1]. This immense amount of waste carries a hefty environmental footprint, with an estimated financial cost of nearly $990 billion, alongside a staggering carbon footprint of 3.3 billion metric tons of carbon dioxide (CO_2) equivalent emissions [2]. Based on current trends, projections indicate that global food waste could reach 2.2 billion tons per year by 2025 and an

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alarming 3.4 billion tons annually by 2030 [3]. This surge in organic waste generation poses multifaceted challenges for waste management, environmental conservation and, importantly, for the broader goal of achieving food security through sustainable agricultural practices [4]. One promising solution to address these challenges lies in the practice of composting food waste, transforming it into a valuable resource for agriculture and horticulture while mitigating the environmental impact of organic waste disposal.

Composting, the controlled decomposition of organic matter, is not only an eco-friendly approach to managing food waste but also presents an opportunity to contribute to conservation efforts by reducing the need for chemical fertilizers and improving soil health. However, not all compost is produced equally. The quality of compost and its impact on plant growth vary substantially based on a multitude of factors, including the composition of the feedstock and the maturation process. The synergy between composting food waste and sustainable agriculture is evident in the potential to create high-quality compost free from phytotoxins. Such compost, rich in organic matter and nutrients, not only diverts food waste from landfills but also enriches the soil and decreases methane emissions while creating a local, circular nutrient source. This, in turn, reduces the reliance on chemical fertilizers, which can have detrimental environmental consequences, including soil acidification, waterway pollution with nitrates and phosphates, and substantial carbon emissions estimated to account for up to 2% of global energy use dedicated to fertilizer production [5].

To effectively enhance conservation efforts while promoting sustainable agriculture, it is crucial to assess the quality of composted food waste and understand its impact on the growth of plant species with significant conservation value. This opportunity becomes even more significant when we consider the goal of producing chemical-free *Azolla Pinnata*, a floating fern with a remarkable ability for its rapid growth and to fix atmospheric nitrogen through symbiosis with the cyanobacterium *Anabaena azollae* [6]. *Azolla Pinnata* is of vital importance for both ecological conservations, particularly in wetland ecosystems and as a potential source of nutrient-rich, sustainable food. *Azolla Pinnata* has emerged as a valuable biofertilizer, particularly for rice cultivation where it can contribute over 60kg N/ha [7].

As mentioned above, compost quality is significantly influenced by the composition of the feedstock and yet there have been no direct comparative tests on the efficacy of fruit, vegetable and mixed food waste composts for optimized *Azolla pinnata*. The application of fertilizers can increase the chlorophyll content, nitrogen and phosphorus levels, biochemical constituents, growth velocity and nutritional values in *Azolla* species [8]. Thus, this controlled experiment aims to compare key growth metrics of *Azolla pinnata* when fertilized with standardized composts derived from vegetable, fruit, or mixed food waste. We will investigate the physical, chemical, and microbial properties of different types of composted food waste to assess their suitability for *Azolla Pinnata* cultivation. Furthermore, we will evaluate the compost's maturity and quality based on key indicators such as the Germination Index (GI) and Compost Quality Index (CQI) to ensure its effectiveness in supporting plant growth.

The findings from this study will play a vital role in advancing efforts to scale up *Azolla* production in an eco-friendly, food-secure manner that concurrently fosters habitat conservation. By tapping into the potential of *Azolla pinnata* and repurposing composted food waste, we can proactively address the critical issues of food security, sustainable agriculture, and conservation while reducing reliance on chemical inputs and mitigating environmental damage. This research represents a significant step towards a more sustainable and resilient future.

Experimental part

Source Materials

The food waste samples consist of mixed food waste (MFW), vegetable waste (VW), and fruit waste (FW) were collected from Arked UTHM and college cafeterias. The Takakura Composting Method (TCM) was employed, utilizing a 2:1 ratio of black soil to rice husk as the decomposing medium. Fermented soybean and brown sugar were used as effective microorganisms (EM) to stimulate microbial activity and expedite organic material decomposition. A solution of 3 liters of water mixed with 250g of brown sugar and a piece of fermented soybean were fermented for a week before being incorporated into the decomposing medium (Fig. 1). Throughout the fermentation process, the bottle caps were periodically unsealed daily to release trapped gases. The fermentation was allowed to continue for a duration of 5 days, enabling the proliferation of beneficial microbes, after which it was mixed homogenously with the decomposing medium and left for seven days (Fig. 2) [9].

Fig. 1. Effective microorganism (EM)

Fig. 2. Fermentation process of EM and decomposing medium

Composting Process

The composting process lasted for 30 days and encompassed four main steps: I) EM preparation, II) decomposing medium preparation, III) compost reactor setup and IV) the composting process itself. Three compost reactors (17.5L) were prepared for the different food waste types (MFW, VW and FW), where 250g of waste were fed daily as tabulated in Table 1. Each reactor had dimensions of 40.0 cm x 28.5 cm x 23.0cm and featured aeration holes (Fig. 3). The reactors were modified with carpet and mosquito nets cover to regulate temperature and prevent pests. Aeration involved daily turning for the first two weeks and weekly turning for the subsequent 30 days.

Table 1. Reactors prepared in the experimental work

Reactor	Types of food waste	Amount of waste (g)
MFW	Mixed food waste	250
VW	Vegetable waste	250
FW	Fruit waste	250

Fig. 3. Compost reactor

Composted Food Waste Analysis

pH values were determined by utilizing a calibrated pH meter and temperature was recorded by digital thermometer, following established procedures as referenced in a prior study [10]. To ascertain moisture content, 10 g of fresh compost samples were subjected to drying in a consistent temperature setting (105°C) with a drying oven for a period of 24 hours [10]. In the assessment of nutrient and heavy metals content, compost samples were first undergoing an acid digestion process as stipulated in US EPA 3050B [11]. Total Nitrogen (TN) and Total Phosphorus (TP) concentrations were quantified utilizing HACH Method 10072 [12] and HACH Method 8190 [13], respectively, through the application of a DR6000 UV-Vis Spectrophotometer. The determination of potassium (K) concentration was executed using Atomic Absorption Spectroscopy (AAS), following standard US EPA Method 3111B [14], while the determination of heavy metals concentration was conducted using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), following standard US EPA Method 6020B [15].

Maturity and Phytotoxicity Analysis of Composted Food Waste

Microbial analysis, germination index (GI), and compost quality index (CQI) were conducted to evaluate the maturity and phytotoxicity of compost samples. The microbial analysis of the compost was calculated using Most Probable Number (MPN) analysis [16]. GI was determined by incubating 10 radish seeds along with 5 mL of water extract, in darkness at a controlled temperature of 20 ± 1°C for a duration of 48 hours. The GI was then computed using the formula in Equation 1 [17]. Meanwhile, the CQI was calculated using the formula in Equation 2 [17], as stated below:

$$\text{Germination index (GI)} = \frac{G}{G0} \text{ X } \frac{L}{L0} \text{ X } 100 \tag{1}$$

where: G - number of germinated seeds in extracted compost (%); G0 - number of germinated seeds in control set (%); L - average of radicle lengths in extracted compost (%); L0 = average of radicle lengths in control set (%).

$$CQI = \frac{NVNPK \times MP \times GI}{C/N\ ratio} \tag{2}$$

where: NVNPK - Total % of NPK; MP - Total microbial population (total bacteria + total fungi + total actinomycetes); GI - Germination Index.

Cutivation of Azolla Pinnata

This experimental study for investigating the growth performance of *Azolla Pinnata* was carried out in the greenhouse built at UTHM (Fig. 4), involving four treatment groups (control including) based on the type of food waste. Each treatment was replicated three times, and the cultivation process extended over six days. *Azolla Pinnata* used in this study were collected from Universiti Sains Malaysia (USM) (Figure and were cultivated in open-top container (45 x 20 x 25cm) exposed to direct sunlight (Fig. 5). To maintain control over water properties and *Azolla* growth, the greenhouse was covered with plastic film to shield against rainwater. 100g of fresh *Azolla Pinnata* were cultivated using fix optimum paramaters as conducted by N. Adzman *et al.* [18] (under 100% sunlight exposure, 20cm water depth with pH set at 7). Different types of composted food waste, approximately 65g each, were added to the containers (excluding the control) containing the *Azolla Pinnata*.

Fig. 4. *Azolla Pinnata* Green House

Fig. 5. Experimental setup for the cultivation of Azolla Pinnata

Azolla Pinnata Growth Performance Analysis

The parameters measured to observe the growth performance of *Azolla Pinnata* in these studies were biomass, relative growth rate (RGR) and doubling time (Td). *Azolla* biomass was harvested after six days of growth. Then, the biomass production was calculated based on fresh weight of day minus initial fresh weight on day 0. RGR is a measure of plants productivity, defined as the growth in the plant mass per unit over a given time period. RGR was calculated as in Equation 3 [19]. Td is the time taken for a certain quantity of plant to double in size or value at a steady rate and Td was calculated using the following Equation 4 [20]:

$$RGR = (\log W2 - \log W1) / (t2 - t1) \quad (3)$$

$$Td = (t2 - t1) \times \log 2 / \log (W2/W1) \quad (4)$$

where: t1 - time initial (0 day); t2 - time of harvest (in 6 days); W1 - fresh *Azolla* biomass at time initial (g); W2 - fresh *Azolla* biomass at harvesting time (g).

Results and discussion

pH value

The pH values observed in MFW, VW, and FW, as illustrated in figure 6, exhibit a similar trend, with values increasing from 7.4 to 8.2, 6.8 to 7.9, and 6.4 to 8, respectively. Previous studies have shown that the optimum pH range for producing high-quality compost often falls between 6 and 8.5 [10]. The observed pH range serves as an indicator of the stability of organic materials present in the compost. Following the outcome of this study, it was determined that the pH of all tested compost reside within the desired range. The obtained findings suggest that the pH values were favorable to enhancing the quality and maturity of the compost.

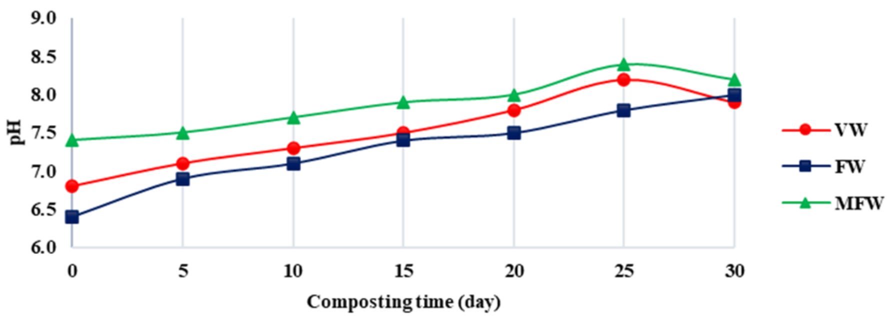

Fig. 6. pH variation versus composting time

The noticed elevation of pH values from acidic to alkaline indicates a depletion of acid content within the compost. The process of composting begins with the addition of organic materials that may naturally contain acidic substances, especially for food waste which encompasses a wide range of constituents. As a result, the initial pH of the composting mixture tends to be substantially lower, which can be attributed to the intrinsic acidity of the organic materials involved.

The increase in pH seen at the beginning of the composting process was due to the formation of ammonia (NH_3) and carbonates (CO_3^{2-}) due to the microbial activities involved in the conversion of organic nitrogen through ammonification and mineralization [21, 22]. These compounds react as bases and play a vital role in the slow transition from an acidic to an alkaline condition. The implementation of effective aeration and regular turning techniques can effectively reduce moisture content levels, hence potentially increasing the pH value. This rise in pH can hinder the growth of anaerobic microbes, which are recognized for their role in pH level reduction. The decline in pH observed in MFW and VW towards the end of the composting process can be ascribed to the release of hydrogen ions (H^+) as a consequence of microbial nitrification occurring during the degradation of organic matter [22, 23].

Temperature

The temperature of composting plays a crucial role in showing the decomposition of organic matter and the level of microbial activity that occurs throughout the composting process. As seen in figure 1a, the temperatures during the composting process exhibited a rapid initial rise followed by a subsequent decline towards the end. During the composting process, all treatments underwent three distinct phases: mesophilic (20°C to 45°C), thermophilic (>50°C), and curing (20°C to 30°C). It is notable that the thermophilic stage was achieved during the initial 3-4 days, as depicted in figure 7. The temperatures of all composts surpassed 50°C, a threshold that effectively suppressed the activity of the most pathogenic microorganisms [24]. The observed result can be attributed to the elevated concentrations of carbohydrates, proteins, and lipids present in food waste, hence facilitating bacterial catabolism and anabolism.

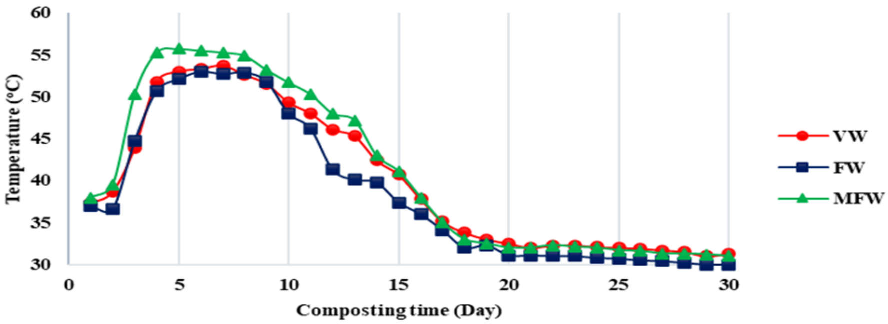

Fig. 7. Temperature versus composting time

The thermophilic temperature of 50.3°C was attained by MFW on the third day and persisted for a duration of nine days. On day 4, VW and FW attained temperatures of 51.8°C and 50.7 ◦C, respectively. However, their durations were limited to a mere four days. The long duration of the thermophilic phase observed in this study may be attributed to the incorporation of effective microorganisms (EM), which augmented microbial activity. Furthermore, thermophiles play a vital role in the further degradation of simple carbohydrates that were initially decomposed by mesophiles in the mesophilic stage of the composting process [25]. Thermophilic phases can expedite the process while decreasing pathogen levels, hence yielding a final product of enhanced value.

However, as stated by L. Zhang and X. Sun [25], it is necessary for the composting mixture to reach a temperature of at least 55°C for a minimum of three consecutive days in order to effectively eliminate pathogens and weed seeds. In this study, only MFW has successfully met this requirement. MFW normally comprises a diverse assortment of biodegradable components, encompassing fruits, vegetables, and many other consumable products. The presence of diverse materials can offer an extensive range of nutrients and carbon sources to microbes, resulting in heightened microbial activity and elevated temperatures in comparison to the use of solely VW and DW. The limiting temperature of VW and FW, not surpassing 55°C, might be attributed to the presence of excessive moisture, which acts as a hindrance to the temperature elevation [25]. Nevertheless, it is important to note that VW and FW have already reached the optimal range of thermophilic temperature required for an efficient composting procedure.

The temperature fluctuations within compost piles are dependent upon various aspects, including the composition of materials undergoing decomposition, the specific composting methodology employed, and the prevailing environmental circumstances. Subsequently, from day 10 onwards, there was a significant and rapid reduction in the temperature of the compost, reaching a level close to the ambient temperature of 30°C. This observation indicates the commencement of the curing stage. The temperature exhibited a progressive decline over the end of the composting process, which can be attributed to the decrease in biodegradable organic matter and microbial activity [24].

Moisture content

As depicted in figure 8, the moisture content (MC) exhibited a consistent reduction throughout the composting process. During the thermophilic phase, a noticeable reduction in MC was noted, leading to the evaporation of water. Following the high-temperature phase on day 5, the MC of the composts (MFW, VW, and FW) experienced a reduction of 26.1%, 21.82%, and 24.1% respectively, in comparison to their initial moisture content. The observed decline in MC during the initial five days of composting may be attributed to an elevated temperature resulting from heightened microbial activity and subsequent accelerated decomposition of organic matter. Increased turning frequencies were found to result in greater moisture loss and improved compost quality in terms of final MC. During the cooling period, there was a steady deceleration in the rate of MC. Following a composting period of 30 days, the MC of the composts, (MFW, VW, and FW) exhibited final reductions to 22.24%, 24.30%, and 31.70%, respectively. MFW and VW fulfilled the criteria of optimum MC, which is recommended to be below 30.0%, as stated by China Bio-organic Fertilizer (NY884-2012). Conversely, FWs exhibited a slightly higher MC than the prescribed limit.

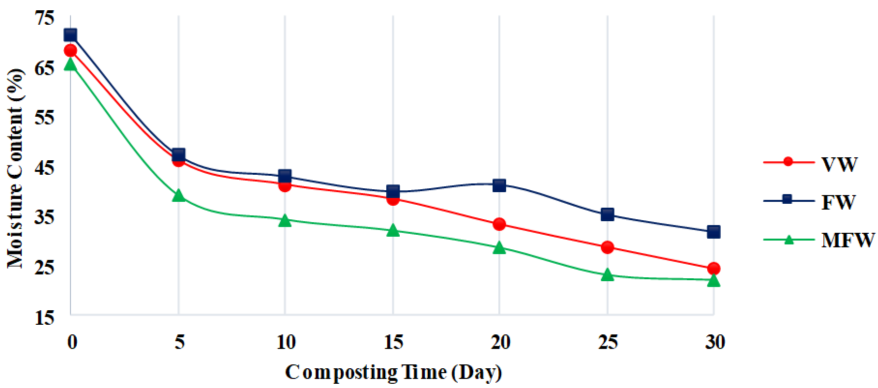

Fig. 8. Moisture content versus composting time

The correlation between the MC of waste material and its physical and chemical properties has been observed. MC serves as a medium for the transportation of nutrients, facilitating microbial activity [26]. The primary factor influencing the composting process was the initial MC of the source materials. Microorganisms break down organic matter, which causes the compost to heat up, necessitating ventilation through turning and ultimately leading to moisture loss through evaporation. When the initial MC is excessively high, it results in the obstruction of pores and subsequently limits the circulation of air. Consequently, this leads to a partial shift in the composting process towards anaerobic conditions [26]. Nevertheless, a low initial MC has a detrimental impact on the dissolution of organic matter, thereby impairing the metabolic processes of microorganisms. The MC of the composts in this study was found to fall within the range advised by previous researchers, who stated that effective composting can be achieved with an initial MC ranging from 50% to 70% [27]. The optimal range facilitates microbial activity and nutrient metabolism, while also regulating composting temperatures and the decomposition of organic matter (50). FW and VWs usually have a high MC; hence, the initial MC were high (Fig. 8).

Nutrient content

Adequate amounts of essential nutrients such as total nitrogen (TN), total phosphorus (TP), and potassium (K) are crucial for generating high-quality compost (Table 2). Figure 9 illustrates the TN values increased during the composting process. TN content reached 2.734% in FW compost, 2.875% in VW compost, and 3.43% in MFW compost. High-quality compost should exhibit a TN percentage ranging from 0.45% to 3.50%. The result showed that all tested compost samples demonstrated TN values falling within this specified range. During composting, the organic nitrogen compounds experience microbial degradation through mineralization process leads to the formation of ammonium (NH_4^+) [28]. As the process of composting progresses, the compost accumulates soluble forms of nitrogen, resulting in elevated amounts of total nitrogen (TN). At the later stages of the composting process, microbial activity tends to be at its peak, thus expedites the process of decomposing organic materials that are rich in nitrogen, resulting in the release of nitrogen into the compost. In addition, as microorganisms thrive and eventually die during the composting process, subsequently reintegrated into the compost as nitrogen, hence, the observed augmentation in TN concentration [28].

Table 2. Nutrient content of different types of composted food waste

Nutrient Content (%) *End of Composting	Type of Composted Food Waste			Recommended Range (%)
	MFW	VW	FW	
Total Nitrogen (TN)	3.43	2.875	2.734	0.4 - 3.5
Total Phosphorus (TP)	1.09	0.874	0.734	0.2 - 1.5
Potassium (K)	0.981	1.327	1.442	0.4 – 1.5

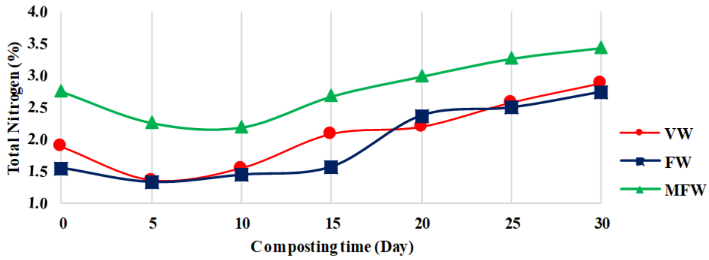

Fig. 9. Total Nitrogen versus composting time

In the meantime, figure 10 illustrates the TP values of FW (0.734%), VW (0.874%), and MFW (1.09%) pertaining to the compost samples. Notably, all of these values are within the optimum range of 0.2-1.55% for compost of high quality. The elevated levels of TP concentration were a result of the rapid carbon loss resulting from the decomposition of organic matter. Compost that possesses a high TN content also influenced an enhanced TP content as a result of heightened microbial activity meant for decomposing P elements [29].

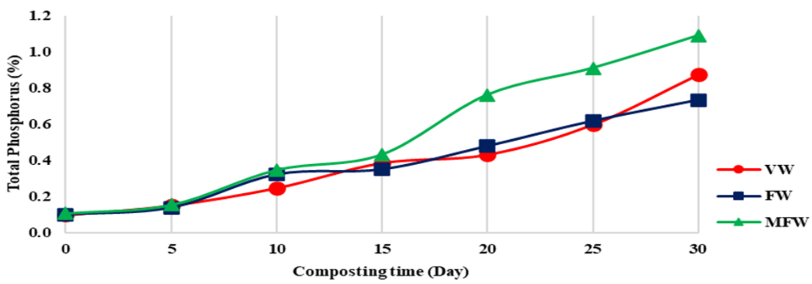

Fig. 10. Total Phosphorus versus composting time

The chemical characteristics of compost of high quality encompass a K concentration ranging from 0.4% to 1.5%. The results presented in figure 11 showed that K content upon completion of composting seemed to be 0.981% in MFW compost, 1.327% in VW compost and 1.442% in FW compost. In the present situation, each compost samples exhibit characteristics typically attributed to mature compost. The observed increase in K value may be due to the utilization of rice husk as a decomposing medium. The utilization of rice husk for composting proved to be efficacious due to its capacity to absorb and retain moisture. The preservation of structural integrity and porosity of material may lead to an increase in the value of K as moisture content is absorbed [30].

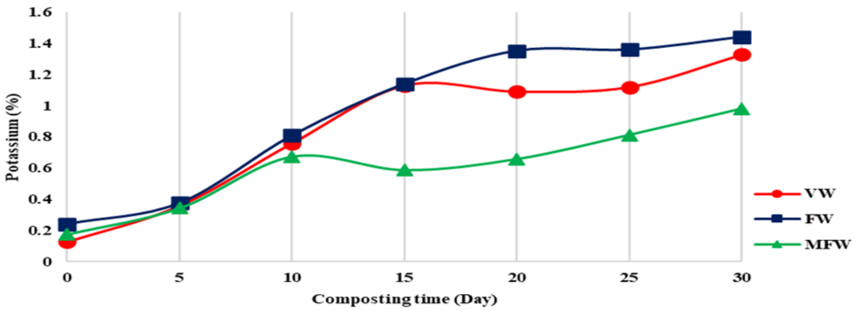

Fig. 11. Potassium versus composting time

Heavy metals

Heavy metals are non-degradable elements that remain in the environment when present in excess, posing a threat due to their harmful effects on plants, animals, and humans. Table 3 illustrates the crucial heavy metals measured, including Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), Zinc (Zn), And Arsenic (As), which contribute significantly to the stimulation of plant growth and development. The enhancement of plant nutritional levels and development mechanisms may be achieved via the optimization of certain elements. Nevertheless, when the levels of these elements are beyond the specified limit values, it might lead to toxicity, impede plant growth, and extended use may cause soil degradation. The concentration of heavy metals in all of the compost samples were found to be complied with in accordance with the prescribed limits of Compost Legislation Standard (Table 3).

Table 3. Heavy metals content in different types of composted food waste

Heavy metals (ppm)	Types of composted food waste			Compost legislation standard (ppm)
	MFW	VW	FW	
Cd	0.00	0.00	0.00	6.7
Cr	0.31	0.13	0.17	4.0
Cu	0.44	0.23	0.21	2.2
Pb	0.50	0.82	0.64	70.0
Ni	0.26	0.13	0.10	3.0
Zn	1.82	1.30	0.90	4.0
As	0.41	0.21	0.18	2.5

Maturity and Phytotoxicity Analysis

Microbial analysis, germination index (GI), and compost quality index (CQI) are commonly included in both the maturity and phytotoxicity analysis of compost. These tests are crucial components of evaluating the overall quality and suitability of compost for agricultural and horticultural applications.

Microbial analysis showed MFW had the highest at 2.34×10^{12}cfu/g, meanwhile VW compost had 1.53×10^{12}cfu/g and FW had 1.47×10^{11}cfu/g. Bacteria were far more abundant than fungi and actinomycetes in all samples (Table 4). Bacteria are critical composting organisms, as they supply nutrition, initiate decomposition, and generate heat and CO_2 to speed the process along [31]. Their rapid growth and multiplication during the thermophilic phase (40-60°C) allow efficient breakdown of organic matter.

Table 4. Maturity and phytotoxicity analysis of *different types of composted food waste*

Maturity and Phytotoxicity Analysis	Types of composted food waste			Recommended range
	MFW	VW	FW	
Microbial parameters (cfu g-1)				
1. Total bacterial count	23×10^{11}	15×10^{11}	13×10^{10}	-
2. Total fungal count	52×10^{6}	68×10^{5}	50×10^{5}	
3. Total actinomycetes count	39×10^{9}	27×10^{9}	17×10^{9}	
4. Total microbial counts	2.34×10^{12}	1.53×10^{12}	1.47×10^{11}	
Germination Index (%)	82.1	89.1	79.3	> 80 [33]
Compost Quality Index (CQI)	7.05 (Very good)	4.24 (Good)	2.92 (Moderate)	> 2.00: Poor 2.00 – 4.00: Moderate 4.00 – 6.00: Good 6.00 – 8.00: Very Good 8.00 – 10.00: Extremely Good

Germination index (GI) was measured to assess compost maturity and phytotoxicity. Compost with a GI over 80% is considered phytotoxin-free and mature enough for use [31]. As seen in figure 5, GI rose during composting, signaling the gradual elimination of phytotoxic compounds. Final GI reached 89.1% in VW compost and 82.1% in MFW compost, surpassing the 80% threshold. However, FW compost had a lower GI of 79.3%, indicating slightly higher residual phytotoxicity compared to the other treatments, potentially due to its higher moisture content which can impact the decomposition process. Excess moisture can lead to anaerobic conditions, reducing oxygen availability for beneficial microorganisms and potentially leading to the production of compounds harmful to germination. In general, the phytotoxicity of the four kinds of feces was in the order: FW > VW > MFW. Overall, the increasing GI values demonstrated the compost became safer and more mature through the composting process.

Compost quality index (CQI) helps in assessing the overall quality of compost, including its maturity and phytotoxicity. As shown in Table 4, by applying equation (1), notably the compost produced from MFW displays a substantial CQI value of 7.05, denoting exceptionally very good-quality compost. Conversely, the compost sample derived from VW demonstrates a CQI of 4.24, signifying good-quality compost, meanwhile, FW compost exhibits a CQI of 2.92, reflecting a moderate level of compost quality. A high CQI value typically indicates that the compost is mature, safe for plant growth, and of high quality.

Azolla Pinnata Growth Performance

Biomass, relative growth rate (RGR), and doubling time (Td) are vital measures of the productivity and growth performance analysis for *Azolla* species. Table 4 shows the impact of fertilized treatments (MFW, VW and FW) on the growth of *Azolla Pinnata*. After a cultivation period of 6 days, it was observed that all three fertilized treatments exhibited substantial increases in *Azolla Pinnata* biomass compared to the control group, with the highest biomass recorded in the MFW treatment (850g), followed by the FW treatment (780g), the VW treatment (750g), and the control group (230g) (Table 5). Furthermore, the fertilized *Azolla Pinnata* also displayed higher doubling times than the control treatment, with an average doubling time of approximately 2 days. Notably, the MFW treatment demonstrated the highest RGR at $0.357 g^{-1}\cdot d^{-1}$, while the VW and FW treatments exhibited comparable RGR values of $0.336 g^{-1}\cdot d^{-1}$ and $0.342 g^{-1}\cdot d^{-1}$, respectively. The control treatment, which did not receive any fertilizer, exhibited the lowest growth rate at $0.106 g^{-1}\cdot d^{-1}$.

Table 5. Growth performance of *Azolla Pinnata* treated with different types of composted food waste after 6 days cultivation in greenhouse

Growth performance of *Azolla Pinnata* (After 6 days cultivation)	*Azolla Pinnata* cultivation treatment			
	Control	MFW	VW	FW
Biomass (g) (fresh weight)	230	850	750	780
Relative Growth Rate (RGR) (g^{-1} d^{-1})	0.106	0.357	0.336	0.342
Doubling time (day)	7.84	1.94	2.07	2.02

The nutrient composition of the compost, particularly the essential elements such as TN, TP, and K, plays a pivotal role in influencing the growth of *Azolla Pinnata*. TP emerged as a limiting factor for *Azolla* growth, as an inadequate supply of P in the environment can impede optimal growth and development, thus constraining overall productivity [32]. In this context, it is worth highlighting that the composted food waste (MFW, VW, and FW) contained elevated TP levels, leading to a considerable increment in *Azolla Pinnata* growth. Besides, this study also involved the treatment of *Azolla Pinnata* with phytotoxin-free compost. This application was conducive to the growth of *Azolla Pinnata*, as the absence of substances with inhibitory or adverse effects facilitated its development.

Conclusions

The compost analysis conducted within this study revealed that the composts derived from MFW, VW, and FW demonstrated characteristics aligning with the acceptable range for high-quality compost, including pH level, temperature, moisture content, nutrient content (TN, TP, and K), and the concentration of heavy metals. The GI and CQI analyses collectively indicated that all the composted food waste attained the desirable maturity stage and were notably free from phytotoxins, with the exception of FW, displaying a slight elevation in residual phytotoxicity as indicated by a GI of 79.3%. In summary, the application of various composted food waste types prominently influences *Azolla Pinnata* growth performance, in terms of its biomass, RGR and doubling time. It is noteworthy that the most substantial enhancements were discerned in response to the application of MFW treatments, followed by FW and VW. Consequently, the integration of *Azolla pinnata* with composted food waste emerges as a promising prospect for an alternative, chemical-free fertilizer, fostering an improved growth performance for *Azolla* species.

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