Valorization of Water Hyacinth with Vegetable Waste and Goat Dung for Improved Growth of Maize Plants

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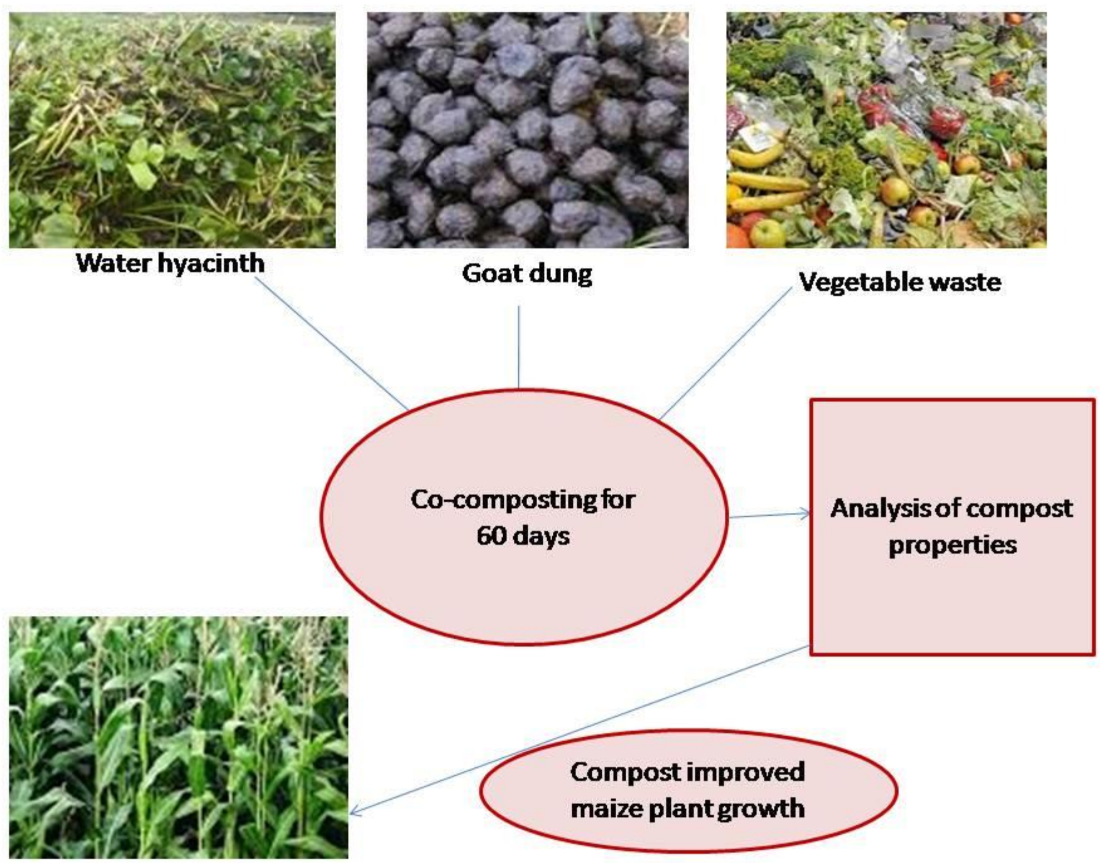
GRAPHICAL ABSTRACT



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Co-composting of water hyacinth, vegetable waste, and goat dung was performed with a ratio of 5:2:1 for a period of 60 days. Water hyacinth is rich in hemicellulose, cellulose, and lignin. In the initial co-composting bulking agent, the moisture content was high (71 ± 2%), and it decreased continuously during composting. The compost reached the mesophilic phase (2 to 10 days), the short thermophilic phase (10 to 18 days), the maturing phase (18 to 40 days), and the cooling phase (40 to 60 days). The increased temperature was observed at the thermophilic stage due to microbial activity. The pH of the composting manure ranged from 6.53 ± 0.02 to 7.12 ± 0.01. The mature compost achieved a stable pH after six weeks. The proteolytic, cellulolytic, and ligninolytic bacteria, fungi, and actinomycetes in the compost digested the lignin and cellulosic substrates and composted the organic matter. The organic matter content decreased during the maturation phase. A field experiment was performed to determine the efficacy of compost materials. Water hyacinth compost improved maize growth in terms of root height, shoot height, and leaf chlorophyll content. The co-composting method is used to produce nutrient-rich nitrogen sources for organic amendment and to improve crop yield.

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Keywords: Weeds; Water hyacinth; Vegetable waste; Goat dung; Compost; Organic amendment

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INTRODUCTION

Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is native to the Amazon forest in South America and was introduced to other countries in the 1950s. Later, it was introduced to various countries to meet feed demand for livestock. Due to the decreased utilization rate, it has grown wild, mainly in eutrophic water, ponds, urban rivers, and lakes (Begum *et al.* 2022). The growth rate of water hyacinth is aggressive. It causes anoxia in the water, and it favors breeding grounds for mosquitoes, affects water flow in rivers, and harms human health (Ndimele *et al*. 2011; Ben Bakrim *et al.* 2022).

India is one of the largest producers of vegetables and fruits, contributing 14% of vegetable and 10% of total fruit production. Fruit and vegetable wastes are generated by harvesting, storing, transporting, processing and marketing. India produces more than 150 million tonnes of vegetables and fruits and generates >50 million tonnes of waste each year. Hence, it is important to utilize these wastes to minimize greenhouse gas emissions (Jaiganesh *et al*. 2014). In addition, food waste is composed of skin, seeds, pomace, and rind and contains various useful compounds (Sagar *et al*. 2018). Bio residues available by vegetation, crop waste, agro-industrial waste, forest residue and organic waste are termed as biomass. Livestock (diary animals) based bio waste is dung from livestock, which comprises less urine and more excreta. Animal dung and waste water generation are very high, and the total generation is approximately 6000 million tons/day. It has been estimated that approximately 9% of dung is utilized for product recovery and that the remaining waste is unutilized. In India, approximately 135 million goats generate approximately 2 kg/day (4 to 5% of body weight). The type of dung generated varies on the basis of several factors, including animal husbandry practices in operation, type of animal, ingredients of feed, and quantity (Avcioglu and Turker 2012). Biocomposting of *E. crassipes* offers a simple biological solution that can tackle its invasiveness by transforming biomass into valuable biofertilizers (Udume *et al*. 2021; Saengsanga and Noinumsai 2023). The biocomposting process offers the design of new molecules for agriculture. The produced product satisfies various ecological laws, such as Shelford's law of tolerance, Liebig's law of the minimum, and Odums' combined law. These proposed laws directly deal with the physicochemical and nutritional requirements of organisms in the ecosystem. Composting, a biological process, improves the breakdown of heterogenous, highly complex molecules found in waste in a range of conditions (Meghvansi and Varma 2020). Compost fertilizers are used in environmental management and agriculture production by improving soil nutrients, soil microbial activity, the potential to remove organic pollutants, and the soil microbial population (Taiwo *et al*. 2016). The compost material supported the growth of bacteria, improved microbial colonization, and enriched nutrients (Xie *et al*. 2023). In compost, agitation and aeration may cause NH_3 loss and moisture loss (Zhou 2017; Xiong 2023).

Optimizing suitable composting conditions is required for improved compost output. The optimum nutrient content and moisture content are essential for improving the microbial composting of biomass (Ali *et al*. 2014). Moreover, the optimum microbial inoculums and moisture content are the most important factors that can influence the biodegradation of water hyacinth. The optimization process improves physico-chemical conditions, which maximizes the nutritional yield of compost (Chowdhury *et al*. 2014). The optimum level of oxygen and moisture content of the compost improves microbial activity (Bernal *et al*. 2009), reduces N losses and CO_2 emissions during composting (Nigussie *et al*. 2016), and improves nutrient content (Nigussie *et al*. 2016). The optimized conditions decrease compost maturity time, improve the fertilizing value of the compost, and accelerate lignocellulose degradation (Chen *et al*. 2019). The dosage of inoculums is an important factor in improving compost quality. The biodegradation of lignocellulosic substances is a recommended composting process. Due to its high stability, lignin is an abundant, recalcitrant, and sustainable substance in the environment (Wang *et al*. 2021). In the conventional degrading process, lignin degradation is slow. The presence of lignin components affects the breakdown of hemicelluloses and cellulose components. There are several pre-treatment methods, and microbes affect microbial deterioration and bioconversion during composting (Zhang *et al*. 2020). Lignin-degrading microbes play a significant role in lignocellulosic biomass degradation. The composting process modifies the lignin structure (reducing monomeric units) (Albrecht *et al*. 2008). The bacteria structure, such as *Sphingobium* sp. and *Pseudomonas* sp., degrade lignin and are involved in composting (Siyoum *et al*. 2016).

The composting process helps to convert organic matter into humic substances. If the compost contains rich humus-like substances, fewer amounts of biodegradable matter, and reduced microbial activity, then it can be considered mature compost. Stable compost reduces pathogen growth and odor generation and is recommended for field applications. The composting of water hyacinth generally solves environmental pollution and reduces the chemical fertilizer load in the soil. The prepared final humic substances have the required amount of nutrients, such as nitrogen, calcium, and potassium, which are required for the improvement of crop yield. Water hyacinth compost was used to promote plant growth, inhibiting soil-borne plant diseases and root pathogens (Balasubramanian *et al*. 2013).

EXPERIMENTAL

Water Hyacinth and Feedstock Materials

The composting study was performed between July 2023 and August 2023. The feedstock materials, water hyacinth, vegetable wastes, and goat dung were used for the preparation of bulking agents. Water hyacinth was collected from the ponds at Kanniyakumari, India. Vegetable waste was collected from the local restaurant, and goat dung was collected from the local farm. All feedstock materials were dried and powdered, and the final particle size ranged from 1.5 to 2.0 mm.

Composting of Bulking Agents

Water hyacinth, vegetable waste, and goat dung were used for composting. These were mixed at a 5:2:1 ratio based on preliminary experimental results. The carbon and nitrogen ratios of the composting material were maintained between 30 and 35 by adjusting the composition of the bulking agent. The optimum bulking agent composition was 5:2:1 (water hyacinth, vegetable waste, and goat dung). The initial moisture content of the medium was set to 60% to favour the growth of bacteria, fungi, and actinomycetes. The bioreactor was filled with bulking agent up to 75% of the total volume. The bioreactor capacity was 50 L, and it was a fixed-bed batch bioreactor type. The size of the reactor was 0.6 m long and 0.4 m wide, and the internal surface was coated with a thermally insulating material. The outer surface of the moving bed reactor was properly insulated with a layer of 30 mm thickness glass wool blanket. The moving bed bioreactor ensures required aeration, and a rotameter was used to control the air inlet. A moist air was ingested to avoid drying and to maintain the required moisture content for composting. The bioreactor was connected with an air compressor and moist air was supplied in reactor at a flow rate of 0.004 $m^3 \cdot min^{-1}$. During composting, moisture content of the compost was monitored to analyze the completion of the composting process. The temperature of the reactor was monitored and composting continued until the reactor temperature dropped below 35 ºC. The temperature of the compost was monitored using a thermocouple sensors, and the pH was monitored using a sensor attached to the surfaces. Over the period of 60 days of the composting process, the bioreactor was monitored and after every 12 h. The samples were withdrawn for physicochemical and microbiological analysis from the middle of the composting materials.

Analytical Experiments

The sample (1.0 kg) was mixed with 5 L of water and agitated for 30 min. It was filtered using a layer of Whatman number 1 filter paper and used for the determination of pH and electrical conductivity (EC). A digital pH meter was used for the determination of pH. Electrical conductivity of the sample was analyzed using a conductivity meter (Elsalam *et al*. 2021). About 100 g of sample was loaded in a crucible and maintained in a muffle furnace (500 °C for 2 h), and the volatile solid content was determined. A Kjeldahl method was used for the analysis of total nitrogen (TN). Briefly, 0.5 g of dried sample was mixed with 12 mL of commercial-grade H_2SO_4 and catalysts ($CuSO_4$ and K_2SO_4). It was heat digested and diluted to 150 mL with double-distilled water. About 5 mL of sample was mixed with 25 mL of NaOH (40%) and placed in the distillation assembly. Then, ammonia gas was collected in a 250-mL Erlenmeyer flask containing boric acid (50 mL), and it was titrated using 0.02 N H_2SO_4. The methylene blue and methyl red (mixed indicator) were prepared in boric acid, and the development of the purple color was tested. The KCl extraction method was followed for the determination of NO_3-N and NH_4-N (Tiquia and Tam 2000). The amounts of Ca, K, and Na were detected using a flame photometer (Systronic). The sample was prepared by mixing 0.5 g of compost or bulking agent, 10 mL of $HClO_4$, and H_2SO_4 (1:5) for 2 h at 300 °C. The total phosphorus content of the sample was determined from the acid-digested sample as described previously (APHA 2005). The amount of total nitrogen in the sample was determined using Eq. 1:

$$\text{TN}\ (\%) = \frac{14 \times (\text{S}-\text{B}) \times \text{N}}{\text{weight (g)}} \times 100 \tag{1}$$

Microbial Analysis

The total bacterial population was determined from the compost after serial dilution and plating on nutrient agar medium (Himedia, India). The samples were serially diluted and plated on nutrient agar medium and incubated for 24 h at 37 °C. To determine actinomycetes population, serially diluted samples were plated on starch casein agar medium and incubated at 28 °C for 5 to 8 days. To determine the fungal population, samples were serially diluted and plated on potato dextrose agar medium. It was incubated for 3 days at 28 °C, and the developed colonies were counted.

Effect of Organic Compost on Maize Growth

To determine the growth of maize, organic compost (0 days, 12 days, 24 days, 36 days, 48 days, and 60 days) was maintained for four months in the field. The other management practices were based on usual practice. The parameters, such as root length, shoot height, and chlorophyll content of leaves, were measured.

Statistical Analysis

An analysis of variance was performed to determine the significant variation of factors during the composting process. To test the effect of compost on the growth of maize plants, a student "t" test was performed to determine the variation between the control and experimental results. The p-value<0.05 was considered as statistically significant. Statistical analysis was carried out with Statistical Package for the Social Sciences (SPSS) software package (version 11.0) (IBM Corp., Armonk, NY).

RESULTS AND DISCUSSION

Composition of Bulking Agent

The pH of the water hyacinth biomass was 6.25 ± 0.28, and the vegetable waste showed an insignificant difference. Moreover, goat dung showed a higher pH value than other agricultural biomass. Singh and Kalamdhad (2015) observed the pH of water hyacinth and reported a pH of 5.98 ± 0.16. In the present work, the moisture content of the selected biomass ranged from 79.3 ± 2.1% to 87.3 ± 0.13%. Total nitrogen content was high in the goat dung (1.71 ± 0.21%), followed by vegetable waste (1.3 ± 0.2%), and water hyacinth (0.93 ± 0.065%). Ash content was 27.5 ± 1.1% in the water hyacinth and 20.58 ± 0.1% in vegetable waste. The physico-chemical and nutrient factors of water hyacinth, goat dung, and vegetable waste are illustrated in Table 1. The selected biomass can act as a substrate for microorganisms and induce enzymes production (Sathya *et al.* 2024). The compost materials can improve soil fertility and increase the activity of soil microorganisms. The application of water hyacinth with vegetable waste and goat dung would result in changes in the compost material, microbial community, and total nitrogen content of the compost. Macroalgal species shows various problem for composting such as accumulation of heavy metals, high salt content, or low C/N levels. Therefore, the addition of high C levels, as well as other fishery, and animal wastes are recommended to enrich the macroalgal biomass for composting. This strategy is useful for large-scale composting of the macroalgae based biomass to obtain nutrient rich and microbiologically enriched mature compost (Biruntha *et al.* 2020). The bulking agents were analyzed, and their characteristics are described in Table 1.

Table 1. Characteristics of Water Hyacinth, Goat Dung, and Vegetable Waste Used for Composting

Parameters	Water Hyacinth	Goat Dung	Vegetable Waste
pH	6.25 ± 0.28	6.82 ± 0.09	6.29 ± 0.25
Moisture (%)	79.3 ± 2.1	81.4 ± 0.25	87.3 ± 0.13
EC (dS/m)	6.75 ± 0.15	4.6 ± 0.34	5.73 ± 0.22
Volatile solids (%)	69.4 ± 1.2	60.5 ± 2.3	62.3 ± 1.2
Total nitrogen (%)	0.93 ± 0.06	1.71 ± 0.21	1.3 ± 0.2
Ash (%)	27.5 ± 1.1	1.52 ± 0.2	20.58 ± 0.1

Moisture Content

The moisture content of the compost was found to be the most significant physico-chemical factor influencing co-composting. In the initial co-composting medium, the moisture content was high (71 ± 2%), and it decreased continuously during composting ($p<0.05$) (Fig. 1). Co-composting has several advantages over the composting of a single substrate. In this study, water hyacinth, goat dung, and vegetable wastes were used for co-composting. Yousefi *et al*. (2013) used municipal solid waste and sawdust for composting. The addition of sawdust (16%) improved the initial C/N ratio and minimized N loss during the composting process. In another study, Fan *et al*. (2019) used solid and liquid manure compost and analyzed the optimum size of the bulking agent. The optimized co-composting process improves the compost quality and achieves mature compost. In a study, different types of olive husks were used for the preparation of compost, and this process was initiated by the force aeration method. This method reduced water-soluble organic matter, lipid contents, and phytotoxicity (Gigliotti *et al*. 2012). In addition, the available microorganisms in the compost improve the composting process, and optimum moisture content is important to increase the rate of composting. The optimum level is required for the growth and multiplication of bacteria, fungi, and actinomycetes in the compost, and the available oxygen content in the medium indirectly provides oxygen (Dong *et al.* 2024). The initial moisture content of the compost was 68.9 ± 2 ºC, which supported the growth of bacterial communities within the compost. The present study was in good agreement with previous reports on composting. The amount of moisture content varied based on the types of bulking agents, and the moisture content was between 55 and 70% preferred for microbial composting (Vijayaraghavan *et al*. 2021). In the case of poultry manure composting, 60% moisture was preferred for the composting process (Nadia *et al*. 2015).

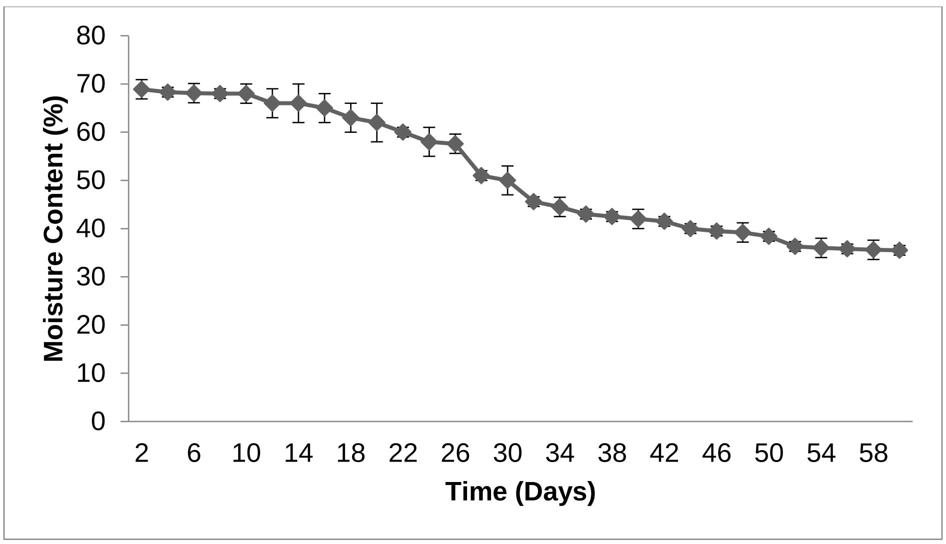

Fig. 1. Moisture content of the co-compost prepared using water hyacinth, goat dung, and vegetable waste. Composting was performed for 60 days, and the experiment was performed in triplicate (n = 3).

Compost Temperature

The composting temperature varied in all three phases: mesophilic ($p<0.05$, 2 to 10 days), thermophilic ($p<0.05$, 10 to 18 days), and cooling (40 to 60 days, $p>0.05$) (Fig. 2). The bulking agents affected the temperature during the composition process. The increased supplementation of goat dung may improve the composting process. In the current study, water hyacinth, vegetable waste, and goat dung were used in a 5:2:1 ratio. A thermophilic phase was observed between 10 and 18 days, and these increased temperatures revealed high microbial activity within three weeks of composting process. This result was in good agreement with previous reports. The metabolic activity of microbes increased with the temperature of the compost (Singh and Kalamdhad 2014). In the current study, maximum temperature was observed (49.2 ± 0 °C) after 16 days of composting (thermophilic stage), and compost reached stability after six weeks of composting. The increase in temperature in the mesophilic stage reduced the pathogenic bacteria load in the composting manure (Pandey *et al*. 2016). Varma and Kalamdhad (2015) observed high heat (>65 °C) in the compost due to the metabolic activity of microorganisms during thermophilic stage. Troy *et al*. (2012) reported 50 °C after 8 days of municipal solid waste composting, and this rapid temperature within 8 days showed a rapid degradation of proteins, fats, and sugars. The temperature observed in the thermophilic stage was similar to the previous result; moreover, in the present study, the bulking agent reached thermophilic stage only after 16 days of composting. The cooling phase was observed after six weeks (<30 °C), revealing the maturity of the compost, and this phase favours the growth of *Actinomyces* in the compost.

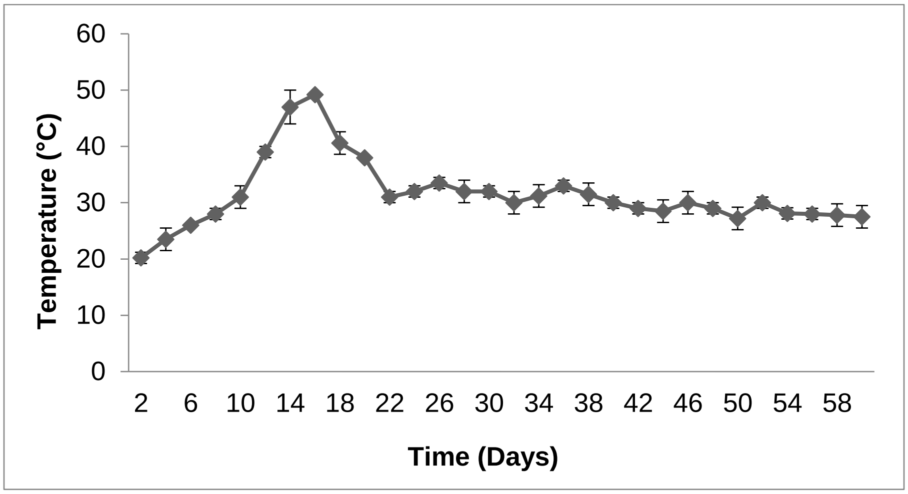

Fig. 2. Temperature variation of the co-compost prepared using water hyacinth, goat dung, and vegetable waste. Composting was performed for 60 days, and the experiment was performed in triplicate (n = 3).

Compost pH

The pH of the composting manure ranged from 6.53 ± 0.02 to 7.08 ± 0.034. The pH of the compost was at its maximum on Day 0, and it decreased slowly. The mature compost achieved stable pH after six weeks ($p > 0.05$) (Fig. 3).

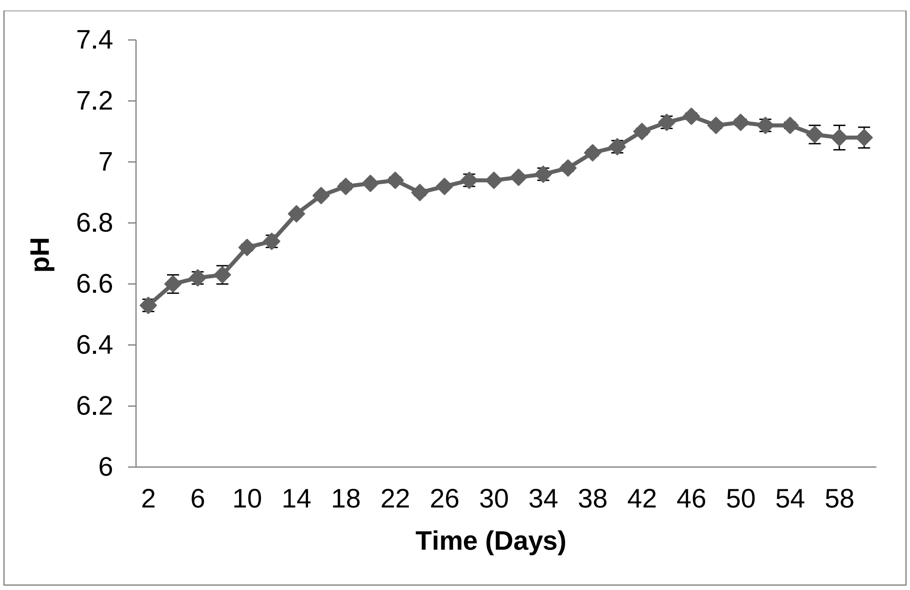

Fig. 3. Variation of pH in the co-compost prepared using water hyacinth, goat dung, and vegetable waste. Composting was performed for 60 days, and the experiment was performed in triplicate (n = 3).

The selected water hyacinth, vegetable waste, and goat dung are composed of lignin, cellulose, proteins, and fats. The proteolytic, cellulolytic, and ligninolytic bacteria in the compost digest these substrates and decompose the organic matter. The production of several nitrogenous substances, including ammonia, within the compost increased the pH of the compost, and an unpleasant smell was not observed from the compost. The stable pH is one of the physical indicators to fix compost. The pH value of the mature compost was 7.12 ± 0.01 and was found to be suitable for microbial activity (Zhang and Sun 2016). The goat dung and vegetable waste were rich of organic matter. The available organic matter in vegetable waste and in goat dung increased pH during the composting process (Lim *et al*. 2015). The ideal pH range was determined as 5.5 to 8.0 (Zhang and Sun 2016), 6.7 to 9.0 (Bernal *et al*. 2009), and 7.40 to 8.89 (Vaverková *et al*. 2020), depending on the substrate used for composting. The pH of the bulking agent analyzed in this study was within this limit with supported composting process.

Total Organic Carbon

The total organic content of the bulking agent was determined to be 38.5 ± 0.02 after Day 0. It declined significantly up to 20 days due to bacterial degradation of organic carbon ($p<0.05$). After four weeks of composting, carbon content was 27.1 ± 0.02% and it reached a stable state ($p >0.05$) (Fig. 4).

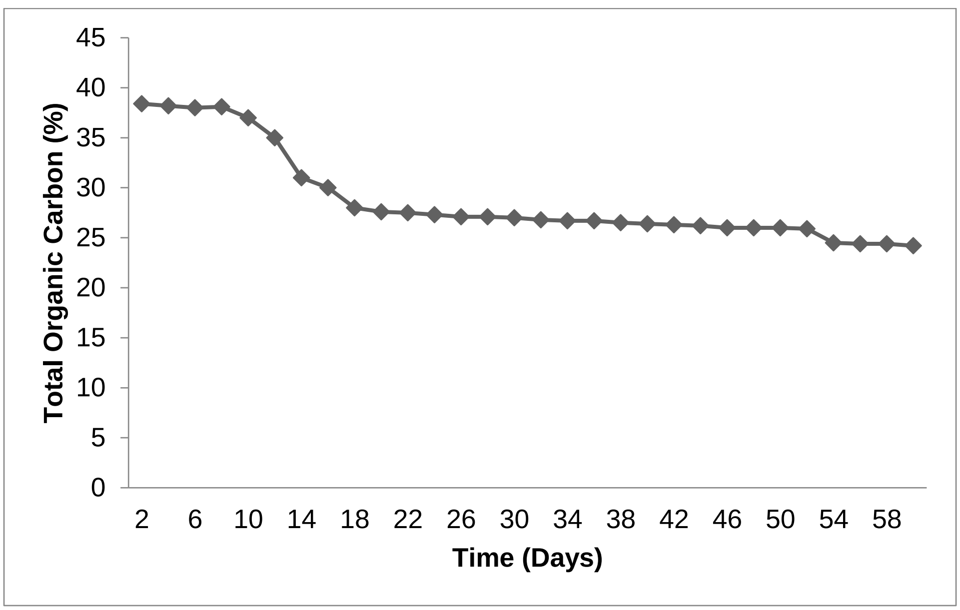

Fig. 4. Variation of organic carbon in the co-compost prepared using water hyacinth, goat dung, and vegetable waste. Composting was performed for 60 days, and the experiment was performed in triplicate (n = 3).

The decreased rate of organic carbon in the compost revealed microbial composting. The reduced total organic carbon in the compost is suitable for plant nutrition (Pan *et al*. 2012). The selection of a suitable bulking agent is an important factor for composting. The microbial population in the compost, especially the microbial consortia in the vegetable waste from various sources, endophytic bacteria, and root-associated bacteria from water hyacinth, and cellulolytic bacteria from goat dung, are collectively involved in composting. These microorganisms produce various extracellular enzymes and are involved in the breakdown of organic matter. The reduction of organic carbon is based on the types of bulking agents, and easily digestible compost materials undergo more rapid changes than hard biomass, such as sawdust. The amount of bulking agent decreased within three weeks of the composting process, and during this period, increased microbial activity was observed, especially bacterial population was high. The result obtained in the present study was consistent with previous reports. Yadav and Garg (2009) reported that the microbial population in the compost utilized organic carbon for their growth and maximum bacterial population was observed within three weeks of composting.

Total Organic Nitrogen

Figure 5 shows the increasing trend of organic nitrogen in compost during the 60-day composting process. The nitrogen content slowly increased from 1.7 ± 0.2% after 2 days of composting to 3.72 ± 0.039% after 60 days of composting ($p<0.05$). The total nitrogen content increased after 28-days of organic waste composting and achieved its maximum value in the cooling phase. The increase of organic nitrogen in the compost observed in this study might be due to the net loss of water and dry mass within the compost due to evaporation during the complete oxidation of organic matter. During composting, the organic matter loss is higher than the NH_4-N loss, which results in an increase in organic nitrogen (Sarika *et al*. 2014). In this study, adequate aeration was provided to enhance microbial composting. Aeration is one of the important factors that increase ammonia loss at the maturation stage of the compost (Kalamdhad *et al*. 2009). It was previously reported that increased total nitrogen content in the compost was mainly due to water loss by evaporation caused by the heat generated due to microbial activity, oxidation of organic substances, and loss of bulking agent (mass) (Santos *et al*. 2018).

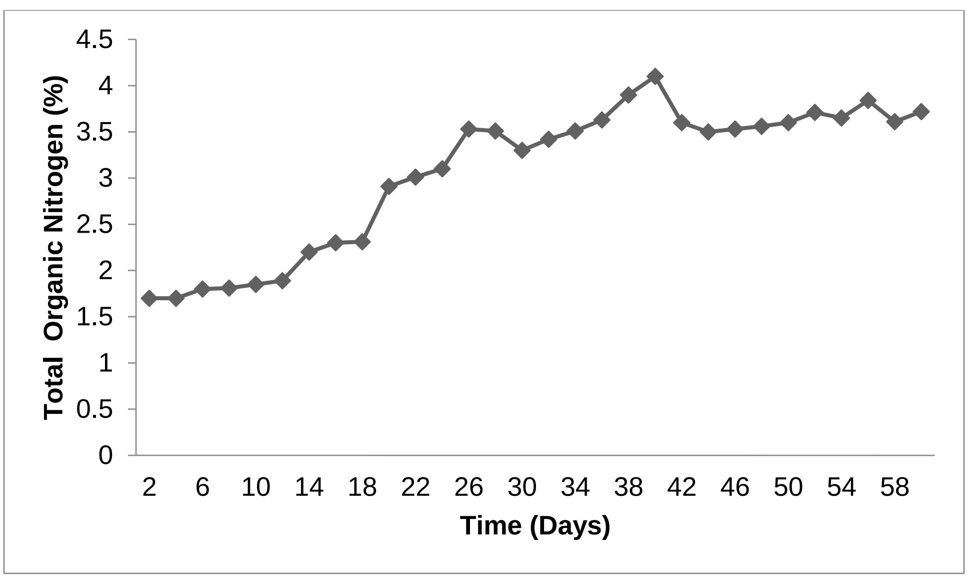

Fig. 5. Variation of organic carbon in the co-compost prepared using water hyacinth, goat dung, and vegetable waste. Composting was performed for 60 days, and the experiment was performed in triplicate (n = 3).

Microbial Population in the Compost

The total bacterial, fungal, and actinomycete population was determined from the compost in all stages. The bacterial population reached its maximum between 2 and 3 weeks and declined afterwards.

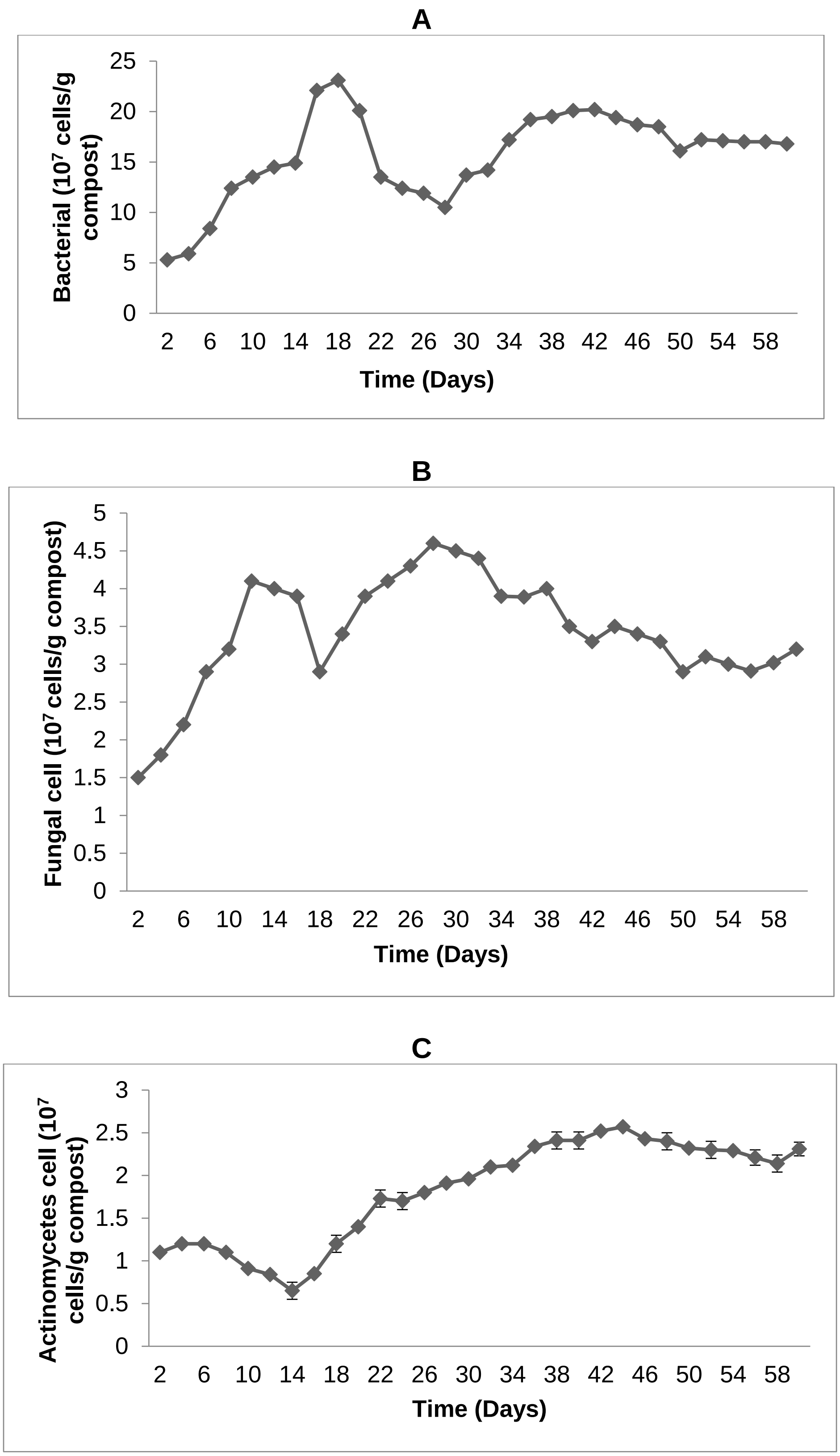

Fig. 6. Microbial population in the compost prepared using water hyacinth, goat dung, and vegetable waste: (a) the bacteria population; (b) the fungi population; and (c) the actinomycetes population.

Moreover, bacterial population was increased after 42 days of composting (maturing phase) and declined in the cooling phase ($p<0.05$) (Fig. 6a). Actinomycetes and fungi populations were determined in the compost, and they varied widely. During the thermophilic stage, the fungi population declined, and it increased in the cooling phase ($p<0.05$) (Fig. 6b). The Actinomycetes population was higher in the cooling phase and it declined in the mature compost due to depletion of carbon sources ($p<0.05$) (Fig. 6c). The microbial population varied depending on the types of bulking agents, nutrient sources, and composting phases. In addition, composting is based on types of microbial sources in the bulking agents and enzymatic activity (Alarjani *et al*. 2024). Microorganisms, especially esterases, proteases, phosphatases, glycosyl-hydrolases, and amino-peptidases producing organisms, contributed to the composting process, and this has been widely reported in literature. In the organic waste compost, soil microorganisms, including, bacteria, fungi, actinomycetes, and protozoa are involved composting (Xiang *et al*. 2013; Chantarasiri *et al*. 2017; Ganguly and Chakraborty 2018). Huang *et al*. (2019) reported the presence of *Solibacillus*, which improved organic matter and lignocellulose degradation. Hemicellulose and cellulose were predominant in water hyacinth-vegetable waste, and the thermostable bacteria, including cellulose and hemicellulose degrading bacteria, contributed toorganic matter degradation in the thermophilic phase (Arokiyaraj *et al*. 2024). The number of mesophilic bacteria decreased in the thermophilic phase. The nutrient quality of the bulking agent is important to analyze the amount of humic substances in the compost. Fungi from Basidiomycota and Ascomycota groups are involved in lignocellulose degradation, and they compete with other fungi for nutrients in the system (Jiang *et al*. 2019). In addition, fungi such as *Aspergillus* and *Candida* were reported throughout the stages. *Aspergillus* species produce various lignocellulose enzymes that influence compost maturity. In the thermophilic stage, *Aspergillus* and other *Mycothermus* strains were reported as the dominant fungal groups. These fungi transformed carbon and nitrogen, and *Candida* was dominant in the mature phase. It produced lignocellulose-degrading enzymes and improved the biosynthesis of humic substances (Zavrel *et al*. 2013).

Water Hyacinth Compost Improved Maize Growth

Water hyacinth compost significantly increased maize root height, shoots height, and leaves chlorophyll content. The 48 days and 60 days of compost material showed improved shoot length after composting than in the in the early stages (Fig. 7a) ($p<0.05$). Likewise, the root height was significantly increased when the plant was treated with between 48 and 60 days of mature compost ($p<0.05$) (Fig. 7b). The chlorophyll content of the control maize leaves was 67 ± 3.4 µg/mL, and it improved in the maize treated with matured compost (112.4 ± 2.9 µg/mL) ($p<0.05$) (Fig. 7c). The mature compost contains nutrients, nitrogen, minerals, and growth factors. These factors significantly influenced plant growth-promoting activities and improved maize growth. The compost substances, including vermin compost materials, increase maize growth and improve dry matter content. The compost manure improved soil fertility and provided growth promoters to enhance plant growth. The supplemented compost manure improved soil organic matter, and the presence of microbiomes improved soil enzymatic activity and soil physical structure. Water hyacinth and goat dung compost increased soil fertility and the soil organic matter content. The high organic contents of compost can combine with soil organic molecules and improve polymerization to form soil aggregates, which can improve the stability of soil organic molecules.

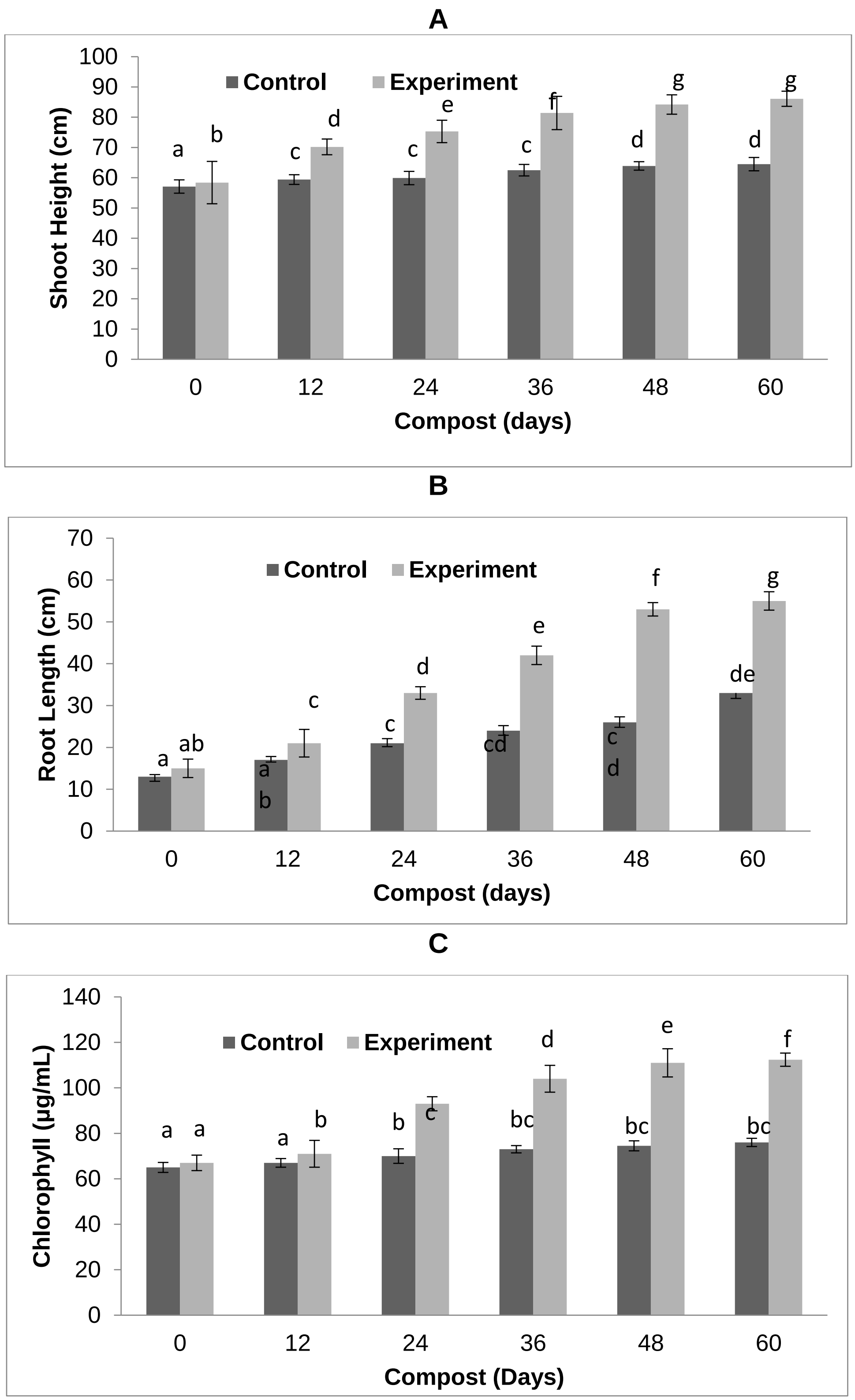

Fig. 7. Effect of water hyacinth, goat dung, and vegetable waste compost on the growth of maize plants. The compost was supplemented with maize plants, and it increased shoot length (A), root length (B), and leaf chlorophyll. The lowercase letters indicate the variations between treatments and control at the 0.05 level, and “0, 12, 24, 36, 48, and 60, indicate the days of compost manure used for maize plantation.

The compost contains several plant-available nutrients. The supplemented compost improved plant growth. This finding is in line with that of Su *et al*. (2015), who reported the effects of the application of organic fertilizers on the nutrient uptake, growth and yield of soil seeds. It has been previously reported that compost improved plant growth and fruit dry matter (Cozzolino *et al*. 2023).

CONCLUSIONS

1. Co-composting of water hyacinth, vegetable waste, and goat dung was a cost-effective and eco-friendly method to improve organic nitrogen.
2. The co-composting process reduced carbon content (27.1 ± 0.02%) and reached a stable state at a mature stage. The nitrogen content increased from 1.7 ± 0.2% to 3.72 ± 0.05t% after 60 days of composting ($p<0.05$).The co-composting improved soil fertility and soil character.
3. The mature compost improved maize plant growth in the field. The mature compost significantly increased shoot length, and root length ($p<0.05$). The chlorophyll content of the control maize leaves was 67 ± 3.4 µg/mL, and it increased in the maize treated with matured compost (112.4 ± 2.9 µg/mL) ($p<0.05$). The compost manure improved soil fertility and provided growth promoters to enhance plant growth.

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