International Journal of Environmental Science and Technology
https://doi.org/10.1007/s13762-024-05964-3

ORIGINAL PAPER

Investigation of biomass ash vermicompost as nutrient rich growing media for impatiens

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Received: 25 July 2022 / Revised: 17 December 2023 / Accepted: 13 August 2024

Abstract

Agro-industry and bioenergy plants produce a huge amount of biomass ash (BA) and bio-waste. Recycling this waste in the ornamental industry is beneficial for the environment and produces nutrient-rich growing media. Hence, present study was conducted at two consecutive stage aiming to evaluate the vermicomposting of BA with cattle manure and its use as a growing media component with hazelnut husk (HH) to enhance flowering performance of *Impatiens walleriana*. Five treatments T_0 (commercial coco peat), T_1 (vermicompost:HH), T_2 (BA-vermicompost equal to 3.5% NPK:HH), T_3 (BA-vermicompost equal to 7.0% NPK:HH), T_4 (BA-vermicompost equal to 10.0% NPK:HH) were evaluated. The results indicated that BA significantly increased nutrient content of vermicompost, likewise pH. Accordingly, nutrient bioavailability decreased as pH increased. The bioavailable fraction of nutrients was in the range of $4.45 \pm 0.12\%$ (P) to $46.26 \pm 1.52\%$ (K). Similar plant growth parameters were observed with BA-vermicompost at 7.0% NPK (T_3) and commercial control media compared with low or higher BA-vermicompost-containing media. Likewise, chlorophyll contents were significantly higher in control and T_3 treatments; only plants on T_4 indicated chlorosis symptoms caused by pH and nutrient imbalance. The combined BA-vermicompost and HH improved the inflorescence trend, similar to the control. Therefore, recycling these wastes as nutrient-rich growing media for bedding flowers is appropriate for horticultural sustainability.

Keywords Biomass ash · Vermicompost · Hazelnut husk · Growing media · Impatiens

Introduction

The process of energy production from a wide variety of biomass is considered as a zero CO_2 impact due to the emissions produced during its utilization counteract the carbon dioxide fixed in the biomass during its growth. On the other hand, the direct incineration of biomass in power plants generates a substantial amount of biomass ash. The beneficial utilization of these wastes is limited, although the biomass ashes are rich in plant nutrients (Leng et al. 2019). Because of alkaline (e.g., pH ≥ 13) nature, spreading biomass ash directly on soil may cause toxic effects on microorganisms and plants, increase pH, and deteriorate physical properties (Turp et al. 2021). The alkali nature of biomass ashes lowers the nutrient bioavailability of plants and causes nutrient imbalance (Ozdemir and Demir 2021). In this context, vermicomposting could be a very useful and practical technology for biomass ash management due to increased environmental and economic benefits (Turp et al. 2021), for transforming combustion ash into nutrient-rich compost for horticultural use.

Finite availability of primarily plant nutrients, waste management and resource conservation concern made recovery of plant nutrients from alternative waste sources an increasingly attractive option in the recent decade (Ahmed et al. 2019; Semerci et al. 2019). Some national regulation, such as Turkey, allows the use of biomass ashes in a vermicomposting process to obtain a final concentration of 7.0% NPK in compost for organic agriculture. Making ash into vermicompost and their recycling in the potting substrate could be a sustainable choice to provide suitable disposal solutions and produce value-added fertilizer products. Compared to the various chemical nutrient

Editorial responsibility: Samareh Mirkia.

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Published online: 24 August 2024

recovering methods, vermicomposting offers an affordable and natural solution strategy for the biomass ash into the bioavailable nutrient resource. One of the advantages of composting biomass ash is that compost made from nutrient-rich material enriches the compost made from nutrient poor but carbon-rich feedstock (Pasquali et al. 2018). Moreover, composting biomass ash can slow down the release rate of nutrients and ensure high nutrient use efficiency (Dede et al. 2023). However, there is a knowledge gap about the influence of vermicomposting on the bioavailability of nutrients in biomass ash during the plant development period.

Bedding flowers are produced primarily for their abundant and long-lasting flowers; thus, the plant species, inflorescence duration, and the quality of flowers are essential economic goals for floriculturists (Dede et al. 2010; Zulfiqar et al. 2019). Impatiens species (*Impatiens wallerana*) are herbaceous flowering perennials, usually grown at a partly shady location for creating a focal point in parks and gardening. Impatiens hybrids are now famous garden and container plants worldwide due to the prolific bloomer at any time in a variety of colors. Hence, nutrient-rich growing media, especially nitrogen, phosphorus, and micronutrients, are vital components required for supporting an extended blooming period in bedding conditions (Dede et al. 2006). However, adding these nutrients via fertilizer application often elicits diverse developmental responses, flowering interruptions, and environmental and economic consequences due to the requirement of frequent fertilizer applications (Chavez et al. 2008). Therefore, regular nutrient supply, particularly during the blooming period, remains a crucial factor for influencing plant growth and inducing flower bud formation, the occurrence of flowering, and plant health (Nambuthiri et al. 2015). In this context sustaining the prolonged flowering potential through modern crop management technologies and innovative growing media management practices has been regarded as essential to overcome the burden of ensuring sufficient nutrient supply with less environmental impact (Havardi-Burger et al. 2020).

Potting media produced from renewable organic waste resources have a vital role in crop fertilization and returning nutrients into the plant production cycle. Furthermore, the physical and chemical properties of growing media ingredients play an essential role in the success of nutrient retention and bioavailability and consequently in plant growth and flowering of ornamentals (Dede et al. 2010). Peat moss and coconut coir are the two most widely used substrates for bedding flower production, and they account for a significant portion of the material used to grow potted plants (Gruda 2019). Besides being predominant components of potting mixture, peat moss and coconut coir are poor in nutrients and need replenishment of depleting nutrients by frequent fertilizer application (Andiru et al. 2013). On the other hand, instead of commercially expensive and nutrient-poor peat and coconut coir growing media, alternatively, nutrient-rich, waste-derived potting mix can potentially be environmentally sustainable and low-cost components for developing appropriate growing media for flowering plants (Dede and Ozdemir 2018).

Vermicompost is a high-quality organic nutrient resource and is very useful as a growing medium component for enriching the potting soil. Moreover, vermicompost is high in microbial enzymes (Turp et al. 2023), humified materials, and surface functional groups (Ozdemir et al. 2019), which regulate the end product's physical and chemical properties and fortified nutrient availability attributes. According to Hashemimajd et al. (2004) vermicast contains plant nutrients essential for plant growth, thus minimizing the application of chemical fertilizers. The release of macro (N, P, K) and micro (Fe, Zn, Cu) nutrients from vermicompost is gradual as the continuous breakdown and decomposition of organic matter makes the nutrients available for plants (Ma et al. 2022).

Growing media's structural and nutritional properties affect the vegetative growth and blooming of potted impatiens (Zawadzinska and Salachna 2014). Furthermore, the flowering potential of potted flowers is greatly influenced by medium components in the mixture (Chen et al. 2004; Dede et al. 2010). Therefore, the correct combination of growing media to optimize plant growth is crucial for flowering plants. So far, researchers have tested numerous renewable materials such as crop residues, forestry by-products, animal manure, municipal waste composts, and biomass char as structural and nutritional ingredients for bedding flowers (Gruda 2019; Zulfiqar et al. 2019). Many previous studies have reported the positive effect of using nutrient-rich organic waste substrates in ornamental nurseries, bedding plants, and turf cultivation (Andiru et al. 2013; Dede and Ozdemir 2015; Vandecasteele et al. 2018). Nutrient-rich materials in growing media components generally positively affect growth indices and uptake macronutrients by the plant (Dede et al. 2006; Ozdemir et al. 2017). Tang et al. (2016) used garden wastes compost and spent mushroom compost as an alternative to peat to cultivate New Guinea impatiens and suggested that nutrient-rich compost can be replaced with peat for better root and shoot growth. Similarly, Grigatti et al. (2007) reported the positive effects of nutrient-rich sewage sludge compost on bedding flower species marigold, sage, and begonia when replaced with peat at 25 and 50%.

Agro-industrial and municipal organic wastes and nutrient-rich residues from various organic sources have been strongly recommended as renewable resources in the potting mixture. Because production and fertilization of ornamentals consume an increased amount of agrochemical inputs, using waste materials for potting soil could maximize recycling of the locally available materials and minimize waste accumulation (Ozdemir et al. 2017). Among the ornamental species, impatiens are considered responsive to nutrient application and best for testing nutrient-rich growing media under container-grown conditions. There are relatively few studies that have been reported on the nutrient-rich growing media, particularly the use of biomass power plant ash as a nutrient source for bedding plants (Gruda

2019; Zulfiqar et al. 2019). To the best of the authors' knowledge, reports on the vermicomposting of biomass power plant ash and recycling via potting media for the ornamental industry are still limited. Considering the literature gap on this subject, a hypothesis was defined to investigate the nutrient enrichment potential of vermicompost by adding biomass ash and recycling of final product in substrate preparation for bedding flowers. Accordingly, keeping in view the physicochemical composition and nutritional status of growing media, the specific objectives of the present study were (a) to test the nutritional potential of biomass ash, (b) to explore the growth of bedding flower and, (c) to evaluate the nutritional sufficiency of growing media for flowering properties. This approach is novel and an efficient strategy for waste management, and results indicate various benefits for sustainable management of biomass ash through the vermicomposting method.

Materials and methods

Growing media materials

Intensive ornamental cultivation is carried out in Sakarya province, Turkey, and this industry needs 30,000 m^{-3} potting media per year. Similarly, hazelnut production is dominated in the region, and a large amount of husk residue is produced after harvest. The biomass power plant in the area also generates ash that needs proper disposal. Several vermicomposting companies in the region make worm casts mainly using cattle manure. Therefore, in the frame of this study, locally available hazelnut husk, biomass ash, and vermicompost were selected to develop nutrient-rich growing media for bedding ornamentals. Naturally decomposed hazelnut husk residue was collected from the dumping site (with latitude 41°03′31″ north, longitude 30°20′31″ east, and elevation 60 m above sea level) at Sakarya province, Turkey. The decomposed hazelnut husk samples were air-dried and crushed by a hammer mill to obtain a particle size between 0 and 4 mm before use in substrate mixtures. The scanning electron microscopic (SEM) and energy dispersive X-ray spectroscopic (EDS) analyses were performed using the FEI Quanta model FEG 250 instrument (FEI Netherlands) to describe the surface characteristics and elemental composition of the particles (Figs. 1, 2).

Chemical properties of cattle manure and biomass ash were determined prior to vermicompost (Table 1). Turkish compost regulation set the total value of 7% for the sum of N, P, and K in vermicompost (Official Gazette 2018). Based on this regulation, the calculated amount of biomass ash was incorporated homogeneously into raw cattle manure to obtain the final NPK content of 3.5, 7.0, and 10.0% in compost samples. Standard vermicompost without containing BA also tested. The ash mixed cattle manure samples were initially pre-composted for 21 days by turning to eliminate the volatile and other toxic substances to earthworms (Ozdemir et al. 2019). After that, the mixtures were filled in open rectangular boxes (length 50, width 34, depth 30 cm), and epigeic (surface living) earthworm at ten worm kg^{-1} material was introduced to each box to allow vermicomposting. The boxes were started with 3 kg of feed consisting of each treatment and the same amount of material added on top of the surface at weekly intervals. The vermicomposting materials under each treatment were incubated under ambient room temperature and moist conditions by surface water spraying in a dark place. The vermicomposting was performed for 60 d to obtain mature compost (Ozdemir et al. 2019). The finished samples were used to prepare the growing media presented in Table 2.

Treatments and experimental design

A completely randomized experiment was conducted to evaluate the impact of growth media on bedding flower impatiens (*Impatiens wallerana* Hook.f.). Hazelnut husk

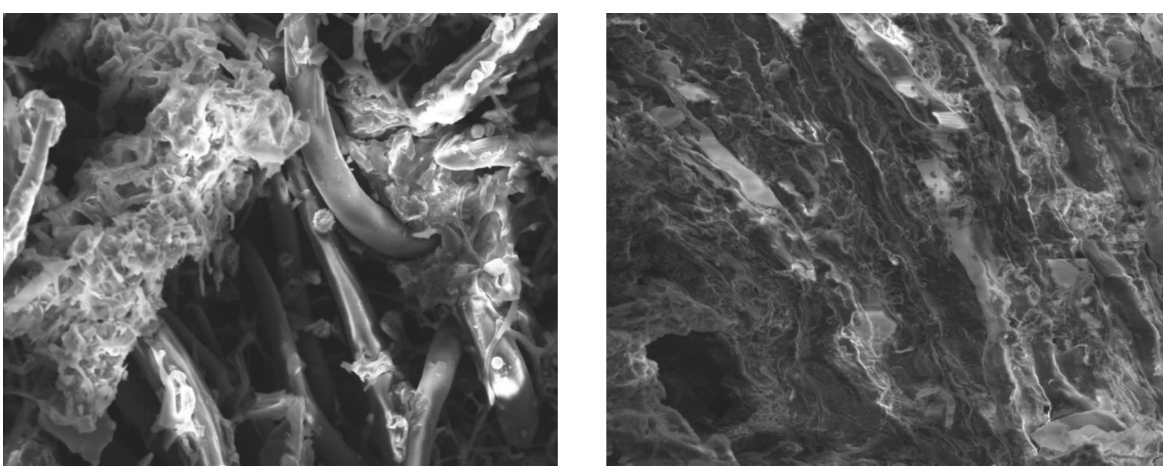


Fig. 1 SEM images of hazelnut husk (left column) and biomass ash vermicompost samples (right column)

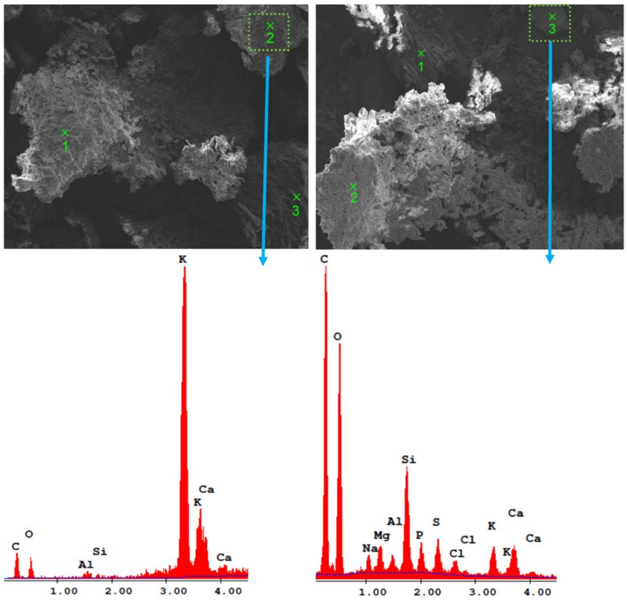


Fig. 2 EDS analysis of hazelnut husk and fermented manure samples, and elemental compositions of their selected spectrum

Table 1 Physicochemical properties of hazelnut husk, cattle manure and biomass ash

Parameters	Hazelnut husk	Cattle manure	Biomass ash
Organic matter (%)	86.15 ± 1.34	67.30 ± 1.83	1.82 ± 0.01
Ash (%)	13.85 ± 0.66	32.82 ± 2.51	98.18 ± 0.04
pH	6.87 ± 0.12	6.84 ± 0.11	13.04 ± 0.23
EC (mS/cm)	2.02 ± 0.03	3.81 ± 0.06	7.74 ± 0.08
N (%)	0.82 ± 0.03	1.46 ± 0.09	ND
P_2O_5 (%)	1.12 ± 0.31	0.12 ± 0.01	16.9 ± 0.31
K_2O (%)	5.68 ± 0.74	0.07 ± 0.00	13.6 ± 0.27
Fe (mg kg^{-1})	16.27 ± 0.83	58.43 ± 1.04	1.6 ± 0.07
Ca (mg kg^{-1})	1.02 ± 0.05	2.79 ± 0.08	22.5 ± 0.14

and biomass ash vermicompost treatments were incorporated into hazelnut husk at a ratio of 1:1 on a volume basis to prepare the growing media presented in Table 2. A commercial coco peat based medium was used as a control. Three replicates containing six pots each replicate were used for each treatment, and these were laid in a completely randomized design.

Plant growth conditions

The same heights of impatiens plugs removed from the pyramidal plug tray were transplanted into 10.5 cm diameter (955 ml) round pots filled with test treatments. The control treatment substrate was amended with 2.5 kg·m^{-3} controlled-release fertilizer (20N–5P–8K with a 90-d release period) to ensure equal plant growth during the experimental period. Prepared substrates were filled in containers, and pots were placed into 6-pocket shuttle trays for one replication. One tray of each treatment type was placed adjacent to the bench to create a randomized experimental unit.

Plants were irrigated daily with tap water to field capacity, avoiding excess leaching from the pot. The overhead drip irrigation system was used to irrigate each pot simultaneously in a shuttle tray. Experimental data were collected during eight weeks of the maximum blooming period. Plants were grown in ambient climatic conditions with retractable shade curtains. The average daily air temperature fluctuated between 27.2 to 33.8 °C, and the average daylight was ≈14 h.

Plant growth measurements

The number of flowers per plant was recorded daily. Plant growth data were collected eight weeks after transplanting. The plant height was measured from the substrate to the tallest growing point. Plant stem diameter was measured using a digital caliper (Asimeto, AS-307-06-04, Hong Kong). The growth index was estimated for each treatment using the formula;

$$\text{Growth Index} = (\text{plant height} + \text{shoot diameter})/2 \quad (1)$$

Shoots from the substrate level were removed, and the harvested shoots were dried at 70 °C until the constant weight to estimate plant dry weight.

Analytical methods

The essential physical properties of the growing media; bulk density, total pore space, water holding capacity, and organic matter content; were measured at the start of the experiment using the gravitational drainage technique and

Table 2 Some physico-chemical properties of growing media prepared from hazelnut husk (HH), vermicompost (VC) produced by increasing rate of biomass ash (BA), compared to the commercial coco peat based control media

Treatment	OM (%)	N (%)	P (mg/kg)	K (mg/kg)	C/N ratio	pH	EC (dS/m)
Control (T_0)	84.24	0.37	0.95	1.05	38.56	6.84	0.97
HH + $VCBA_0$ (T_1)	77.65	1.41	0.62	0.47	42.02	6.71	2.65
HH + $VCBA_1$ (T_2)	73.09	1.38	0.75	0.68	44.13	7.72	2.87
HH + $VCBA_3$ (T_3)	69.12	1.40	1.42	0.92	43.64	7.96	3.56
HH + $VCBA_4$ (T_4)	65.38	1.39	1.68	1.34	44.42	8.14	4.32
p value	0.024	0.008	0.015	0.023	0.004	0.035	0.041

loss on ignition technique at 550 °C, respectively that briefly described by Dede et al. (2017).

The initial chemical properties of substrates were measured. The sub-substrate samples were dried at 70 °C until reaching a constant weight and were grounded and sieved with a 2-mm mesh size before being subjected to any chemical analysis. pH and electrical conductivity (EC) of samples were measured at a solid: water ratio of 1:10 (w/v) by using a pH meter (Schott CG 840, The Netherlands) and EC electrode (HACH, HQ14D, US). Nitrogen (N) was determined based on the Kjeldahl procedure (Dede et al. 2017). Plant available P was measured by spectrophotometric methods after extraction with 0.5 M $NaHCO_3$ (pH 8.5), and potassium (K) was measured using ICP-OES (Spectro Arcos, Kleve, Germany) by employing the ammonium acetate procedure (Dede et al. 2017). Table 2 shows some chemical properties of the used media.

At the complete flowering stage, the leaf chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (t-Chl), and carotenoid content were determined by the Lichtenthaler reference method using a spectrophotometer (Shimadzu UV-3000, Japan) as described by Turp et al. (2021).

Statistical analysis

Data from growing media and plant experiments were analyzed using a completely randomized design model with Statgraphics Centurion version XVI (Statpoint technologies Inc., Warrenton, VA, USA. Normality of residual, equality of variance, and sphericity of assumption were tested, and appropriate transformation and correction were made if necessary, with the skewed method. Mean separation was performed at $p < 0.05$, using the Least Significant Difference (LSD) test at $p \leq 0.05$.

Results and discussion

Growing media properties

Structural suitability, physical reliability and biological stability of potting substrate ingredients are vital for provision of good quality horticultural plants since these properties cannot be amended during cultivation in container (Mendoza-Hernández et al. 2014). The SEM images of both growing media components; hazelnut husk and vermicompost in different magnification (Fig. 1) indicated porous structure which is necessary for satisfactory air–water retention entire cultivation period. A SEM images shows different surface properties of individual particles between the two components. Hazelnut husk shows a considerably rougher and porous structure of the surface than for the vermicompost samples. The SEM images of vermicompost particle have a smoother compared to the HH particles. This can be explained by a very nature of organic matter (Aşkın and Aygün, 2018) and expected to contribute positive porosity distribution and nutrient retention capacity of ornamental substrates (Gruda 2019).

The cattle manure was successfully vermicompost by epigeic earth worm, no worm mortality was observed by increasing dose of power plant ash into the cattle manure. As a better indicator of vermicomposting, the C:N ratios of the vermicompost samples were lower than the before vermicomposting for all treatments. Organic carbon decomposition during vermicomposting as a CO_2 lost and, N increase relative to the C could be reason for alleviated C:N ratio in finished compost. On the other hand, biomass ash addition did not significantly effect on C:N ratio. In contrast, the pH was higher in the samples that received higher dose of ash, probably due to the fact that a higher pH of power plant ash (Table 2) and alkali nutrients such as K, P and Ca as indicated (Table 1). However, a decrease of pH was observed during for pre-fermentation and for the 5 weeks of vermicomposting, yet pH was significantly higher ($p < 0.05$) in samples that received higher dose of ash. The results further indicated that fermented cattle manure provided a better substrate component for the power plant ash that extreme pH and EC were improved during the vermicomposting. The alleviation pH may be attributed to the bioconversion of the excess nutrients into organic material and various intermediate types of organic acid or higher mineralization of the pH and EC producing minerals such as P, K, Ca that's dominated in power plant ash.

Biomass ash, cattle manure and hazelnut husk are all byproduct of the agricultural waste. In all form of these material is generally rich in plant nutrients (Table 1), thereby being utilized as fertilizers. In the present study the possible use of their combination was evaluated to produce growing media for bedding ornamentals. Addition of BA to cattle manure improved the nutritional properties of vermicompost without hastening vermicomposting process and final physicochemical properties intended for as a growing media utilization. The BA application rate to create a 7.0% NPK vermicompost performed better final OM, pH and EC properties than 10.0% NKP treatment. This may be due to the promotion of microbial activity by providing organic carbon by cattle manure and less pH effect (Turp et al. 2021), thus releasing nutrients provided by BA.

Nutrient bioavailability during plant growth

The bioavailability of plant nutrients of prepared growing media and the coco peat control are monitored weekly during growing period and selected nutrients are presented in Fig. 3. The concentrations of C and N in the biomass ash were significantly lower ($p < 0.05$) than in the cattle manure. However, the biomass ash had higher main plant nutrients of P and K ($p < 0.05$) concentrations than the cattle manure.

Therefore, the amounts of P and K were significantly increased ($p < 0.05$) in vermicompost by adding biomass ash in a pre-composted cattle manure.

Composted materials do not provide all necessary plant nutrients well alone. In most cases, additional plant nutrients are needed to overcome nutrient deficiency and boost flowering (Andiru et al. 2013). Therefore, nutrient-rich grooving media acting slow-release fertilizer could overpass the above requirements and equalize mineral deficiencies. The use of BA in vermicompost at increasing ratios with HH increased all investigated nutrients except nitrogen. On the other hand, BA in vermicompost significantly raised pH for all the growing media (Table 2). Hence, the bioavailability of all nutrients is low at each increasing BA rates (Fig. 3). The bioavailable fraction of nutrients was in the range of 4.45 ± 0.12% (P) to 46.26 ± 1.52% (K). The decrease in P can be attributed to the high BA pH since P indicates high reactivity to many minerals, mainly phosphates (Semerci et al. 2019). The low bioavailable form observed for P, Fe, and Ca can be further attributable to the fact that P form moderately labile Fe–P and Ca-P depending on pH variation (Turp et al. 2021). On the other hand, during the study, it was found that the percentage of bioavailable fraction in all growing media was steady stable for the entire growing period for almost all investigated nutrients (Fig. 3). Benefits in plant growth because of an arrangement in substrate pH were reported before (Akintoye et al. 2013). In the present study, substrate pH decreased in all BA vermicompost treatments during the experiments. The decrease in pH from 8.07 to 7.54 in the current study may have induced nutrient release as well as the dilution effects of plant uptake from

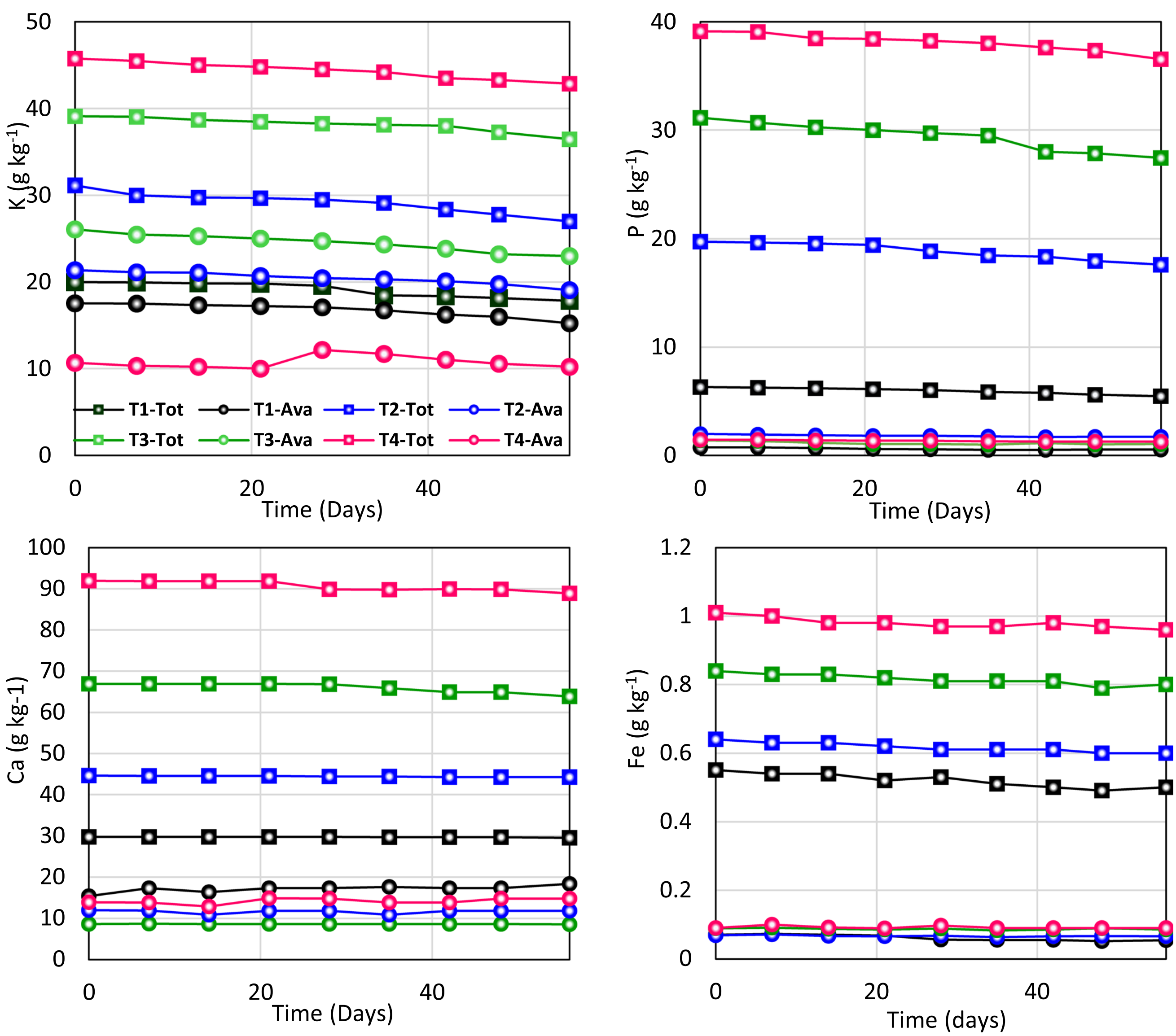


Fig. 3 Concentration of total and available nutrients in BA-vermicompost added growing media during experimental period

substrate solution. Moreover, the availability of nutrients in the rhizosphere may be stimulated by the presence of root exudates and decomposition products of organic matter, which comprises organic acids and reversible labile fractions (Turp et al. 2021). The results further suggest that BA-vermicompost nutrients can act as slow nutrient fertilizers and minimize the ecological risks of nutrient leaching.

The biomass ash P is considered as one of the major nutrients, and its dynamics during vermicomposting and crop growth have been the subjects of previous studies (Vandecasteele et al. 2018; Zhang et al. 2018). Generally, P release from ash is mainly related to the pH changes induced by various biochemical reactions (Turp et al. 2023). In the present study, the highest bioavailable P content was found in the T_1, which has the lowest amount of ash and thus it has the lowest pH during the experimental period. The relatively low pH in T_3 compared to the T_4 may lead to the bioavailability of nutrients from BA used in combination with cattle manure and HH. The combination of BA with the bio-waste may be a source of protons (H^+) and lead to a decrease in pH, thus causing the release of nutrients from BA (Turp et al. 2021). Additionally, structural chemistry of both hazelnut husk medium and vermicompost samples showed the carbon, hydrogen, oxygen, and nitrogen (Fig. 2), which expected the presence of corresponding functional groups such as aliphatic C-H, aromatic C = C, C = C alkene bond, C = O bond, and O–H / N–H stretch (Ozdemir et al. 2019) that regulating the nutrient bioavailability during the vegetation period.

Plant growth parameters

The nutrient-rich growing media positively impacted plant growth parameters such as plant height and stem diameter when biomass ash in vermicompost was increased from 0 to 7% in tested growing media. The biomass ash used in growing media also significantly affected the index values estimated using plant height and stem diameter ($p < 0.01$). The plants cultivated in the T_3 containing 7.0% NPK medium had the most significant plant height, stem diameter, and total shoot biomass, followed by the commercial medium control, and the plants are grown on 10.0% NPK medium. On the contrary, the shoot biomass was the lowest on the growing medium made with HH and vermicompost that did not contain BA and fertilizer. Accordingly, a great influence was found on growth index values that comprehensively indicate growth parameters in plant height, stem diameter, and dry biomass per plant (Fig. 4). The highest index values occurred in plants grown in T_3 medium, followed by commercial substrate control and T_4. Relatively low nutrients containing T_1 and T_2 medium produced the lowest growth index. Higher NPK concentration in growing media was positively correlated with plant height, stem diameter, and growth index (r = 0.623, 0.425, and 0.617, respectively).

Previous studies report that the growth parameters of both impatiens species and other bedding flowers are significantly improved by NPK fertilizer application (Uleanu and Oprea 2017) or nutrient-rich composted materials (Dede et al. 2010). The present study results are in accordance with Chen et al. (2004) and Mendoza-Hernández et al. (2014). Also, Chavez et al. (2008) found that the application of highly fertigation solutions to impatiens plants reduced the plant growth parameters and growing media quality. These findings are by the present study results that tested plant species and gave the best plant growth parameters in media containing mild amounts of BA nutrients (7.0% NPK). An increasing amount of BA or its nutrients in vermicompost did not support the vegetative growth of impatiens.

The addition of biomass ash significantly affects both vermicompost and, later on, growing media mixed with BA-vermicompost. BA addition increased the total amount of main fertilizer nutrients (N, P, K) in treatment groups and bioavailable fractions depending on pH and mineralization rate. Therefore, the difference in plant growth parameters could be attributed to the addition rate of the BA into the cattle manures, which resulted in a differential pattern of uptake of the nutrient. We observed a decrease in substrate pH during the plant growth period in all BA-vermicompost blended growing media. The initial high substrate pH might be attributable to higher ranges of oxides and hydroxides in ash. The buffering capacity in higher BA-vermicompost treatment (T_4) might not be sufficient to decrease medium pH, thereby alleviating nutrient uptake that supports plant growth. Additionally, a higher rate of BA application reduced the N concentration of growing media, which might be responsible for reduced growth parameters in T_4 treatment (Dede et al. 2006).

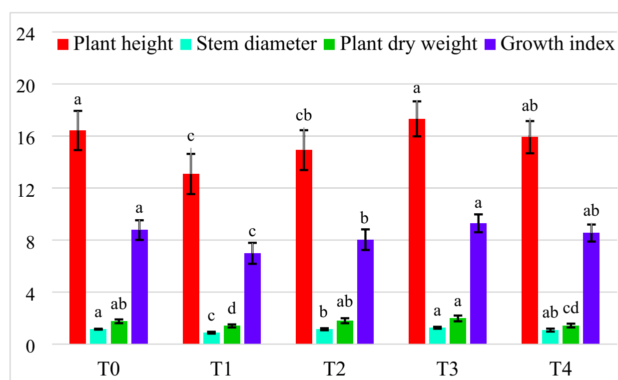


Fig. 4 Difference in plant growth parameters of Impatiens walleriana grown in nutrient-rich growing media (T1 to T4) compared to the commercial coco peat control. Data are presented as means ± standard deviations (SD) as bar plots. Treatments followed by different letters are significantly different at $p < 0.05$

Flowering trends

Flower number per plant presented in Fig. 3 revealed that flowering per plant trend showed a linearly increasing trend during the initial three weeks due to rapid active plant in all treatments. Then, the flower number per plant reached a plateau and fluctuated at the end of the experiment. The differences in flowering trends were significant among the different growing media. Plants grown in T_3 and T_2 showed an improved flowering trend and were significantly similar to the fertilizer control treatment. It is clear from the flower number per plant presented in Fig. 5 that high rates of biomass ash in vermicompost (T_4) significantly reduced inflorescence parameters compared to fertilizer control. Likewise, the flowering trend in T_1 (without BA amendment) was similar to that of T_4. In this respect, Uleanu and Oprea, (2017) reported that the application of NPK to peat base media increased the number of flowers in different impatiens species. Similar results were obtained by Dede et al. (2006) on impatiens plants when nutrient-rich compost had applied. The improved flowering trend observed in nutrient-rich treatment both from commercial fertilizer and provided by BA-vermicompost may be due to improving the plant growth such as plant height, stem diameter, and dry mass, as shown in Fig. 3, which led to an increase in the growth index that is important to initiate flowering buds.

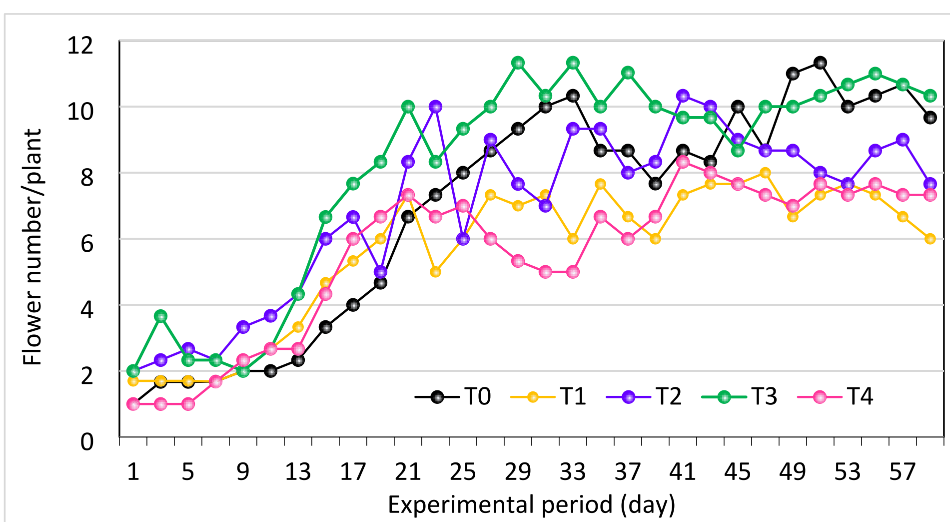
At the experiment completion, no deficiencies or accumulation/toxicities of minerals have been identified macroscopically on the plants, owing to the well-balanced fertigation that corrected possible nutrient imbalances except, T_4. It was proved that, nutrients from BA-vermicompost support plant growth, since treatment T_3 (7.0% NPK) had showed abundant and long lasting inflorescence similar to the commercial substrate (T_0). Dede et al. (2006) found that nutrient rich poultry manure and sewage sludge compost increased flower number and duration of abundant inflorescence in impatiens. Similar to the present study, Akintoye et al. (2013) showed that nutrient rich growing media component is essential for plant growth parameters and sustain flower production for a good length of time in begonia.

Leaf chlorophyll contents

Chlorophyll content results presented in Fig. 6. clearly showed that, chl *a*, chl *b* and total chlorophyll were significantly affected by increasing amount of BA-vermicompost in different growing media. Impatiens plants grown in T_3 treatment recorded the highest values of chlorophyll content and, followed by T_2, T_1 and control, respectively. Treatment T_4 (highest dose of BA) gave less chlorophyll content. The relatively high chlorophyll content in T_3 apparently indicates the positive contribution of BA nutrients and vermicompost effects on improvement of essential plant nutrients such as N, P, K and others. Contrary, the low chlorophyll content in T_4 may be attributed to high pH of medium that reduced the nutrient availability, consequently reduced the chlorophyll formation. The positive effect of BA nutrients rates was pronounced at 7.0% NPK in vermicompost followed by 3.5% NPK containing samples, respectively. The least values were observed in vermicompost containing the 10.0% NPK by biomass ash.

The chlorophyll contents of plants receiving BA at 7.0% NPK were similar to commercial growing media and higher than the rest of the treatments (Fig. 6), indicating higher plant growth due to the sufficient nutrient uptake. Because high chlorophyll contents are generally linked with higher photosynthetic activity, uptake of nutrients, and boosting the higher total biomass (Fig. 4) and flowering (Fig. 5). The visual inspection and chlorophyll results of the test plants show that only the highest dose of BA-vermicompost addition to

Fig. 5 Difference in number of flower per plant during the bloom period of Impatiens walleriana grown in nutrient-rich growing media (T1 to T4) compared to the commercial coco peat control



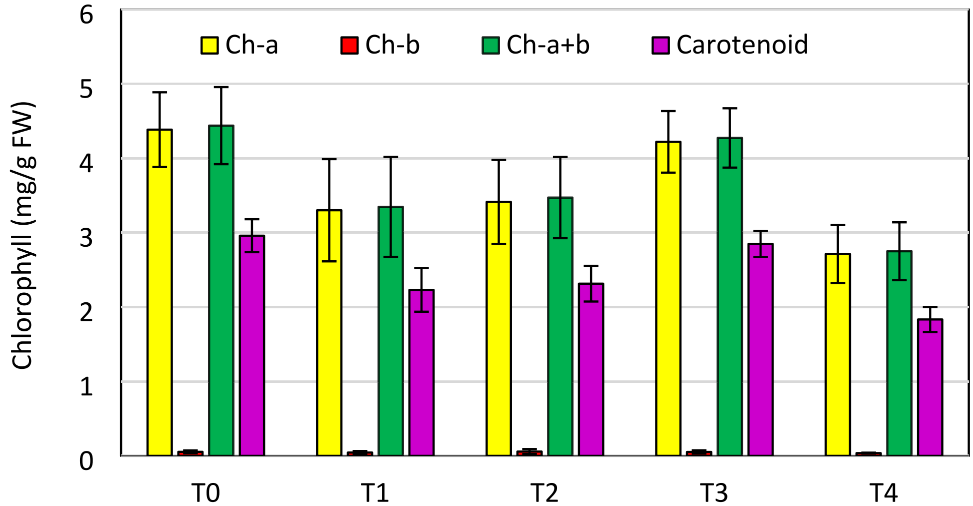


Fig. 6 Leaf chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid content, under varying levels of the BA-vermicompost (T2 to T4) compared to the unamended (T1) and fertilized control (T0) treatments (bar shows ± standard deviations)

HH growing media (1:1 v/v) indicated apparent symptoms of chlorosis on the leaves. Smith et al. (2004) confirm that increasing pH in growing media decreased the chlorophyll content in bedding flowers when dolomitic hydrated lime and fertilizer were used. They also noted a leaf chlorosis formation after two weeks at high pH (≥ 7) when sufficient fertilizer was applied with irrigation water. These results indicate the limiting factor for decreasing chlorophyll due to the pH rise above the tolerable range for impatiens. This result also agrees with those obtained by Caspersen and Bergstrand (2020), as they reported that increasing phosphorus application rates increased leaf chlorophyll contents in the chrysanthemum flower. Similarly, Park and Faust (2021) revealed that the leaf contents of chlorophyll showed a positive relationship with growing media nitrogen and phosphorus content in petunia. From a management perspective, the pH rise governed by biomass ash and the bioavailable nutrient fraction constraints needs to be controlled to maintain the visual quality and blooming of bedding plants.

Conclusion

The horticultural recycling of bio-based waste through vermicomposting is crucial for the circular economy, the promotion of a zero-waste policies, the reduction of the need for chemical fertilizers and the creation of a sustainable ornamental plant industry. The present study concludes that biomass ash vermicomposting study is very essential to link nutrient release and enrich vermicompost towards the sustainability of low-tech nutrient recycling programs. Recycling of biomass ash as a growing media for ornamental plants after vermicomposting has the ability of providing slow release nutrients that makes ornamental production system more reliable and sustainable. On the basis of vermicompost studies, we identified the potential impact of biomass ash on vermicomposting and nutrient bioavailability to aid nutrient release from biomass ash. Vermicompost containing 7.0% biomass ash NPK contained nitrogen (1.12%), available phosphorus (2.95%) and potassium (3.47%). According to the vermicompost and plant growth results, nutrient enrichment of vermicompost up to 7.0% has not negative effects on vermicomposting, and nutrient bioavailability, and BA-vermicompost has positive effects on bedding ornamental (*Impatiens walleriana*), which can support sufficient chlorophyll content, promote growth and hence increase flower number.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose. The authors have no conflicts of interest to declare that are relevant to the content of this article.

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