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Enhancing growth and flowering of petunia (*Petunia hybrida* L.) through the application of jujube biochar and vermicompost

Hassan Bayat[1,*], Mohammad Javad Vahidi[2] and Abdulghiyas Radan[1]

1, Department of Horticultural Sciences, Faculty of Agriculture, University of Birjand, Birjand, Iran
2, Department of Soil Science, Faculty of Agriculture, University of Birjand, Birjand, Iran

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***Corresponding author:**
Department of Horticultural Sciences, Faculty of Agriculture, University of Birjand, Birjand, Iran.

Email: hassanbayat@birjand.ac.ir, hassanbayat55@gmail.com

ABSTRACT

Purpose: This study investigates the enhancing growth and flowering traits of petunia (*Petunia hybrida* L.) through the application of biochar and vermicompost. **Research Method:** The experiment employed a completely randomized design with four replications in a greenhouse setting during the years of 2022-2023. The experimental treatments comprised the control group (without vermicompost and biochar), vermicompost at 5% by weight, jujube biochar at 2% by weight, or combination of vermicompost with biochar. **Findings:** Results revealed that the application of vermicompost significantly increased the dry weight of root, shoot, and total biomass by 23%, 51%, and 46%, respectively, compared to the control. Additionally, the vermicompost treatment yielded the highest number of leaves and plant height, while the biochar treatment resulted in the maximum number of flowers per plant. The durability of flowers on the plant varied, with biochar treatment exhibiting the highest durability (6.75 days) while control treatment gave the lowest durability (4.75 days). Biochar-treated plants also displayed the highest levels of total chlorophyll and relative water content in the leaves, exhibiting increases of 29% and 14%, respectively, compared to the control. Leaf nutrient content demonstrated significant changes, with the biochar + vermicompost treatment exhibiting the highest nitrogen and potassium content, demonstrating a 34% and 19% increase, respectively, compared to the control. **Research limitations:** No limitations were identified**. Originality/Value:** In summary, the findings underscore the positive influence of biochar and vermicompost fertilizers on the growth, ornamental features, and physiological characteristics of petunia. Notably, biochar demonstrated superior effectiveness in enhancing ornamental parameters compared to vermicompost. Biochar and vermicompost can be used as organic fertilizers to reduce the use of chemical fertilizers and increase the production and yield of petunia plant.

INTRODUCTION

The petunia (*Petunia hybrida* L.) plant is a perennial ornamental species belonging to the Solanaceae family (Sahu et al., 2023). Indigenous to South America, the petunia has gained widespread popularity as one of the most favored seasonal plants for urban green spaces, owing to its undemanding nature and ease of cultivation (Chen et al., 2017). Renowned for its aesthetically pleasing features, including a captivatingly beautiful form, flowers with vibrant colors, and extended flowering duration, the petunia holds a distinguished position among the world's finest plants (Keykha et al., 2016).

Nutrition management plays a crucial role in enhancing ornamental plants' yield and quality (Davoudi & Bayat, 2024). An optimal bed for these plants should possess attributes such as high water-holding capacity, proper ventilation, effective drainage, and the incorporation of organic matter. Utilizing organic fertilizers stands out as a key method to foster the growth and overall performance of ornamental plants, leading to the production of flowers with desirable quality. In soil fertility and quality, organic matter emerges as a paramount factor. Particularly in arid and semi-arid regions, the deficiency of organic matter is more pronounced. In such instances, farmers often prioritize using organic matter to augment crop production. This practice is especially prevalent in areas characterized by higher organic matter poverty (Zhang et al., 2020; Lachkar et al., 2021; Yan et al., 2022). Organic matter stands out as a pivotal factor influencing the fertility of agricultural land. Typically, intensive agricultural practices reliant on chemical fertilizers lead to a reduction in soil organic content, consequently diminishing the quality of agricultural products (Vahidi et al., 2022; Yan et al., 2022). Moreover, the excessive use of mineral fertilizers to boost crop production poses heightened risks to human health and contributes to environmental challenges, such as water and soil pollution (Suthar, 2021). Consequently, the adoption of organic fertilizers has been recognized as a viable solution to promote sustainable agriculture (Lehmann & Joseph, 2015; Jatuwong et al., 2024). Within the realm of sustainable agriculture, there has been a notable focus on the utilization of biochar and vermicompost as innovative alternatives to chemical fertilizers. These methods serve as sustainable modifiers to enhance soil fertility and reduce reliance on chemical fertilizers in agriculture (Mak-Mensah et al., 2021). Biochar, a product derived from the pyrolysis of natural organic materials in the absence or limited presence of oxygen, has demonstrated diverse mechanisms for improving plant growth. These include the augmentation and preservation of nutrients (You et al., 2021), enhanced availability of elements for plants (Xi et al., 2020), and alterations in the soil microbial population (Zheng et al., 2018). Additionally, biochar has been observed to enhance plant tolerance to abiotic stresses such as drought, salinity, and heat (Yoo et al., 2020; Liang et al., 2021; Fedeli et al., 2024). The distinctive properties of biochar position it as a valuable soil conditioner. It not only provides essential elements to plants but also contributes to the removal of mineral pollutants from water and soil, mitigating the adverse effects of heavy metals or pesticides (Du et al., 2021; Vahidi et al., 2023). Moreover, biochar plays a role in increasing carbon sequestration in the soil, reducing the release of greenhouse gases, and enhancing nutrient consumption efficiency, thereby promoting plant growth and performance (Ginebra et al., 2022; Bhatia et al., 2021). Similarly, vermicompost, as an organic fertilizer, exerts positive effects on the physical, chemical, and biological properties of the soil. Serving as a rich source of vitamins, essential and trace elements, growth-stimulating hormones, and enzymes, vermicompost enhances the soil microbial community, fostering nutrient absorption for sustainable plant growth in agriculture (Manzoor et al., 2024). In recent years, numerous studies have investigated the impact of biochar on soil fertility and the yield and quality of various crops, displaying its effectiveness across a range of plant species. Notable examples include its positive effects on lettuce (*Lactuca sativa* L.) (Jabborova et al., 2021), mullein (*Verbascum thapsus*) (Esfahani et al., 2023), and periwinkle (*Catharanthus roseus* L.) (Mohammadi Kabari et al., 2024). Similarly, vermicompost has demonstrated its ability to significantly enhance the growth and yield of diverse plant varieties, including cucumber (Piri & Rashki, 2019) and tomato (Zucco et al., 2015). A growing trend in agricultural research is the exploration of combined biochar and vermicompost applications to restore soil fertility, improve overall plant growth, and yield (EL-Mogy et al., 2024). Several studies have indicated that the simultaneous use of biochar and vermicompost positively influences the physicochemical and microbial properties of the soil, thereby contributing to increased plant growth and performance (Zhang et al., 2016; Lu et al., 2020). Notably, findings from Liu et al. (2022) demonstrate the positive impact of biochar and vermicompost on tomato yield. Additionally, research by Lin et al. (2015) reveals increased bean biomass and seed yield associated with the application of biochar and vermicompost.

The jujube plant, (*Ziziphus jujuba* Mill.), is indigenous to China and is found in various regions of Iran with a cultivated area spanning 3621 hectares and an annual production of 5460 tons of dry jujube; Iran ranks as the third-largest producer of this medicinal and important fruit tree after China and South Korea (Ebrahimi et al., 2022; Zeraatgar et al., 2019). This tree has gained significance in arid and semi-arid lands due to its remarkable resilience and adaptation to drought, as well as infertile and saline soil (Liu et al., 2022; Vahidi, 2020). Despite its agricultural importance, a substantial amount of pruned jujube foliage is annually discarded as waste without any specific or planned utilization in nature. Consequently, there is a pressing need to develop innovative methods for repurposing this waste (Vahidi et al., 2022). The waste, comprising jujube branches, leaves, and cores, can be immediately utilized as raw material for biochar production (Vahidi et al., 2022; Zhang et al., 2020). Biochar derived from jujube residues proves to be an effective and economical solution for enhancing soil properties, mitigating erosion, and managing waste (Vahidi et al., 2022; Al Wabel et al., 2021). The primary objective of incorporating biochar into soil is to facilitate the recycling of organic waste and improve soil conditions. Given the rich composition of both high and low-use nutrients in biochar and vermicompost, these fertilizers play a crucial role in enhancing plant growth and performance. Despite various studies on the subject, there is a notable absence of experiments exploring the impact of jujube biochar on the growth and performance of plants. Therefore, the focus of this study is to investigate the influence of jujube biochar and vermicompost on the growth, ornamental features, and physiological characteristics of the petunia plant.

MATERIALS AND METHODS

Plant material and treatments

This study seeks to examine the impact of biochar derived from the remnants of the jujube plant (*Ziziphus jujuba* Mill.) and vermicompost on the morphological, physiological, and biochemical traits of the petunia plant. The investigation was conducted using a completely randomized design with four replications in the research greenhouse of University of Birjand, Iran during the period 2022-2023. The experimental treatments comprised four groups: the control group (without the application of biochar or vermicompost), vermicompost at a 5% weight ratio, jujube biochar at a 2% weight ratio, or a combination of biochar at 2% with vermicompost at 5% by weight. Each replication involved four pots, each housing one petunia plant. The experiment utilized sixteen pots with a diameter and height of 14 cm. prior to use, the soil for the experiment underwent air drying and was subsequently sieved through a 2 mm mesh. The physical and chemical properties of the soil were then assessed using standard methods (Wilke, 2005) (Table 1).

Petunia seeds (*Petunia hybrida* L.) were sourced from Poponik Company in Tehran, Iran. The cultivation process began with the seeds being planted in 105-hole seedling trays, each with a diameter of 2.3 cm and a height of 5 cm. The trays contained a blend of cocopeat and peat in a 2:1 ratio. After 45 days of seed germination, individual seedlings at the 6-8 leaf stage were transplanted into separate pots. Throughout the experiment, irrigation was conducted twice a week, providing 250 ml of water per pot, tailored to the plant's specific needs. Subsequent to the seedling establishment (14 days after transplantation), key growth parameters, including the number of leaves and plant height, were measured at 10-day intervals. The comprehensive assessment of growth, reproductive, and physiological parameters took place at the conclusion of the experiment, 155 days post-seed sowing. The biochar utilized in the experiment was prepared using pruned leaves from the jujube tree. After air-drying, the leaves were crushed, and each sample was subjected to 24 hours of exposure in an oven at 105 degrees Celsius. Following this, the material was further crushed into smaller fragments. During the thermal decomposition inside the furnace, vapors were released, and a stainless metal container was employed to generate biochar. The furnace environment's oxygen was restricted with the use of a candle. The chopped jujube pieces were then subjected to a temperature of 300 degrees Celsius for 2 hours, resulting in the production of biochar. The final product was sieved through a 2 mm mesh. (Table 1) provides some physiochemical properties of the produced biochar. Additionally, (Table 1) presents selected chemical characteristics of the vermicompost used in the experiment.

Table 1. The physical and chemical properties of the soil and soil amendments.

	Initial Jujube	Jujube biochar	Vermicompost	Soil
Oxygen %	23.4	12.4	33.9	
pH	7.2	8.9	6.9	7.9
Saturation percentage (Sp)				27
EC (mmho/cm)	6.8	4.5	1.58	2.3
Carbon (%)			11.88	
Hydrogen(%)	7.2	3.4	4.22	
Nitrogen(%)	0.42	0.76	1.02	0.78
Phosphorous(%)	0.19	0.42	0.3	13.8
Calcium(%)	3.55	6.23	0.17	5.13
Potassium(%)	0.42	0.66		0.53
Magnesium(%)	0.06	0.17	0.06	2.53
Ca+Mg				8
C/N	125.48	92.37	11.64	
Organic carbon(%)	52.7	76.2		
Sodium(%)	0.06	0.12		
Bulk density	0.57	0.68	0.54	1.81
Biochar performance (%)		29		2.65
Ash biochar (%)		14.2		
Sand				76
Silt				18
Clay				6
Organic matter				0.2
Textural				Loamy Sand

Measurements

Arnon's approach involved the quantification of chlorophyll and carotenoid content (Arnon, 1949). The absorbance levels were then assessed at 470, 645, and 663 nm wavelengths using a spectrophotometer (Model Unico 2100, China).

Leaf relative water content (RWC) was determined according to Galmes et al (2007) method. Sampling involved collecting newly matured leaves, followed by the measurement of their fresh weight (FW). Subsequently, the samples were immersed in distilled water for 24 hours, and the saturated weight (SW) of the leaves was recorded. To determine the dry weight (DW), the samples were then subjected to an oven at a temperature of 70°C for 24 hours. The calculation of RWC was performed using the formula (1):

$$\mathrm{RWC} = \frac{(\mathrm{FW}-\mathrm{DW})}{(\mathrm{SW}-\mathrm{DW})} \times 100 \qquad (1)$$

To determine nitrogen, phosphorus, potassium, calcium, and magnesium concentrations, leaf samples collected during the flowering stage underwent a series of processes. After drying and pulverizing, phosphorus, potassium, calcium, and magnesium elements were digested using concentrated hydrochloric acid. Potassium concentration was measured using a Film photometer device (Model JENWAY-PFP7), and phosphorus concentration was determined with a spectrophotometer at a wavelength of 660 nm. Magnesium and calcium concentrations were assessed using the EDTA complexometric method. The detailed methodology, including specific procedures and equipment, follows protocols outlined by Jones (2005) for potassium, magnesium and calcium. Nitrogen content was determined using the Kjeldahl method, wherein 1 gram of plant sample and 6 grams of catalyst were placed into Kjeldahl digestion balloons. Subsequently, 15 ml of concentrated sulfuric acid (98%) was added. Following digestion and cooling, 100 ml of distilled water was introduced into each balloon. Erlenmeyer flasks were then prepared corresponding to the number of balloons, and 20 ml of reagent was added to each flask. Each balloon, accompanied by its dedicated flask, was positioned within the distillation apparatus. Upon completion of the distillation process, the solution in the flasks underwent titration with 0.05 normal sulfuric acid until a pink coloration emerged (Jones, 2005).

Data analysis

Data were subjected to analysis of variance (ANOVA) using the JMP 13 software (SAS Campus, Cary, NC, USA), and graphical representations were generated using Excel software. Mean comparisons were performed employing the Least Significant Difference (LSD) Test at a 5% probability level.

RESULTS

Growth and reproduction traits

The analysis of variance results indicated that the fertilizer treatments significantly influenced various growth and reproductive traits (Table 2). Comparing the average growth parameters (Table 2) revealed a 32% increase in leaf length with biochar application compared to the control. The highest number of branches was observed in the control, vermicompost, or biochar + vermicompost treatments, while the lowest value was observed in biochar treatment. The maximum stem diameter recorded in the biochar treatment, which showing a 28% increase compared to the control. Stem diameter was greater in the vermicompost or biochar treatments compared to control or biochar + vermicompost treatments. Root length values were highest in the control or biochar treatments, followed by vermicompost or biochar + vermicompost treatments, which exhibited the lowest root length values. Biochar application led to an 11% increase in root fresh weight. Plants treated with vermicompost showed the highest root dry weight, reflecting a 23% increase. The fresh weight of shoots was greatest in plants treated with biochar, indicating a 35% increase compared to the control. Aerial parts' dry weight in plants treated with vermicompost surpassed the control or vermicompost + biochar treatments, with the highest dry weight recorded in the vermicompost treatment, showing 51% increase. The total dry weight of plants treated with vermicompost or biochar exceeded that control or vermicompost + biochar treatments, with 46% increase in dry weight for the vermicompost treatment and 38% increase for the biochar treatment (Table 2). During the observation period for leaf number changes, plants treated with vermicompost exhibited more leaves than other treatments, followed by biochar or biochar + vermicompost treatments (Fig. 1). The trend in plant height changes indicated that plants treated with vermicompost were taller than other treatments, followed by biochar or control treatments (Fig. 2).

Table 2. Effects of vermicompost or jujube biochar or their combination on growth parameters of petunia (*Petunia hybrida* L.).

Treatment	Leaf width (cm)	Leaf length (cm)	Number of branch per plant	Stem diameter (mm)	Root length (cm)	Root fresh weight (g)	Root dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)	Total dry weight (g)
Control	3.22 a	6.55 b	5.25 a	3.66 b	30.25 a	29.02 a	2.49 b	67.68 c	6.41 b	8.91 b
Vermicompost	3.35 a	7.75 ab	5.00 a	4.31 a	22.25 b	27.89 a	3.07 a	78.58 b	9.96 a	13.03 a
Jujube biochar	3.17 a	8.67 a	3.00 b	4.70 a	28.00 a	32.17 a	2.64 b	91.79 a	9.69 a	12.34 a
Vermicompost+ Jujube biochar	3.12 a	7.37 ab	5.25 a	3.55 b	21.25 b	18.53 b	1.63 c	65.97 c	6.11 b	7.74 b
Significance level	ns	*	**	**	**	**	**	**	**	**

*, **, ns: Significance at %5 and %1 probability levels and non-significance, respectively. The LSD test indicates that there is no significant difference between the means in the columns that are followed by the same letter at P < 0.05.

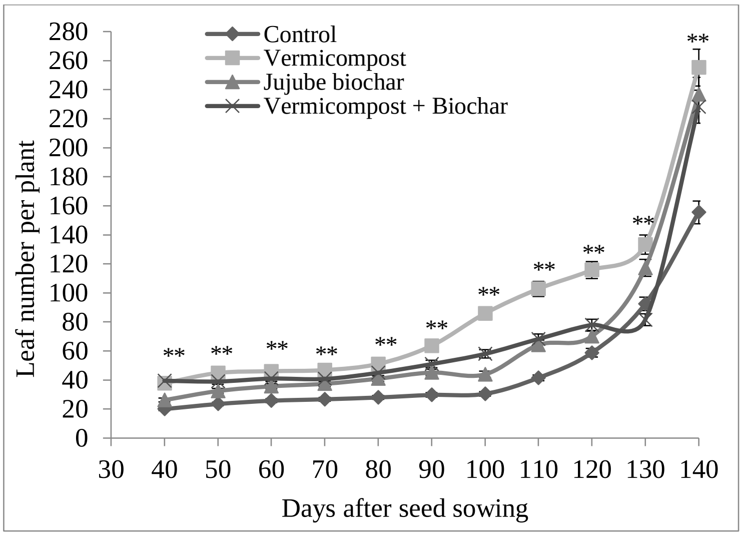

Fig. 1. Effects of vermicompost, jujube biochar or their combination on leaf number of petunia (*Petunia hybrida* L.) during the experiment period. **: Significance at %1 probability level.

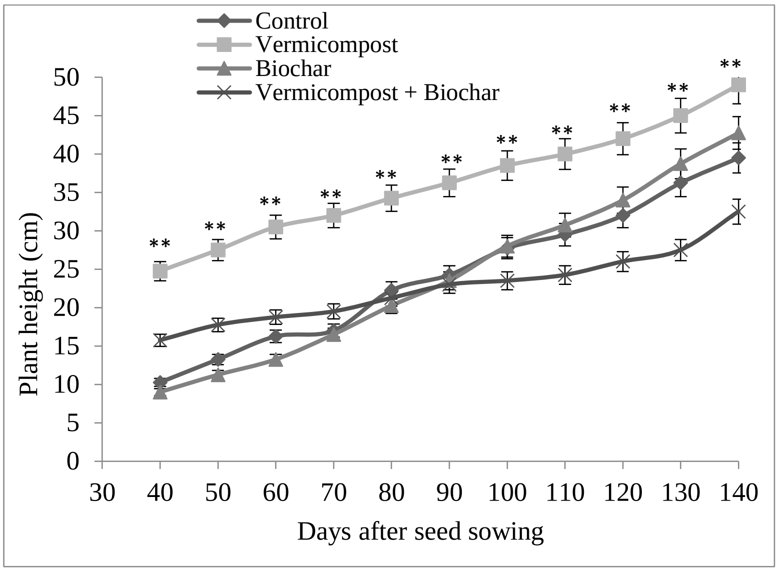

Fig. 2. Effects of vermicompost, jujube biochar or their combination on plant height of petunia (*Petunia hybrida* L.) during the experiment period. **: Significance at %1 probability level. Vertical bars indicate ± SE.

The results of the analysis of variance indicated that the flowering traits were statistically significant at a 1% probability level. The longest flower durability on the plant was observed in the biochar treatment (6.75 days), while the shortest was in the control treatment (4.75 days) (Fig. 3). Additionally, the highest (122 days) and lowest (104 days) number of days until flowering were recorded in the biochar and vermicompost treatments, respectively (Fig. 4). Investigation into the changes in the number of flowers revealed that the biochar treatment recorded the highest number, followed by vermicompost, control, or biochar + vermicompost treatments, respectively (Fig. 5).

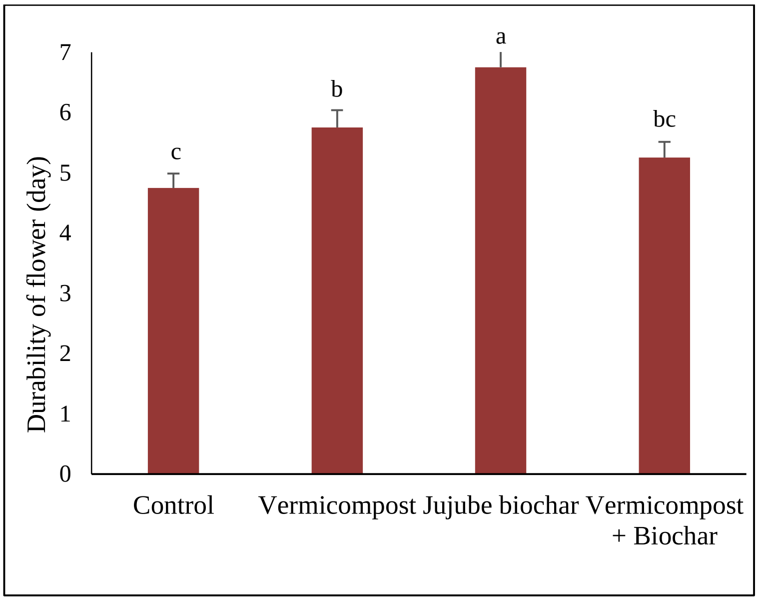

Fig. 3. Effects of vermicompost, jujube biochar or their combination on flower durability of petunia (*Petunia hybrida* L.). The LSD test indicates that there is no significant difference between the means in the columns that are followed by the same letter at P < 0.05. Vertical bars indicate ± SE.

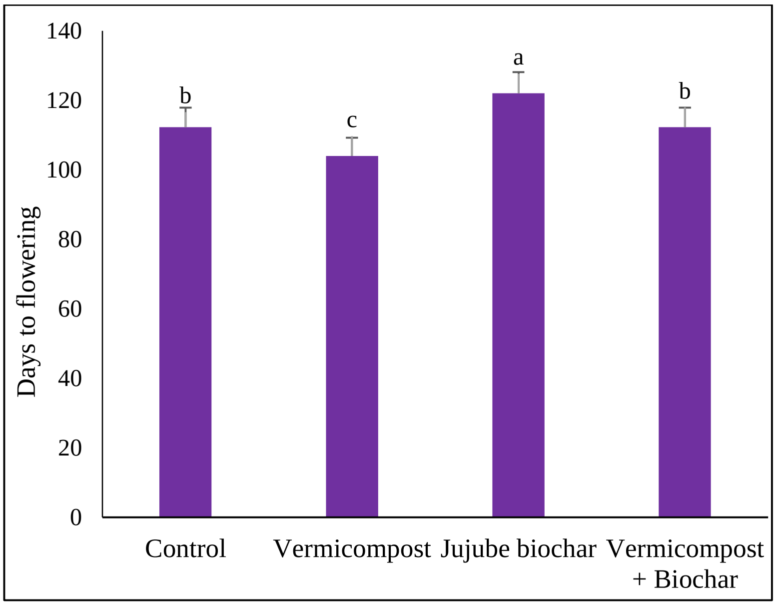

Fig. 4. Effects of vermicompost, jujube biochar or their combination on flower durability of petunia (*Petunia hybrida* L.). The LSD test indicates that there is no significant difference between the means in the columns that are followed by the same letter at $P < 0.05$. Vertical bars indicate ± SE.

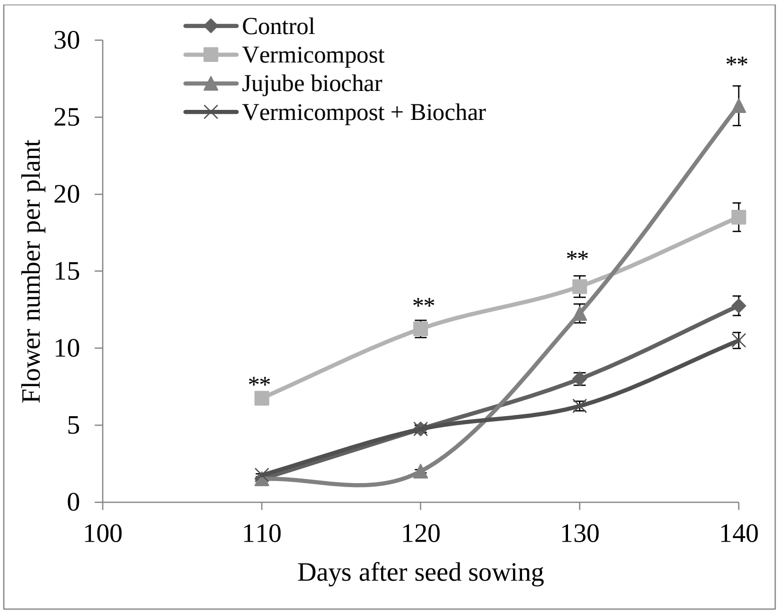

Fig. 5. Effects of vermicompost, jujube biochar or their combination on flower number per plant of petunia (*Petunia hybrida* L.) during the experiment period. **: Significance at %1 probability level. Vertical bars indicate ± SE.

Table 3. Effects of vermicompost, jujube biochar or their combination on chlorophylls, carotenoids, and relative water content (RWC) of petunia (*Petunia hybrida* L.).

Treatment	Chlorophyll a (mg. g FW^{-1})	Chlorophyll b (mg. g FW^{-1})	Total Chlorophylls (mg. g FW^{-1})	Carotenoids (mg. g FW^{-1})	RWC (%)
Control	0.63 b	0.21 b	0.84 b	0.19 b	73.01 c
Vermicompost	0.77 ab	0.29 a	1.06 a	0.28 a	80.75 b
Jujube biochar	0.82 a	0.26 a	1.09 a	0.24 a	87.52 a
Vermicompost+ Jujube biochar	0.44 c	0.19 b	0.63 c	0.14 c	71.05 c
Significance level	**	**	**	**	**

**: Significance at %1 probability level. The LSD test indicates that there is no significant difference between the means in the columns that are followed by the same letter at $P < 0.05$.

Table 4. Effects of vermicompost, jujube biochar or their combination on leaf nutrient content of petunia (*Petunia hybrida* L.).

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Control	2.49 c	0.27 b	4.25 b	1.62 a	0.34 c
Vermicompost	2.85 b	0.42 a	4.31 b	1.20 bc	0.63 b
Jujube Biochar	2.50 c	0.14 d	3.86 b	1.45 ab	0.42 c
Vermicompost+ Jujube biochar	3.36 a	0.21 c	5.07 a	1.17 c	0.79 a
Significance level	**	**	**	**	**

**: Significance at %1 probability level. The LSD test indicates that there is no significant difference between the means in the columns that are followed by the same letter at $P < 0.05$.

Physiological traits

The results of analysis variance for photosynthetic pigments exhibited statistical significance at the 1% probability level (Table 3). According to the average comparison results (Table 3), the biochar treatment yielded the highest chlorophyll content, surpassing the control by 30%. Similarly, plants treated with vermicompost showed the highest chlorophyll b content, representing a 38% increase. The biochar treatment also resulted in the highest total chlorophyll content, demonstrating a 29% increase. Carotenoid levels in plants treated with vermicompost or biochar surpassed those in the control or biochar + vermicompost treatments. Specifically, the highest carotenoid content was observed in the vermicompost treatment, indicating a 47% increase. The RWC in plants treated with biochar or vermicompost exceeded that of other treatments. Notably, the use of biochar led to a 14% increase in RWC (Table 3).

Nutrient elements

The results of the variance analysis regarding the impact of fertilizer treatments on leaf nutrient content were statistically significant at the 1% probability level (Table 4). According to the average comparison results (Table 4), plants treated with vermicompost + biochar exhibited the highest nitrogen content, representing a 34% increase. The application of vermicompost led to a 55% increase in phosphorus content. The highest potassium content was observed in plants treated with vermicompost + biochar, showing a 19% increase with respect to control. Regarding calcium content, plants treated with the control or biochar had significantly higher levels compared to other treatments. The highest magnesium content was recorded in the vermicompost + biochar treatment, showing an increase of 2.3 times with respect to control (Table 4).

DISCUSSION

The outcomes of this experiment demonstrate that treating petunia plants with jujube biochar or vermicompost enhances both vegetative and reproductive indicators. Previous studies support these findings, with research by Jabborova et al. (2021) noting significant improvements in plant height, leaf length, leaf number, and root length in lettuce treated with cherry biochar. Similarly, Zulfiqar et al. (2021) reported enhanced growth parameters in ginger plants (*Zingiber officinale*) following the application of wheat biochar. Additionally, Safari et al. (2023) found that a 10% weight application of rice husk biochar positively impacted the growth indicators of *Lolium perenne* L. The use of biochar or vermicompost, in addition to directly improving nutritional conditions by adding nutrients to the soil, has positive effects on the environmental conditions of plant growth and nutrition. These effects can also be indirectly facilitated through increasing soil porosity and promoting root growth. Consequently, they contribute to enhancing the growth and reproductive characteristics of plants, aiding in their overall development and expansion (Roy et al., 2022; Sahu et al., 2023; Safari et al., 2023). The benefits of biochar are not limited to petunia plants, as evidenced by the work of Reddy et al (2023), who reported that rice husk biochar improved the dry weight and ornamental parameters of African parsley (*Tagetes erecta* L). Likewise, Conversa et al. (2015) observed increased leaf and flower numbers in *Pelargonium zonale* L. with the use of *Abies alba* mill biochar. Furthermore, Goswami et al. (2017) found that vermicompost fertilizer significantly influenced the growth parameters of cabbage. It appears that due to the presence of essential nutrients, especially nitrogen, phosphorus, calcium, and trace elements, biochar plays a significant role in plant growth and flowering. Its ability to provide these nutrients, along with its improvement of soil conditions, leads to increased plant growth and development (Reddy et al., 2023). In various studies, vermicompost has shown positive effects on plant growth and flowering. Esfahani et al. (2023) reported increased reproductive parameters in the mullein (*Verbascum thapsus*) plant, while Kural & Coşkan (2023) found that vermicompost application enhanced flower life, daily flower yield, flower bloom, and flower count in the Oily Rose plant. The use of vermicompost in plant growth substrates, by modifying substrate characteristics and improving the accessibility and uptake of nutrients, leads to enhanced plant growth (Farjana et al., 2019; Manzoor et al., 2024). In this study, it also resulted in improvements in growth and reproductive indices in the petunia plant. Both vermicompost and biochar positively influence petunia growth and flowering by enhancing soil physical and chemical structures, increasing nutrient availability, and improving water retention capacity. Notably, the current study suggests that the effect of biochar surpasses that of vermicompost in improving reproductive traits. The combined application of biochar and vermicompost did not yield favorable outcomes, which may be due to the nutrient toxicity and disruption of the physicochemical properties of the soil (Li et al., 2022).

The outcomes of this experiment revealed that the addition of biochar or vermicompost to the soil augmented the chlorophylls, carotenoid, and RWC in the leaves of petunia plants. These findings align with the results reported by Younis et al. (2016), who observed enhanced chlorophylls and carotenoid levels in spinach (*Spinacia oleracea* L.) plants with the application of ear cleaning biochar (ear cotton). In lettuce (*Lactuca sativa* L.), Jabborova et al. (2021) found that the application of 3% cherry biochar led to increased chlorophyll and carotenoid content. Altaf et al. (2021) reported heightened chlorophyll levels in the leaves of (*Matthiola incana* and *Pelargonium* spp.) with the application of plant waste biochar. Additionally, Esfahani et al. (2023) observed increased chlorophyll content in mullein plants with the application of 8 kg of vermicompost per square meter. The positive impact of vermicompost and biochar on photosynthetic pigments can be inferred from their role in providing low-use and high-use nutrients to these pigments. The application of biochar and vermicompost enriches the soil and plants with these essential elements, ultimately leading to an increase in chlorophyll content in the plant (Theunissen et al., 2010). Furthermore, nitrogen, a vital component of all amino acids in proteins and fats, serves as a structural compound for chloroplasts (Farhan et al., 2024). The findings of this report align with those of Jabborova et al. (2021), who reported an increase in the RWC in lettuce with the use of cherry biochar. Additionally, Yoo et al. (2021) observed an augmentation in the RWC of spinach leaves with the application of biochar derived from the waste of a local Korean brewing company, Jeongnim-dong. The capacity of biochar and vermicompost to absorb and retain water in the soil may be the reason for the observed improvement in RWC in plants. This suggests that soils modified with biochar exhibit enhanced water retention capabilities, providing more optimal humidity conditions for plant growth throughout the growth period (Esfahani et al., 2023).

The application of biochar or vermicompost has influenced the nutrient content in petunia leaves. The treatment involving biochar + vermicompost resulted in the highest levels of nitrogen, potassium, and magnesium, while the highest phosphorus content was observed with vermicompost alone. Similar findings were observed in rapeseed treated with vermicompost + biochar, where potassium concentration in aerial plant parts was highest compared to other treatments (Mamnabia et al., 2020). Vermicompost, known for promoting nitrogen fixation and phosphorus solubilization, enhances the availability of these nutrients (Zucco et al., 2015). The organic matter in vermicompost, coupled with its ability to stimulate soil microorganisms, facilitates the plant's access to otherwise unavailable resources, particularly phosphorus. Contrarily, a study by Karimi et al. (2020) reported that the use of biochar did not significantly affect calcium levels in marigolds. The impacts of biochar and vermicompost on soil calcium and sodium are intricate and depend on various factors. While biochar may contribute to calcium content, its impact on sodium absorption is not well-established. Vermicompost, being nutrient-rich, likely enhances calcium availability without introducing significant sodium, though the specific outcomes hinge on factors such as the type and quality of biochar and vermicompost, soil composition, and environmental conditions. The combined use of vermicompost and biochar, owing to their high specific surface area, cation exchange capacity, and soluble solutes, has improved nutrient availability for petunia plants, potentially enhancing overall plant performance (Kulczycki et al., 2020). The gradual release of nutrients from vermicompost and biochar contributes to sustained availability, resulting in increased nutrient levels in the petunia plant (Lehmann et al., 2011). The use of biochar and vermicompost in soils deficient in organic matter can improve the physical, chemical, and biological properties of the soil, leading to increased levels of calcium and magnesium in the soil. However, a significant increase in these elements in plants may not be observed. This could be attributed to factors such as the precipitation of these elements in the soil or competition with other elements. Biochar and vermicompost typically contain various amounts of nutrients such as calcium, magnesium, potassium, and other elements. Their use can enhance plant access to these nutrients, thereby improving plant quality and performance (Zucco et al., 2015; Karimi et al., 2020)

CONCLUSION

The current study's findings highlight the positive impact of employing biochar or vermicompost fertilizers on enhancing the growth, ornamental features, and physiological attributes of the petunia plant. However, the effectiveness of biochar, particularly in improving ornamental parameters, surpassed that of vermicompost. The combined application of biochar and vermicompost did not yield favorable outcomes, so further research on their concentrations can be conducted in the future. Consequently, the use of these fertilizers emerges as a viable solution to diminish reliance on chemical fertilizers, stabilize soil resources, mitigate environmental pollution, and ultimately yield a healthier product.

Conflict of interest

The authors declare no conflict of interest.

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