Effect of Poultry Manure, Potassium Polyacrylate and Biochar Treatments on the Physiological Traits of Eruca Sativa Grown in Sandy Soil

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Abstract: Study aimed to investigate effects of poultry manure, biochar, and potassium polyacrylate, applied individually and in combination, on improving sandy soil properties and influencing selected physiological and chemical traits of rocket Eruca sativa L A field experiment was conducted using a randomized complete block design with three replications. Treatments consisted of two levels of Poultry manure 0 and 10 t ha^{-1}, three levels of potassium polyacrylate 0, 50, and 100 kg ha^{-1}, and three levels of biochar 0, 10, and 20 t ha^{-1}. Application of soil amendments significantly enhanced soil physical and chemical properties, including an increase in volumetric water content at field capacity from 8.00% to 13.93%, organic matter content from 1.18 to 1.46 g kg^{-1}, and the availability of essential nutrients (N, P, and K), without increasing soil salinity. The highest rates of each amendment demonstrated superior performance. Poultry manure at 10 t ha^{-1} produced the highest chlorophyll content 52.04 SPAD, quercetin 132.6 ppm, erucin 181.7 mg g, and nitrate 547.5 mg 100 g^{-1}, while recording the lowest proline content 50.88 ppm. Similarly, potassium polyacrylate at 100 kg ha^{-1} resulted in the highest values for chlorophyll 53.04 SPAD, quercetin 143.1 pp, erucin 190.2 mg g^{-1}, and nitrate 559.0 mg 100 g^{-1}, with a corresponding reduction in proline 50.05 ppm. Biochar at 20 t ha^{-1} showed comparable improvements across all measured parameters. Interaction effects revealed that combined application of potassium polyacrylate 100 kg ha^{-1} and biochar 20 t ha^{-1} was the most effective binary treatment, significantly increasing quercetin 154.8 ppm and erucin 199.9 mg g^{-1} .Furthermore, combined use of all three amendments resulted in the highest chlorophyll content (54.40 SPAD) and maximized quercetin and erucin concentrations to 161.6 ppm and 206.8 mg g^{-1}, respectively.

1 INTRODUCTION

These types of leafy vegetables (spinach, lettuce, arugula) are critical components of the food supply because they provide essential nutrients as well as contribute to the overall public health in the world. When produced in low-income areas, they also have a major impact on food security; therefore, growing Eruca sativa (Eruca sativa) in sandy soils is particularly challenging due to their limited fertility, low cation exchange capacity, and rapid evaporation of water and nutrients [1]. Additionally, Eruca sativa is part of the Brassicaceae family, which includes many other leafy vegetables; i.e., other greens. Significant phytochemicals, such as phenolic compounds, flavonoids, and isothiocyanates, make Eruca sativa an important source of nutrition. The most prevalent, and most researched, flavonoid found in Eruca sativa leaves is quercetin, which acts as an antioxidant by increasing how well our bodies neutralize free radicals and thus decreasing oxidative stress. Quercetin also increases the health benefits of Eruca sativa by reducing inflammation [2], [3]. Another type of secondary plant compound found in Eruca sativa is erucin, which results from the breakdown of glucosinolates to create isothiocyanates. Erucin has been shown to have a role in cancer prevention, primarily through its interaction with detoxifying enzymes and regulation of cell division [4], [5]. Watercress contains a significant concentration of phytochemicals that demonstrate health benefits.

This has contributed to improving the physical and structural properties of sandy soils through the application of fertilizers that enhance soil fertility and stability [6], [7]. The latest advances in research and development have also looked into the use of organic and inorganic formulations, including restructured agricultural fertilisers, super absorbent potassium polyacrylate s and delayed deformations [8]-[10]. Poultry manure is an abundant source of organic matter and nitrogen, both of which are important components of soil fertility. It also contains large quantities of agricultural chemicals. The conversion of poultry manure into Poultry manure can help restore soil fertility, particularly for soils that have been depleted, such as sandy soils, [11]. The application of poultry manure has been shown to enhance the availability of nitrogen and other nutrients to plants, thereby increasing soil fertility, preserving soil nutrients, improving soil structure, enhancing microbial activity and increasing crop yields [12]. In addition, the application of poultry manure improves soil structure and nutrient dynamics, leading to enhanced availability of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K) [11]. Potassium polyacrylate s are large molecules consisting of many smaller molecules connected together and are capable of having different characteristics after they go through the potassium polyacrylate ization process. Potassium polyacrylate s, both naturally occurring and synthetic, are commonly used to increase the stability of soil [13]. The use of synthetic potassium polyacrylate s has recently gained popularity for their ability to improve arid and semi-arid soils and reduce the rate of degradation of these soils [14]. Superabsorbent Potassium polyacrylate s (SAPs) are hydrophilic (water holding) potassium polyacrylate networks and have the ability to absorb a lot of water quickly but release the water slowly, so they can help sandy soils hold moisture longer, keep more water from leaving the soil, and increase productivity of crops grown in arid conditions.[15]. When hydrogels are added to sandy soils, a significant physical improvement occurs, including an increase in how much water the soil is capable of holding (field capacity) and how much water is available to the plants. A significant reduction in soil bulk density and an improvement in the soil's granular structure occurs. High soil permeability reduces the amount of water and nutrients that are lost through leaching. Typically, the improvement in the plant's ability to survive under drought-like conditions and the overall increase in water use efficiency is directly related to the type of potassium polyacrylate used, how much is added and which type of crop is used [16]. While there may be many benefits associated with using SAPs, it is important to consider how much will be beneficial to soil, the potential environmental ramifications, how to facilitate nutrient movement and the cost of the SAP when determining the appropriate usage, therefore further applied studies are necessary [17]. Biochar is an organic compound with a lot of potential to enhance fertility of the soil because it is able to do so over a long period of time; in comparison, many untreated organic materials would not provide this same benefit in terms of lasting multiple years. [18], [19]. There have been many research studies conducted to determine how effective biochar will be in improving agricultural yields and soil quality from one study to another. Some studies have concluded that biochar improves fertility of the soil because it gives the soil structure or contributes to the biological activity in the soil, while other studies concluded that biochar reduces the fertility of the soil - but it is vital to remember that many factors affect these various conclusions including: the type of biochar used, what kind of soil is being tested with the biochar, and how much biochar is being utilized.[20]-[22].

Based on the above research studies, it can be concluded that biochar can and will increase soil water holding capacity due to the high retention of moisture in biochar; in particular, this is true when applied to sandy soils. Alkaline biochar generated at higher temperatures shows further promise in increasing both field capacity (the amount of moisture or water that the soil can hold when saturated with water) and organic matter content, as well as enhancing the overall growth rate of crops.[23], [24].

Despite numerous studies examining the individual effects of Poultry manure s, biochar, and superabsorbent potassium polyacrylate son soil properties and plant performance, knowledge regarding their combined interactions remains limited, particularly in sandy soils within arid and semi-arid environments characterized by low fertility, poor water retention, and nutrient loss. Most previous studies have focused on the singular or combined use of these amendments, highlighting a significant research gap concerning the evaluation of the integrated use of poultry manure, potassium polyacrylate, and biochar, especially on the physiological and biochemical aspects of rocket (Eruca sativa). Therefore, this study aims to evaluate the individual and combined effects of these treatments on improving sandy soil properties and enhancing certain plant physiological and biochemical indicators, including chlorophyll, quercetin, erucicin, nitrate, and proline content, to determine the most efficient treatment for improving plant performance under these conditions.

2 MATERIALS AND METHODS

2.1 Location and Implementation of the Experiment

A factorial container experiment was conducted under open-field nursery conditions in Al-Muqdadiyah District, Diyala Governorate, Iraq, during the autumn season (September 2024). The experiment was arranged in a randomized complete block design (RCBD) with three replications.The samples were sent to the laboratories of the Soil Department/Diyala Agriculture Directorate for analysis of some physical and chemical properties and to determine the soil texture. The results showed that the soil texture was sandy, as shown in Table 1.

Table 1: Study soil texture.

Soil Texture	Clay 3.12 %	Sand 92.4 %	Loam 4.48 %
Sandy Soil			

2.2 Experimental Design

The study included three factors: poultry manure at two levels (0 and 10 t ha^{-1}), potassium polyacrylate at three levels (0, 50, and 100 kg ha^{-1}), and biochar at three levels (0, 10, and 20 t ha^{-1}), resulting in 18 treatment combinations and 54 experimental units. The selected application rates of poultry manure, potassium polyacrylate, and biochar were based on previous studies that demonstrated their effectiveness in improving soil fertility, water retention, and plant growth under sandy soil conditions [15], [16], [23] these rates were chosen to represent practical and commonly used ranges in agricultural applications.

2.3 Experimental Treatments

Plastic basins designated for growing arugula, measuring (90 × 30 × 30 cm), were filled with approximately 40 kg of soil after sifting through a 1 mm sieve. On September 3, 2024, Eruca sativa seeds were sown at a rate of 3 seeds per hole, then thinned to one plant per hole. Four holes were planted per basin, with a spacing of 20 cm between holes and 15 cm from the basin edges. The basins were divided into 3 sections according to the experimental design, with a spacing of 1 m between sections, and covered with shade netting to protect the plants from the heat.A basal dose of DAP fertilizer and urea was applied uniformly to all experimental units to ensure minimum nutrient availability and avoid nutrient deficiency that could limit plant growth. This approach allowed for a clearer evaluation of the relative effects of the tested soil amendments rather than replacing standard fertilization practices. Phosphoric acid (85%) was applied at a uniform concentration of 1 ml L^{-1} to all experimental units to adjust soil pH and maintain consistent experimental conditions. Irrigation was carried out regularly to maintain soil moisture near field capacity, depending on weather conditions. Equal amounts of water were applied to all treatments to ensure uniform moisture conditions throughout the experiment. Leaf samples were collected at the vegetative growth stage (45 days after planting) to ensure consistency in physiological and biochemical analyses.

2.4 Biochar Preparation

Biochar was prepared from Palm frond waste at home using a 30-liter metal container modified to prevent oxygen from entering during thermal decomposition. Palm frond waste was collected from orchards near the experiment site and cut into small pieces. It was then placed in a container and heated using a laser torch to 400°C for approximately three hours, or until smoke emission ceased, indicating the completion of pyrolysis and the formation of biochar. After cooling, the resulting biochar was ground and sieved through a 1 mm sieve to obtain a homogeneous particle size. The preparation method was based on previously established protocols for biochar production [25] A sample was then sent to the laboratories of the College of Science at the University of Kufa for diagnostic, physical, and chemical analysis.

2.5 Studied Characteristics

All measurements were conducted using three replicates per treatment. For each replicate, samples were collected from randomly selected plants within each experimental unit. The same sample weights and procedures were applied consistently across all treatments to ensure comparability of results.

2.5.1 Chlorophyll Index Measurement (SPAD)

The chlorophyll index in leaves was measured using a SPAD-502 instrument (Konica-Minolta, Japan). Five readings were taken from different areas of the leaf blade of three randomly selected plants from each experimental unit, avoiding the main veins. The average of these readings was then calculated and used as the final SPAD value.

2.5.2 Estimation of Quercetin (ppm) and Erosin Content in Leaves (mg/g)

Extraction was performed on the plant sample (leaves) after thorough grinding and defat removal-using chloroform with stirring for 3 hours. The sample was then dried at 50°C to remove residual solvent. Ten grams of the dried sample were collected using an ethanol/water mixture (70:30) in an ultrasonic bath for one hour at room temperature. The extract was filtered and the solvent removed using a rotary evaporator under vacuum. It was then dried at 40°C to a constant weight, and the dried extracts were stored at 4°C until analysis. Quercetin and erucicin were determined using reverse-phase HPLC with a C18 column (25 cm × 4.6 mm) at 30°C, using an Elwin gradient system with methanol and 1% formic acid as solvents, at a flow rate of 1 mL/min and an injection volume of 100 µL, with detection at a wavelength of 280 nm [26].

2.5.3 Estimation of Proline Content in Leaves (ppm)

The extraction process was carried out by grinding 50 mg of leaves and homogenizing them with 10 mL of 3% aqueous sulfosalicylic acid. The homogenate was then filtered, and the residue was re-extracted twice with the same solvent. The filtrate was collected and the volume was increased to 20 mL. For proline estimation, 1 mL of the extract was taken and 1 mL of acidic ninhydrin reagent and 1 mL of glacial acetic acid were added. The mixture was then incubated in a water bath at 100°C for 1 hour. After cooling, 4 mL of toluene was added, and the mixture was shaken well to extract the chromophore. The organic phase was separated, and the absorbance was measured at a wavelength of 520 nm using an ultraviolet spectrometer [27].

2.5.4 Estimation of Nitrate Content in Leaves (mg/100 g)

The nitrate content of plant samples was determined using the cadmium reduction-Griess method, according to the Standard Methods for the Examination of Water and Wastewater. Leaves were collected, washed, and dried at 60–70°C until weight was constant. They were then ground into a homogeneous powder, and 0.1–1.0 g of the powder was weighed and extracted in 50 mL of hot distilled water with shaking for 30–60 minutes before filtration. The filtrate was reduced to nitrite using a copper-treated cadmium column. A colorimetric reaction was then performed by adding sulfanylamide followed by N-(1-Naphthyl)-ethylenediamine dihydrochloride to form a pink azo dye. The mixture was left to stand for 10 minutes to allow the color to develop. Absorption was measured at 540 nm using a spectrophotometer, and the nitrate concentration was calculated using a standard curve. The results were then converted to a dry weight basis. [28].

2.6 Statistical Analysis

The data were statistically analyzed using analysis of variance (ANOVA) in a completely randomized block design (RCBD). Means were compared using Duncan's multiple range test (DMRT) at a probability level of 0.05 using SPSS software. A t-test was also used to compare the mean physical and chemical properties of the soil before and after the addition of the amendments.

3 RESULTS AND DISCUSSION

3.1 Results of Biochar Analyses

3.1.1 Field Emission Scanning Microscopy Diagnosis

The biochar (sample 1) in image (1) shows a porous structure that has multiple holes and channels along with various sizes of the holes due to the decomposition of organic materials after carbonization at 400 °C (using the FE-SEM). Many cracks and gray accumulations caused by the minerals are also visible on the surface of the biochar, which provide increased surface area to adsorb nutrients to the biochar and enhance its cation retention capacity; therefore, these characteristics improve the ability of the biochar to retain water and nutrients from its surroundings [29], [30].

3.1.2 Diagnosis by Fourier Transform Infrared Spectroscopy

The FT-IR analysis provided information regarding the presence of chemical functional groups in the analysed biochar sample according to the results displayed in Figure 2. The peak at 232920 cm^{-1} showed that there were aliphatic C-H bonds; additionally, the peak at 2310.72 cm^{-1} was due to CO2 being absorbed into the porous structure of the biochar. This indicates that the biochar was produced through moderate carbonisation temperatures (+/-350 - 500°C) and contained some incompletely decomposted organic material [31], [32]. The peak at

1589.34 cm⁻¹ shows that C=C vibrations were present in the aromatic structure formed, which adds to its stability and helps it enhance carbon fixation in soils [33]. Another peak (1417.68 cm⁻¹) indicates that there are polar groups (e.g., phenolics and carboxylates) that will improve cation exchange capacity (CEC) and increase the biochar's ability to hold nutrients [34]. The peaks observed at 750.31 cm⁻¹ and 813.96 cm⁻¹ were attributed to C-H vibrations in the aromatic rings. Finally, peaks observed below 500 cm⁻¹ indicated the presence of metallic bonds (e.g., Si-O and Fe-O), which are a result of ash-derived metallic components [35]; therefore, the overall FT-IR spectrum illustrated how biochar had a balance between active functional groups, and stable/aromatic structures, which supported the beneficial qualities of biochar throughout the enhancement of soil properties and enhancing carbon fixation.

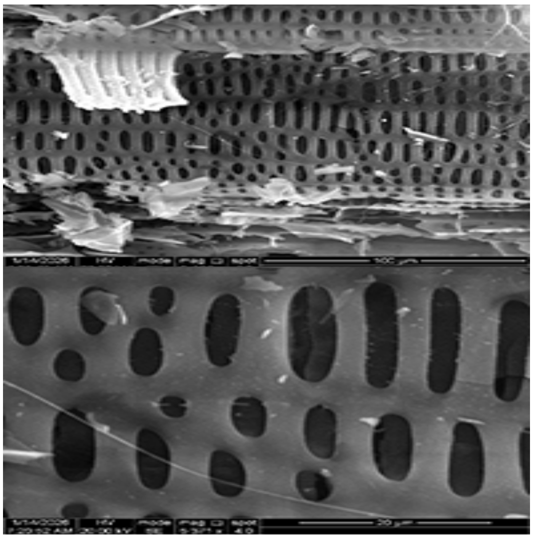

Figure 1: Images of biochar under a scanning electron microscope.

3.1.3 Diagnosis by Energy-Dispersive X-ray Spectroscopy

The EDX analysis shown in Figure 3 shows the dominance of carbon (80.36%) followed by oxygen (17.86%) with the presence of minor mineral elements such as Ca, K and Mg, a composition that reflects a suitable degree of carbonation with the biochar retaining some of the mineral elements beneficial to the soil [25].

Field capacity increased markedly from 8.00% to 13.93%, accompanied by an increase in organic matter from 1.18 to 1.46 g/kg, reflecting improved soil structure and water retention capacity.

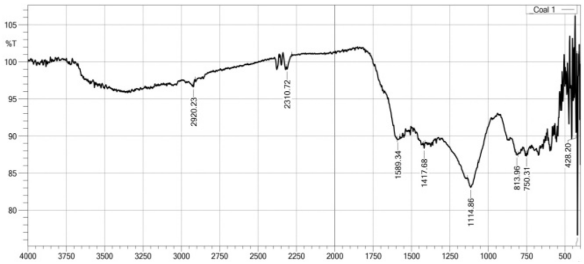

Figure 2: Infrared spectrum of biochar surfaces.

3.2 The Effect of Treatment with Potassium Polyacrylate, Biochar and Poultry Manure on the Chemical and Physical Properties of the Study Soil

The t-test (see Table 2) indicated that the addition of amendments significantly affected most of the measured soil properties. Soil samples were analyzed in triplicate, and results are presented as mean ± standard deviation.

The pH value increased from 7.39 to 7.53, while electrical conductivity showed a slight, non-significant increase from 5.30 to 5.57 dS/m⁻¹, indicating no salinity buildup.

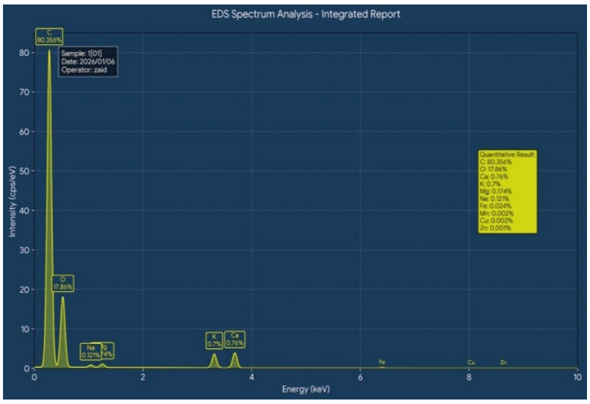

Figure 3: X-ray spectrum of a biochar sample.

Additionally, nutrient availability increased significantly, with nitrogen rising from 66.57 to 74.53 mg/kg, phosphorus from 10.27 to 11.64 mg/kg, and potassium from 180.60 to 188.95 mg/kg.Overall, these results demonstrate that soil amendments improved soil fertility without causing salinity issues.

Table 2: Comparison of selected physical and chemical properties of sandy soil before and after amendment application (mean ± SD, n = 3).

Trait		Mean ± SD	t-value	P-value
pH	Before	7.39 ± 0.09	-8.126	0.015
	After	7.53 ± 0.06		
EC (dS/m)	Before	5.30 ± 0.02	-1.800	0.214
	After	5.57 ± 0.25		
FC (%)	Before	8.00 ± 0.03	-178.00	0.000
	After	13.93 ± 0.06		
OM (g/kg)	Before	1.18 ± 0.01	-83.000	0.000
	After	1.46 ± 0.01		
N (mg/kg)	Before	66.57 ± 0.32	-36.447	0.001
	After	74.53 ± 0.12		
P (mg/kg)	Before	10.27 ± 0.06	-20.424	0.002
	After	11.64 ± 0.05		
K (mg/kg)	Before	180.60 ± 0.26	-51.951	0.000
	After	188.95 ± 0.05		

4 EFFECTS OF TREATMENT WITH POTASSIUM POLYACRYLATE, BIOCHAR, AND POULTRY MANURE ON THE PHYSIOLOGICAL CHARACTERISTICS OF ARUGULA

4.1 Chlorophyll Index (SPAD)

Significant differences at the 5% probability level were obtained in the chlorophyll index (SPAD) trait as a result of treating Eruca sativa plants with Poultry manure (poultry manure) at a concentration of 10 tons ha^{-1} compared to the control treatment (0 tons ha^{-1}). The results in Table 3 show that the plants treated with Poultry manure at a concentration of 10 tons ha^{-1} recorded the highest average SPAD value, reaching 52.04, with an increase of 3.41% compared to the control treatment, which recorded the lowest average SPAD value of 50.32.

The rise in chlorophyll amounts inside leaves when using Poultry manure s can be explained because of what elements (that are vital for creating photosynthetic pigments) Poultry manure s contain (nitrogen, magnesium, iron), how they enhance the quality of soil, and how they help stimulate the activity of micro-organisms (which stimulates the availability of those elements for absorption), thus resulting in an improvement to the overall effectiveness of photosynthesis and growth of plants [36].

The results also indicate that there are highly significant differences at the probability level of 5% between the averages of this trait as a result of treating Eruca sativa plants with potassium polyacrylate at concentrations of 0, 50 and 100 kg ha^{-1}. The results in Tables 2, 3 show that the highest average was obtained as a result of treating the plants with the potassium polyacrylate at a concentration of 100 kg ha^{-1}, as this addition recorded the highest average, which reached 53.04 SPAD, with an increase of 3.77% and 7.41%, compared to treating the plants with the potassium polyacrylate at a concentration of 50 kg ha^{-1}, which recorded an average of 51.11 SPAD, and the control treatment, which recorded the lowest average, which reached 49.38 SPAD, respectively.

Potassium polyacrylate has been shown to enhance the chlorophyll content in treated plants due to a higher level of soil moisture retention and decreased nutrient leaching, which in turn leads to an increase in the amount of nitrogen available for plant uptake (Fig. 1). As a result of increased chlorophyll development, a greater degree of photosynthetic efficiency, and a lower rate of decomposition due to water stress [37].

The results shown in the same table also indicate highly significant differences in the average chlorophyll index trait when treating Eruca sativa plants with biochar at concentrations of 0, 10, and 20 tons ha^{-1}. The highest average for this trait was recorded at a concentration of 20 tons ha^{-1}, which was 52.07 SPAD, with an increase of 1.42% and 3.89%, respectively, compared to a concentration of 10 tons ha^{-1}, which recorded an average of 51.34 SPAD, and the control treatment of 0 tons ha⁻¹, which recorded the lowest average of 50.12 SPAD, respectively.

By increasing the amount of biochar applied to soil, there may be an increase in chlorophyll content within the plant's leaves due to an increase in the overall nutrient supply to the plant, along with improved availability of several key nutrients (e.g. nitrogen, magnesium and iron) necessary for the formation of chlorophyll and efficient photosynthesis in plants. [38]

The two-way interaction of the treatments caused highly significant differences at the 5% probability level for the mean chlorophyll index (Table 3). The highest mean value for this characteristic was 53.68 SPAD at the combination of 10 T ha-1 of Poultry manure with 100 kg ha-1 of potassium polyacrylate, which was 10.38% greater than the lowest mean value of 48.63 SPAD found in the combination of 0 T ha-1 of Poultry manure with 0 kg ha-1 of potassium polyacrylate.

The three-way interaction of Poultry manure, biochar and potassium polyacrylate also indicated highly significant differences at the 0.05 probability level for this trait (Table 3). The highest mean value for this characteristic was 54.40 SPAD for the combination of 10 T ha-1 of Poultry manure, 100 kg ha-1 of potassium polyacrylate and 20 T ha-1 of biochar, which represented a 13.49% increase from the lowest mean value of 47.93 SPAD found in the combination of 0 T ha-1 of Poultry manure, 0 kg ha-1 of potassium polyacrylate, and 0 T ha-1 of biochar.

4.2 Leaf Content of Qurcetine (ppm)

The results shown in Table 4 indicate highly significant differences at the probability level of 5% in the leaf content of Qurcetine because of treating the Eruca sativa plant with Poultry manure at a concentration of 10 tons ha⁻¹ compared to the treatment of no addition of 0 tons ha⁻¹. The results in the table show that the treatment of the plants with Poultry manure at a concentration of 10 tons ha⁻¹ recorded the highest average, which amounted to 132.6 ppm, with an increase of 20.76% compared to the control treatment, which recorded the lowest average, which amounted to 109.8.

High amounts of quercetin in rocket leaves are due to Poultry manure improving root growth, providing nutrients for plants, and stimulating microorganisms in the soil to improve plant health and produce more carbon that flows to secondary metabolism pathways such as chimicrons and phenylpropanoids, which play an important role in producing phenolics. Organic farming enhances the production of secondary metabolites such as flavonoids [39].

The results also show that there are highly significant differences at the 5% probability level between the averages of this trait resulting from the treatment of Eruca sativa plants with potassium polyacrylate at concentrations of 0, 50 and 100 kg ha⁻¹. The results presented in Table 4 show that the highest average was obtained as a result of treating the plants with the potassium polyacrylate at a concentration of 100 kg ha⁻¹, as this addition recorded the highest average, which reached 143.1 ppm, with an increase of 17.68% and 49.14%, compared to the treatment of the plants with the potassium polyacrylate at a concentration of 50 kg ha⁻¹, which recorded an average of 121.6 ppm, and the control treatment, which recorded the lowest average of 98.91 ppm, respectively.

The reason that rocket plants treated with the superabsorbent potassium polyacrylate have more quercetin is due to how the superabsorbent potassium polyacrylate s improve the soil's water status through the processes of absorbing, retaining, and then gradually releasing the water from the soil and thereby maintaining soil moisture, which reduces water stress and the production of reactive oxygen species (ROS).

These results in enhancing the plant's physiological balance and so directing the plant's metabolic activity toward producing antioxidant phenolic compounds like quercetin as well as helping with root development and the efficiency of using water and nutrients [40].

The results also show highly significant differences between the average leaf content of quercetin when treating Eruca sativa plants with biochar at concentrations of 0, 10, and 20 tons ha⁻¹. The highest average for this trait was recorded at a concentration of 20 tons ha⁻¹, which was 131.7 ppm, with an increase of 7.86% and 19.94%, respectively, compared to the treatment at a concentration of 10 tons ha⁻¹, which recorded an average of 122.1 ppm, and the control treatment of 0 tons ha⁻¹, which recorded the lowest average of 109.8 ppm, respectively.

The incorporation of Biochar on the ground can increase some plant’s flavonoids due to increased soil quality, increased microbial activity, and improved photosynthesis efficiency providing more carbohydrates for synthesizing secondary compounds. Factors that contribute to this method’s success include soil quality, species of plant, and qualities of the biochar chosen to be used [41].

Table 3: Effect of treatment with poultry manure, potassium polyacrylate and biochar on chlorophyll index.

Poultry manure	Potassium polyacrylate	Biochar			The dual interaction between Poultry manure and potassium polyacrylate
		0	10	20	
0	0	47.93 i	48.26 i	49.70 g	48.63 d
	50	48.33 i	50.40 f	51.06 de	49.93 c
	100	51.53 d	52.30 c	53.36 b	52.40 b
10	0	49.06 h	50.43 f	50.93 e	50.14 c
	50	51.43 de	52.43 c	53.00 b	52.28 b
	100	52.43 c	54.23 a	54.40 a	53.68 a
Average impact of biochar		50.12 c	51.34 b	52.07 a	51.17
The dual interaction between Poultry manure and biochar					
Poultry manure concentration		biochar concentrate			Average effect of Poultry manure
		0	10	20	
0		49.26 d	50.32 cd	51.37 abc	50.32 b
10		50.97 bc	52.36 ab	52.77 a	52.04 a
The dual interaction between potassium polyacrylate and biochar					
Potassium polyacrylate concentrations		Biochar concentrations			Average potassium polyacrylate effect
		0	10	20	
0		48.50 a	49.35 a	50.31 a	49.38 c
50		49.88 a	51.41 a	52.03 a	51.11 b
100		51.98 a	53.26 a	53.88 a	53.04 a

Average leaf quercetin content was significantly affected at a 5% probability level based on the various treatments applied in this experiment (2). It should be noted from Table 4 that the best trait existed with the use of (100 kg/ha) potassium polyacrylate and (20 t/ha) biochar yielding an average of 154.8 ppm, an increase of 71.10% over the lowest average of 90.47 ppm, which occurred on plants using no potassium polyacrylate and no biochar (0 kg/ha and 0 t/ha respectively).

In addition, there were significant differences among treatments at a level of 5% probability due to the interaction of three variables (Poultry manure) and (100 kg/ha potassium polyacrylate) and (20 t/ha biochar). The best average in this case came from the combination of (10 t/ha Poultry manure) and (100 kg/ha potassium polyacrylate) and (20 t/ha biochar) producing an average value of 161.6 ppm, which is again an 18.92% increase over the lowest average of 84.76 ppm recorded using no Poultry manure, no potassium polyacrylate and no biochar combination.

4.3 Leaf Erucin Content mg gm^{-1}

The results in Table 5 show highly significant differences at a probability level of 5% between the average leaf erucin content mg gm^{-1} resulting from the treatment of Eruca sativa plants with Poultry manure at a concentration of 10 tons ha^{-1} compared to the control treatment (0 tons ha^{-1}). The results in the table show that the treatment of plants with Poultry manure at a concentration of 10 tons ha^{-1} recorded the highest average, amounting to 181.7 mg gm^{-1}, with an increase of 12.99% compared to the control treatment, which recorded the lowest average, amounting to 160.8 mg gm^{-1}.

The effect of using Poultry manure on reducing or preventing Erucin in plant life may be attributed to the enhancement of plant nutrient uptake and efficiency of metabolism provided by using organic matter. Poultry manure s are decomposed slowly and release nutrients like nitrogen, phosphorus, and potassium over time; these nutrients help promote the enzyme activity that produces erosin within the plants, as well as improve soil quality and increase microbial activity, thus allowing for greater nutrient use by the plant and increasing the amount of secondary metabolite accumulation [42].

The results also indicate that there are highly significant differences at the probability level of 5% between the averages of this trait as a result of treating Eruca sativa plants with potassium polyacrylate at concentrations of 0, 50 and 100 kg ha^{-1}. The results shown in Table 5 show that the highest average was obtained as a result of treating the plants with the potassium polyacrylate at a concentration of 100 kg ha^{-1}, as this addition recorded the highest average, which reached 190.2 mg g^{-1}, with an increase of 10.71% and 25.37%, compared to treating the plants with the potassium polyacrylate at a concentration of

50 kg ha^{-1}, which recorded an average of 171.8 mg gm^{-1}.and the control treatment, which recorded the lowest average of 151.7 mg gm^{-1}.respectively.

Treating rocket plants with superabsorbent potassium polyacrylate leads to higher erucin levels because superabsorbent potassium polyacrylate s improve the amount of moisture available in the soil by holding on to moisture and releasing moisture slowly over time in the root zone. These improvements benefit the plant's overall water balance and increase nutrient intake efficiencies (i.e., sulfur and nitrogen). Also, increasing moisture levels results in the activation of metabolic pathways within plants that synthesize glucosinolates, the primary source of isothiocyanate compounds like erucin, while reducing oxidative stress, increasing plant physiological conditions, and enhancing overall health. [43], [44].

The results also show highly significant differences between the average leaf content of erucin when treating Eruca sativa plants with biochar at concentrations of 0, 10, and 20 tons ha^{-1}. The highest average for this trait was recorded at a concentration of 20 tons ha^{-1}, which was 180.6 mg g^{-1}, with an increase of 4.57% and 12.59%, respectively, compared to the treatment at a concentration of 10 tons ha^{-1}, which recorded an average of 172.7 mg gm^{-1}.and the control treatment of 0 tons ha^{-1}, which recorded the lowest average of 160.4 mg gm^{-1}.respectively.

Biochar has been found to increase the levels of glucosinolates in the leaves of crops due to its enhancement of both the physical and chemical attributes of soil, as well as its ability to regulate the amount of chemical nutrients available to a plant, therefore having a positive effect on plant metabolism. In addition, biochar also has benefits related to improving the structure of soil, i.e., enhancing its abilities to retain moisture and nutrients while also causing an overall increase in the level of microbial activity (including fungi and bacteria) in and around the root zone which may stimulate secondary metabolites' metabolic pathways responsible for glucosinolates' development. Evidence from earlier studies have demonstrated the positive influence that biochar has had on glucosinolate levels in broccoli which were treated with biochar versus control crops [45].

The average leaf Erucin contents were found to differ greatly at a very high level of significance ($p < 0.005$) as a result of interactions between the two factors tested. The results presented in Table 5 indicate that the largest amount of leaf Erucin 199.9 mg gm^{-1} occurred with the combination treatment (100 kg ha^{-1} of potassium polyacrylate + 20 tons ha^{-1} of biochar). This represented a 39.59% increase when compared to the minimum amount of leaf Erucin 143.2 mg gm^{-1} measured from the combination treatment (0 kg ha^{-1} potassium polyacrylate + 0 tons ha^{-1} biochar).

Table 4: Effect of treatment with poultry manure, potassium polyacrylate and biochar on the quercetin content of leaves.

Poultry manure	Potassium polyacrylate	Biochar			The dual interaction between Poultry manure and potassium polyacrylate
		0	10	20	
0	0	84.76 r	88.26 q	99.20 n	90.74 d
	50	93.06 p	101.9 m	113.1 k	102.7 c
	100	122.8 i	137.1 f	148.1 d	136.0 b
10	0	96.16 o	108.1 l	116.9 j	107.0 c
	50	128.2 h	142.0 e	151.3 c	140.5 b
	100	133.9 g	155.3 b	161.6 a	150.3 a
Average impact of biochar		109.8 c	122.1 b	131.7 a	121.2
The dual interaction between Poultry manur and biochar					
Poultry manure concentration		Biochar concentrate			Average effect of Poultry manure
		0	10	20	
0		100.2 c	109.1 c	120.1 bc	109.8 b
10		119.4 bc	135.1 ab	143.2 a	132.6 a
The dual interaction between potassium polyacrylate and biochar					
Potassium polyacrylate concentrations		Biochar concentrate			Average potassium polyacrylate effect
		0	10	20	
0		90.47 f	98.21 ef	108.0 de	98.91 c
50		110.6 de	121.9 cd	132.2 bc	121.6 b
100		128.4 c	146.2 ab	154.8 a	143.1 a

Table 5: Effect of treatment with Poultry manure, potassium polyacrylate and biochar on the erucin content of leaves.

Poultry manure	potassium polyacrylate	biochar			The dual interaction between Poultry manure and potassium polyacrylate
		0	10	20	
0	0	137.2 r	142.0 q	152.9 n	144.0 d
	50	144.9 p	157.2 m	164.2 k	155.4 c
	100	171.8 i	184.6 i	193.0 d	183.1 b
10	0	149.3 o	160.7 l	168.3 j	159.4 c
	50	177.3 h	188.9 e	198.7 c	188.3 b
	100	182.0 g	203.0 b	206.8 a	197.3 a
Average impact of biochar		160.4 c	172.7 b	180.6 a	171.2
The dual interaction between Poultry manure and biochar					
Poultry manure concentration		biochar concentrate			Average effect of Poultry manure
		0	10	20	
0		151.3 d	161.3 cd	170.0 bc	160.8 b
10		169.5 bc	184.2 ab	191.3 a	181.7 a
The dual interaction between potassium polyacrylate and biochar					
Potassium polyacrylate concentrations		biochar concentrate			Average potassium polyacrylate effect
		0	10	20	
0		143.2 f	151.4 ef	160.6 de	151.7 c
50		161.1 de	173.1 cd	181.4 bc	171.8 b
100		176.9 c	193.8 ab	199.9 a	190.2 a

The treatment combination that resulted in the largest average amount of Erucin 206.8 mg gm^{-1} was achieved by using (10 tons ha^{-1} of Poultry manure + 100 kg ha^{-1} potassium polyacrylate + 20 tons ha^{-1} biochar). This represents a 50.72% increase as compared with the average amount of Erucin 137.2 mg gm^{-1} obtained with the combination treatment (0 tons ha^{-1} Poultry manure + 0 kg ha^{-1} potassium polyacrylate + 0 tons ha^{-1} biochar).

4.4 Leaf Nitrate Content (mg 100 g^{-1})

The results indicate significant differences at the 5% probability level in leaf nitrate content (mg 100 g^{-1}) resulting from the treatment of Eruca sativa plants with Poultry manure at a concentration of 10 tons ha^{-1} compared to the control treatment (0 tons ha^{-1}). Table 6 shows that the highest average for this characteristic was obtained from the treatment of plants with Poultry manure at a concentration of 10 tons ha^{-1}, reaching 547.5 mg/100 g^{-1}, representing an increase of 5.20% compared to the control treatment, which recorded the lowest average of 520.4 mg 100 g^{-1}.

Nitrate levels in plant tissues indicate nitrogen status within the plant and depend on the nitrogen source from the soil.

Poultry manure s generally allow for a more even supply of nitrogen over time due to microbial mineralization than do mineral fertilizers. So, therefore, Poultry manure s will cause less nitrate to accumulate in plant tissues than do mineral fertilizers. Poultry manure s also enhance activity of microorganisms and improve physical and chemical properties of the soil which may improve the efficiency of nitrogen uptake by plants and the activity of nitrate reductase enzymes, but this effect will ultimately depend on the type of fertilizer used and on the condition of the soil [46].

The results also show that there are highly significant differences at the 5% probability level between the averages of this trait resulting from the treatment of Eruca sativa plants with potassium polyacrylate at concentrations of 0, 50 and 100 kg ha^{-1}. The results presented in Table 6 show that the highest average obtained was the result of treating the plants with the potassium polyacrylate at a concentration of 100 kg ha^{-1}, as this addition recorded the highest average, which reached 559.0 mg 100 g^{-1}, with an increase of 2.82% and 10.06%, compared to the treatment of the plants with the potassium polyacrylate at a concentration of 50 kg ha^{-1}, which recorded an average of 534.9 mg 100 g^{-1}, and the control treatment, which recorded the lowest average of 507.9 mg 100 g^{-1}, respectively.

The increase in nitrate levels in plants that are treated with super absorbent potassium polyacrylate s can be explained by the way these materials improve the soil's ability to hold water and how they control the movement of both water and nutrients. By retaining and gradually releasing water from themselves to the root zone, super absorbent potassium polyacrylate s reduce nitrate leaching out of the root zone, keeping nitrates close to the roots and making them more readily available to the plant.

By holding more nitrates in the root zone, their efficiency in utilization by the plant will also improve, leading to greater overall growth and productivity due to enhanced uptake [47].

The results showed highly significant differences between the mean nitrate content of Eruca sativa leaves due to the addition of biochar at levels of 0, 10, and 20 tons ha^{-1}. The highest mean was recorded at the 20 tons ha^{-1} level, reaching 547.0 mg/100 g^{-1}, achieving increases of 2.14% and 5.33% compared to the 10 tons ha^{-1} treatment, which recorded an average of 535.5 mg/100 g^{-1}, and the control treatment of 0 tons ha^{-1}, which recorded the lowest average of 519.3 mg/100 g^{-1}, respectively.

The increase of nitrate content in Eruca sativa leaves due to the addition of biochar is likely due to the enhancement of soil physical and chemical characteristics, improving the retention of nitrogen in the soil, reducing its loss from soil, and increasing its availability within the root zone of plants. All of these aspects could ultimately lead to higher rates of nitrogen absorption by plants than what they are able to incorporate in their leaves thus resulting in an increased level of nitrate accumulation in Eruca sativa leaves [38].

The average for the trait was 571.3 mg 100 g^{-1}. Associated with the application of 100 kg ha^{-1} potassium polyacrylate and 20 t ha^{-1} biochar. This represents an increase of 15.39% compared to the lowest average for this characteristic of 495.1 mg 100 g^{-1} associated with 0 kg ha^{-1} potassium polyacrylate and 0 t ha^{-1} biochar combinations.

In addition, the highest average for the trait was recorded at 580.1 mg/100 g in combination with the application of 10 t ha^{-1} of Poultry manure, 100 kg ha^{-1} potassium polyacrylate and 20 t ha^{-1} biochar. This represents an increase of 18.92% compared to the lowest average 487.8 mg 100 g^{-1} for the trait associated with 0 t ha^{-1} Poultry manure, 0 kg ha^{-1} potassium polyacrylate and 0 tons ha^{-1} biochar combinations.

4.5 Leaf Proline Content (ppm)

The results shown in Table 7 indicate highly significant differences at the 5% probability level between the mean leaf proline content (ppm) of Eruca sativa plants treated with Poultry manure at a concentration of 10 tons ha^{-1} compared to the control treatment (0 tons ha^{-1}). Table 7 shows that the plants treated with Poultry manure at a concentration of 10 tons ha^{-1} recorded the lowest mean, at 50.88 ppm, representing a 4% decrease compared to the control treatment, which recorded the highest mean, at 53.00 ppm.

The reduction for proline in the plants treated with Poultry manure can be attributed to the accumulation of proline in plants experiencing environmental stresses like drought, salinity, and nutrient deficiency. Due to the application of Poultry manure s, soil properties improve, and nutrients become available, improving the physiological state of the plant and decreasing its stress levels, ultimately causing the plant to have a reduction of proline in its tissues.

Consequently, the reduction of proline in the plants is indicative of improved environmental conditions and increased efficiency of metabolic processes related to growth [48].

Table 6: Effect of treatment with Poultry manure, potassium polyacrylate and biochar on the nitrate content of leaves (mg 100 g-1).

Poultry manure	potassium polyacrylate	biochar			The dual interaction between Poultry manure and potassium polyacrylate
		0	10	20	
0	0	487.8 r	492.3 q	511.6 n	497.2 d
	50	498.2 p	515.9 m	527.1 k	513.7 c
	100	536.8 i	551.8 f	562.5 d	550.4 b
10	0	502.4 o	521.0 l	532.5 j	518.6 c
	50	542.3 h	558.0 e	568.2 c	556.2 ab
	100	548.5 g	574.2 b	580.1 a	567.6 a
Average impact of biochar		519.3 c	535.5 b	547.0 a	533.9
The dual interaction between Poultry manure and biochar					
Poultry manure concentration		biochar concentrate			Average effect of Poultry manure
		0	10	20	
0		507.6 d	520.0 d	533.7 bc	520.4 b
10		531.1 bc	551.1 ab	560.3 a	547.5 a
The dual interaction between potassium polyacrylate and biochar					
Potassium polyacrylate concentrations		biochar concentrate			Average potassium polyacrylate effect
		0	10	20	
0		495.1 f	506.6 ef	522.0 de	507.9 c
50		520.2 de	537.0 cd	547.6 bc	534.9 b
100		542.6 c	563.0 ab	571.3 a	559.0 a

The results also indicate that there are highly significant differences at the probability level of 5% between the averages of this trait as a result of treating Eruca sativa plants with potassium polyacrylate at concentrations of 0, 50 and 100 kg ha⁻¹. The results shown in the same table show that the lowest average was obtained as a result of treating the plants with the potassium polyacrylate at a concentration of 100 kg ha⁻¹, as this addition recorded the lowest average, which reached 50.05 ppm, with a decrease of 3.52% and 7.12%, compared to treating the plants with the potassium polyacrylate at a concentration of 50 kg ha⁻¹, which recorded an average of 51.88 ppm, and the control treatment, which recorded the highest average, which was 53.89 ppm, respectively.

The superabsorbent potassium polyacrylate (potassium polyacrylate) improved water status for both plants and their soils. This has resulted in less osmotic stress due to the increased amount of water available to the roots and more balanced water within cells. In turn, less osmotic stress will lead to less need for plants to produce compatible compounds (e.g., proline), which is one of the largest indicators of stress in plants. Improved water status has also resulted in decreased stimulation of the glutamic-dependent proline synthesis pathway, possibly due to an increase in proline catabolism, which accounts for the decreased levels of proline in plants. [49].

The results shown in Table 7 show highly significant differences in the average leaf proline content when treating Eruca sativa plants with biochar at concentrations of 0, 10, and 20 tons ha⁻¹. The lowest average for this trait was recorded at a concentration of 20 tons ha⁻¹, which was 50.90 ppm, with a decrease of 1.85% and 4.07%, respectively, compared to the treatment at a concentration of 10 tons ha⁻¹, which recorded an average of 51.86 ppm, and the control treatment of 0 tons ha⁻¹, which recorded the highest average of 53.06 ppm, respectively.

Proline is an organic compound found in different types of plants as a result of being stressed from different environmental factors like salt or drought. The effects of biochar can influence how much proline accumulates due to biochar's ability to improve soil moisture and provide for greater retention of that moisture, thus lessening the effect of the reduced amount of water on the plant. Biochar will also allow for better absorption of nutrients and more active metabolism, both of which can affect the rate at which proline is produced in plants and allow cells in plants to regulate their amounts and maintain an osmotic balance [38].

The maximum average for this characteristic at 48.86 ppm resulted from a combination of 100 kg/ha potassium polyacrylate and 20 tons/ha biochar, which was 10.87% lower than the highest average of 54.82 ppm achieved from a combination of 0 kg/ha potassium polyacrylate and 0 tons/ha biochar .

Similarly, the combination of 10 tons/ha Poultry manure, 100 kg/ha potassium polyacrylate, and 20 tons/ha biochar also had the highest average leaf proline content of 48.02 ppm or 13.63% lower than the highest average of 55.60 PPM achieved from a combination of 0 tons/ha Poultry manure, 0 kg/ha potassium polyacrylate, and 0 tons/ha biochar (see Table 7).

Table 7: Effect of treatment with poultry manure, potassium polyacrylate and biochar on the leaf content of proline (ppm).

Poultry manure	potassium polyacrylate	biochar			The dual interaction between Poultry manure and potassium polyacrylate
		0	10	20	
0	0	55.60 a	55.13 b	53.71 e	54.82 a
	50	54.67 c	53.36 f	52.45 h	53.49 b
	100	51.73 j	50.62 m	49.71 o	50.68 c
10	0	54.04 d	52.83 g	52.05 i	52.97 b
	50	51.26 k	50.04 n	49.48 p	50.26 cd
	100	51.04 l	49.21 q	48.02 r	49.42 d
Average impact of biochar		53.06 a	51.86 b	50.90 c	51.94

The dual interaction between Poultry manure and biochar

Poultry manure concentration	biochar concentrate			Average effect of Poultry manure
	0	10	20	
0	54.00 a	53.03 ab	51.96 bc	53.00 a
10	52.11 bc	50.69 cd	49.85 d	50.88 b

The dual interaction between potassium polyacrylate and biochar

Potassium polyacrylate concentrations	biochar concentrate			Average potassium polyacrylate effect
	0	10	20	
0	54.82 a	53.98 ab	52.88 bc	53.89 a
50	52.97 bc	51.70 cd	50.97 de	51.88 b
100	51.38 cde	49.91 ef	48.86 f	50.05 c

5 CONCLUSIONS

This study demonstrated that the application of poultry manure, potassium polyacrylate, and biochar, both individually and in combination, significantly improved the physical and chemical properties of sandy soil, as well as the physiological and biochemical performance of *Eruca sativa* plants.

The results confirmed that the combined application of these amendments produced superior effects compared to individual treatments. The triple interaction of poultry manure (10 t ha^{-1}), potassium polyacrylate (100 kg ha^{-1}), and biochar (20 t ha^{-1}) resulted in the highest chlorophyll content, quercetin, erucin, and nitrate levels, along with the lowest proline content, indicating enhanced plant growth, improved metabolic activity, and reduced stress conditions.

These findings demonstrate that the integration of organic and soil-conditioning amendments can effectively enhance nutrient availability, water retention, and overall soil fertility in sandy soils, thereby improving crop performance under challenging environmental conditions.

6 RECOMMENDATIONS

Based on the obtained results, the combined application of poultry manure, potassium polyacrylate, and biochar is recommended for improving sandy soil productivity and enhancing plant performance.

The combination of poultry manure at 10 t ha^{-1}, potassium polyacrylate at 100 kg ha^{-1}, and biochar at 20 t ha^{-1} is suggested as an effective treatment under similar environmental conditions.

Further research should focus on evaluating the long-term effects of these amendments on soil properties, crop yield, environmental sustainability, and economic feasibility across different agricultural systems.

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