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RESEARCH ARTICLE

Response of fig seedlings cv. Aswad Diyala to biochar application and tryptophan foliar spray

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Abstract

Fig is an ancient fruit that grows well in hot and dry climates, making it well-suited to the prevailing climatic conditions in Iraq. It contains many health benefits, including improving digestion, lowering cholesterol levels and providing a variety of vitamins and minerals. Additionally, fig cultivation is an important source of income for many farmers in Iraq, contributing to local economic development. The experiment was conducted in the lath house of the Department of Horticulture and Landscape Gardening, College of Agriculture, University of Anbar. The study period extended from March 15 to November 15, 2024 and aimed to investigate the effects of applying reed biochar at three levels (0 %, 2 % and 4 %), denoted as B0, B1 and B2, respectively and foliar spraying of the amino acid tryptophan at four concentrations (0, 50, 100 and 150 mg L^{-1}), represented as T0, T1, T2 and T3, on selected vegetative and root growth traits of fig seedlings of the 'Aswad Diyala' cultivar. A total of 108 seedlings with uniform vegetative growth were selected. The study was laid out in a 3 × 4 factorial experiment using a Completely Randomized Block Design (CRBD) with 12 treatment combinations, three replications and four seedlings per experimental unit. A two-factor 3 x 4 factorial experiment was implemented according to a CRBD. The experiment contained 12 treatments, three replicates and four seedlings per experimental unit. The addition of reed biochar significantly affected all the traits studied, with the highest level (B2) showing the most notable improvements. It led to a marked increase in seedling height, number of vegetative branches, stem diameter, leaf count, dry weight of both vegetative and root systems and leaf area. Similarly, foliar spraying with the amino acid tryptophan had a significant impact on all traits, with the highest concentration (T3) achieving the best results in terms of seedling growth, leaf development and dry matter accumulation. The interaction between biochar and tryptophan treatments also showed significant effects on most of the traits, with the B2T3 combination yielding the best results for many of the parameters, while the control treatment (B0T0) exhibited the lowest values across all traits.

Keywords: Aswad Diyala; biochar; fig seedlings; root growth; tryoptophan; vegetative growth

Introduction

Ficus carica L., commonly known as fig, is a member of the Moraceae family and the Ficus genus, which includes over 800 plant species (1, 2). The original homeland of figs is West Asia and its cultivation has spread in the Mediterranean basin (3). According to previous study, the homeland of the fig is the fertile part of the Arabian peninsula and it still grows in its wild state and from there it spread to southern Syria and then to the shores of the Mediterranean Sea (4). Today, figs are cultivated in different regions of the world, including Turkey, Egypt, Spain, Greece, America, Italy, Brazil and other places in the world (5, 6). Recently, many countries have recognized the economic potential of plant waste and are actively exploring ways to valorize it rather than treat it as agricultural refuse. The interest of these countries does not stop at the limit of agricultural production and how to increase the quantity of the crop to achieve the highest possible productivity, but rather extends to how to find a new integrated method that guarantees the benefit of plant waste by reusing it and transforming it from the usual concept that it is a huge burden on the farmer and the environment by accumulating and burning it to economic value with diversified uses and investments (7). Plant waste is used in animal nutrition, energy generation, fertilization, paper pulp manufacturing, high-quality wooden boards such as sunflower waste, cotton and grape pruning waste and the production of manufactured materials such as ethyl alcohol, biogas, vinegar, carbon dioxide liquid and others (8).

The process of preparing biochar from recycling plant wastes rich in nutrients is one of the important directions for optimal exploitation of these wastes and the quality of biochar depends on the type of original material from which it is made. The process of direct burning of organic matter leads to the loss of part of the carbon, which is evaporated in the form of carbon dioxide gas into the atmosphere, While the obtained biochar can retain approximately 50 % of the original carbon in the soil-thereby enhancing soil fertility-its carbon sequestration potential largely depends on the pyrolysis temperature and the type of feedstock used during production (9, 10). In addition to the important role of biochar in increasing the soil's storage capacity for nutrients and water, biocarbon added to the soil improves the chemical and physical properties of the soil and is more stable than the organic materials that can be added to the soil. Therefore, all the benefits associated with using biochar, including the ability to preserve nutrients in the soil and increase fertility, are more permanent compared to alternative soil management methods or adding fertilizers (11, 12).

Over the years, improving soil fertility for agricultural production has become limited to the use of chemical fertilizers, which have recently shown their negative impact on the deterioration of soil properties and microorganisms, as well as their cumulative impact on human and animal health. Therefore, biochar fertilizer has been proposed as one of the effective options for improving soil traits and increasing its ability to retain moisture, which reflects positively in increasing crop growth and production (13). These positive effects of adding biochar to soil have been studied by many researchers (14-17).

Amino acids are natural chelating agents with low molecular weights, characterized by high solubility in water and the ability to penetrate plant cell membranes, especially when applied as foliar sprays. When combined with biochar, which improves soil structure and nutrient retention, amino acids may act synergistically by enhancing nutrient uptake and physiological activity in plants. This potential synergy is supported by previous studies suggesting that biochar can serve as a carrier for amino acids and improve their effectiveness in promoting plant growth. Therefore, they directly or indirectly affect the physiological activities that contribute to building basic compounds such as carbohydrates, proteins, fats, vitamins, etc. (18, 19). Amino acids also contribute to increasing pollen germination and pollen tube growth, which enhances the percentage of setting. Additionally, they play a crucial role in improving vegetative growth and the overall health of the plant, which boosts its resistance to diseases, insect infestations and stress conditions (20). Amino acids are also one of the most important biostimulants that are rapidly transported within the plant and have a role in the formation of important and necessary hormones and enzymes for the plant at all stages of its growth (21). Tryptophan plays a crucial role as a precursor in multiple auxin (IAA) biosynthetic pathways, highlighting its importance in plant development (22).

Given the limited research on the combined effect of biochar and tryptophan foliar application on fig seedlings under Anbar Governorate conditions, this study aims to evaluate their impact on the vegetative and root development of *Ficus carica* cv. Aswad Diyala. This study is crucial to fill the knowledge gap in this area, focusing on optimizing nutrient utilization during early seedling stages while reducing reliance on chemical fertilizers, which is particularly important given the limited environmental conditions in the region.

Material and Methods

Experiment implementation site

The study was conducted in the lath house of the Department of Horticulture and Landscape Gardening, College of Agriculture, Anbar University for the period from mid-March of the year 2024 until mid-November of the same year to determine the response of two-year-old fig seedlings cv. Aswad Diyala to the addition of biochar and spraying with the amino acid tryptophan. Seedlings that were as homogeneous as possible in terms of their vegetative growth, including height, leaf size and branch development, were selected as possible were brought on January 3, 2024 and were planted in 15 kg plastic pots containing a mixture of river soil and peat moss at a ratio of 3:1. Routine practices, including pest control and drip irrigation, were applied uniformly to all treatments. In addition, all seedlings were fertilized with NPK (20:20:20) in an amount of 7 g per seedling and for three dates (March 5, June 5 and September 5). An analysis was conducted to determine several chemical and physical properties of the soil as shown in Table 1, including "pH, Electrical Conductivity (EC), organic matter content, available phosphorus, total nitrogen, available potassium, calcium carbonate and texture".

Table 1. Some physical and chemical characteristics of culture medium

Av. P mg Kg^{-1}	Total N %	$CaCO_3$ g Kg^{-1}	Bulk density g cm^{-3}	O.M %	EC ds m^{-1}	pH
2.68	0.095	117.49	1.13	0.24	0.82	7.47
Cl^- Mq L^{-1}	**$HCO_3^=$ Mq L^{-1}**	**$CO_3^=$ Mq L^{-1}**	**Na^+ Mq L^{-1}**	**Mg^{++} Mq L^{-1}**	**Ca^{++} Mq L^{-1}**	**Av. K mg Kg^{-1}**
1.92	1.27	Nil	0.36	3.57	4.16	83.30
Texture			**Clay g Kg^{-1}**	**Silt g Kg^{-1}**	**Sand g Kg^{-1}**	**$SO_4^=$ Mq L^{-1}**
Sandy clay loam			239.4	79.2	681.4	1.63

Treatments used in the experiment

Reed biochar (It is one of the aquatic plants that grow particularly in the marshes, as well as in the Tigris and Euphrates rivers and lakes) was air-dried, manually cut and assembled into individual piles, which were then pyrolyzed for 6-7 hrs until the temperature reached 300-380 °C (22). The combustion was then extinguished by gradually adding water and soil to the pile to seal ventilation openings, while creating small perforations at various locations to allow controlled aeration. Ventilation was controlled by adjusting the number of openings to regulate combustion speed. This method allowed for slow combustion, with the temperature gradually dropping to about 60 °C at the halfway point and the completion of the combustion process was indicated by a change in the color of the flame from black to blue. The biochar was then allowed to cool completely before being considered ready (23). Three weight-by-weight levels of biochar were applied to the seedlings on March 15, 2024: 0 % (B0), 2 % (B1) and 4 % (B2), calculated based on the dry weight of the soil. Table 2 shows some of the chemical components of biochar. The amino acid "tryptophan" was sprayed on the seedlings' leaves until they were completely wet at four different concentrations: 0, 50, 100 and 150 mg L^{-1} (designated as T0, T1, T2 and T3, respectively). March 15, April 15, May 15, June 15 and September 15 were the dates of the spraying.

Table 2. Characteristics of the biochar used in the experiment

pH	**8.03**
EC ds m^{-1}	**11.14**
Nitrogen (%)	**0.348**
Phosphorus (%)	**17**
Potassium (%)	**0.553**
Zinc (mg kg^{-1})	**51.8**

Experimental design

Three replicates were used in a Randomized Complete Block Design (RCBD) factorial experiment (3 × 4). A total of 108 seedlings were employed in the experiment, with 36 experimental units (seedlings) each block. Each treatment was replicated three times, with a total of 108 seedlings arranged in 36 experimental units. The Least Significant Difference (LSD) test was used to evaluate the means of the traits under study at a 0.05 probability level after the data were statistically processed using the Genstat statistical software (24).

Studied traits

Increase in seedling height (cm)

In the beginning (March 15, 2024) and end (November 15, 2024) of the experiment, the height of the seedlings was measured using a metal measuring tape from the soil surface to the plant apex.

Increase in the number of vegetative branches (seedling branch^{-1})

At the start of the experiment and at the conclusion, the number of freshly formed shoots per seedling was noted. By deducting the initial count from the final count, the increase was calculated.

Increase in main stem diameter (mm)

At the start and finish of the experiment, the stem diameter was measured with an electronic caliper at a height of 2 cm above the soil surface. The difference between the final and first values was used to compute the increase.

Average diameter of vegetative branches (mm)

Using an electronic calliper, the diameters of the recently formed shoots were measured.

Increase in leaf number (leaves seedling^{-1})

Before and after the experiment, the number of leaves per seedling was noted. By deducting the original count from the end count, the increase in leaf number was calculated.

Dry weight of vegetative and root systems

The experiment was conducted to determine the dry weight of the root and vegetative systems. Two seedlings were chosen from each treatment and the vegetative system was separated from the root system, weighed and repeatedly washed with tap water before being dried in an electric oven at 70 °C until the weight remained constant (25). The samples were then removed from the oven to allow them to equilibrate to room temperature before being reweighed using a sensitive balance and the dry matter content was calculated.

Leaf area (cm^2)

After the experiment was completed, leaf area was measured using the procedure outlined previously (26).

Results

Increase in seedling height (cm)

The use of biochar significantly increased the height of fig seedlings cv. Aswad Diyala, according to statistical data shown in Fig. 1. The B0 (0 %) and B1 (2 %) treatments had the lowest values, measuring 34.39 cm and 34.53 cm, respectively, while the B2 (4 %) treatment showed the highest statistically significant increase, reaching the highest value of 45.66 cm. Applying tryptophan also had a substantial impact; the T3 treatment (150 mg L^{-1}) produced the largest rise, measuring 44.49 cm, followed by T1 (50 mg L^{-1}) and T2 (100 mg L^{-1}), which produced increases of 38.21 cm and 36.44 cm, respectively. At 33.64 cm, the T0 (0 mg L^{-1}) therapy showed the smallest rise. In terms of the interaction impact, the B2T3 treatment showed the largest significant increase in seedling height (54.48 cm), which was not much different from B2T1. The control therapy (B0T0), on the other hand, showed the least gain, with a mean height increase of 28.74 cm (Table 3).

Increase in the number of vegetative branches (branches seedling^{-1})

According to the findings shown in Fig. 2, the application of biochar had a major impact on the growth in the number of vegetative branches per seedling. With 6.92 branches seedling^{-1}, the B2 (4 %) treatment showed the largest significant increase, while the B0 (0 %) treatment showed the lowest value, with 5.81 branches seedling^{-1}. The application of tryptophan also caused notable differences between treatments; the T3 treatment (150 mg L^{-1}) achieved the highest value of 7.76 branches seedling^{-1}, indicating a significant difference from T1 (50 mg L^{-1}) and T2 (100 mg L^{-1}), which did not significantly differ from one another. With 5.84 branches seedling^{-1}, the T0 (0 mg L^{-1}) treatment had the lowest value. The B2T3 treatment had the largest increase of 7.7 branches seedling^{-1} in terms of the interaction effect, whereas the control treatment (B0T0) was the one with the lowest value of 3.4 branches seedling^{-1}.

Increase in main stem diameter (mm)

The application of biochar significantly impacted the growth in main stem diameter, according to the statistical data shown in Fig. 3. With an increase of 4.97 mm, the B2 (4 %) therapy had the largest rise and was noticeably greater than the B0 (0 %) treatment. The B0 (0 %) therapy showed the least rise, measuring 4.16 mm, while the B1 (2 %) treatment came in second with 4.58 mm. The T3 (150 mg L^{-1}) treatment had the largest increase (5.07 mm), which was significantly different from the T0 (0 mg L^{-1}) and T2 (100 mg L^{-1}) treatments. Similarly, the foliar application of tryptophan had a significant impact on this characteristic. The T0 therapy showed the smallest growth (4.21 mm). The increase in stem diameter was also significantly impacted by the interaction between tryptophan and biochar. Compared to the B1T3, B2T2, B2T0 and B3T1 treatments, the B2T3 therapy had the greatest value (5.84 mm). On the other hand, the B0T0 and B0T2 treatments had the lowest values, measuring 3.64 mm and 3.65 mm, respectively.

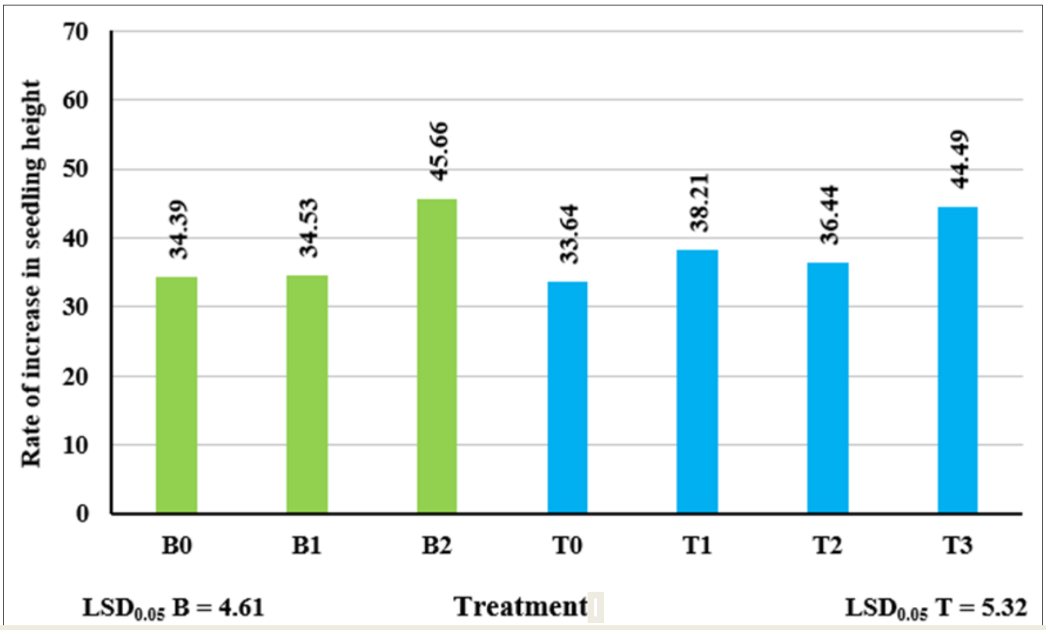

Fig. 1. Effect of biochar application and tryptophan foliar spray on rate of increase in seedling height of fig seedlings (cv. Aswad Diyala).

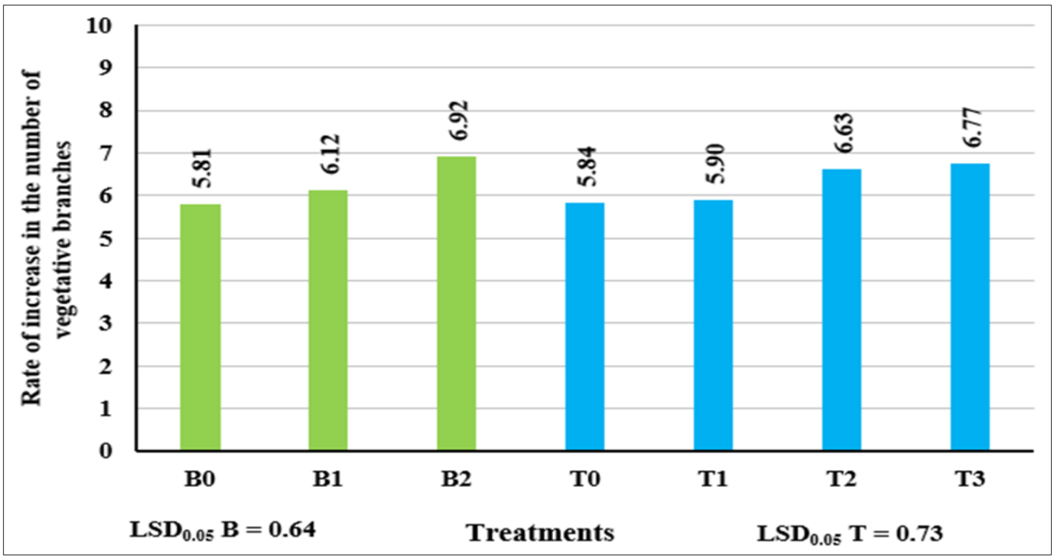

Fig. 2. Effect of biochar application and tryptophan foliar spray on rate of increase in the number of vegetative branches (seedling branch-1) of fig seedlings (cv. Aswad Diyala).

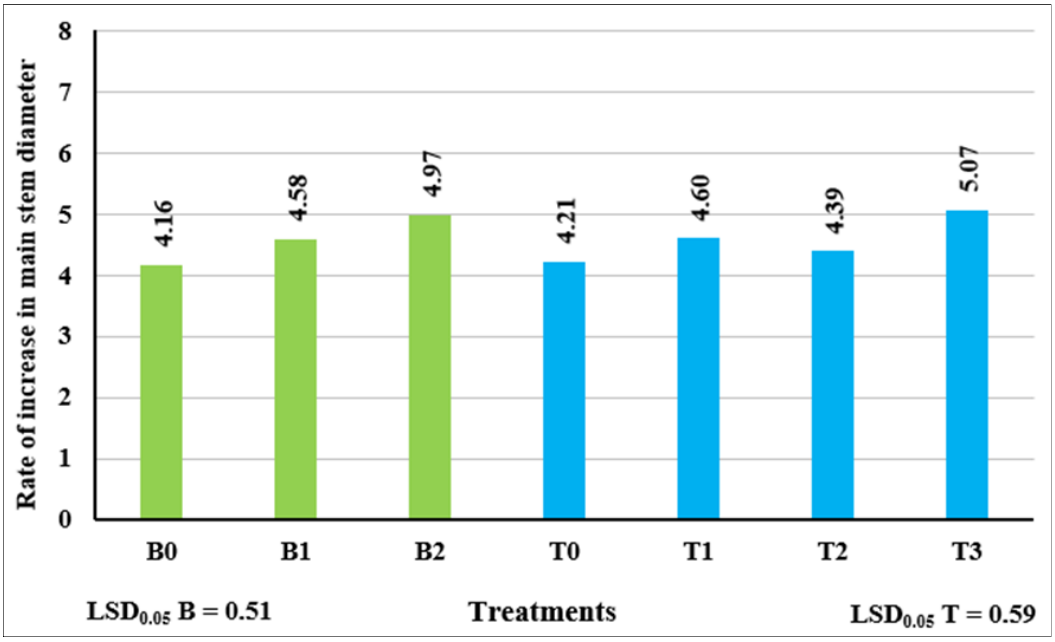

Fig. 3. Effect of biochar application and tryptophan foliar spray on rate of increase in main stem diameter (mm) of fig seedlings (cv. Aswad Diyala).

Diameter of vegetative branches (mm)

The diameter of the vegetative branches was statistically significantly impacted by the application of biochar to fig seedlings, as shown in Fig. 4. In comparison to the B0 (0 %) treatment, which had the lowest value of 5.47 mm, the B2 (4 %) treatment demonstrated the largest significant increase, measuring 7.01 mm, or 28.15 % more. The T2 (100 mg L^{-1}) treatment achieved the greatest value (7.10 mm), indicating a 25 % increase over the T0 (0 mg L^{-1}) treatment, which recorded the lowest value of 5.68 mm. In the same way, the foliar administration of tryptophan had a considerable impact on this characteristic. Additionally, values of 6.67 mm and 5.87 mm were reported for the T3 (150 mg L^{-1}) and T1 (50 mg L^{-1}) treatments, respectively. With respect to the interaction effect, the B2T3 treatment had the largest vegetative branch diameter (7.95 mm), while the B0T2, B1T0, B1T2, B1T3 and B2T2 treatments did not differ significantly from one another. However, the B0T0 therapy had the lowest value, measuring 4.28 mm.

Increase in the number of leaves (leaf seedling^{-1})

The results shown in Fig. 5 show that the application of biochar increased the number of leaves in a way that was statistically significant. In contrast to the B0 (0 %) and B1 (2 %) treatments, which recorded the lowest values of 48.72 and 49.35 leaf seedling^{-1}, respectively, the B2 (4 %) treatment showed the largest increase, reaching 60.52 leaf seedling^{-1}. The T3 (150 mg L^{-1}) treatment achieved the greatest value (58.82 leaf seedling^{-1}), significantly different from all other treatments. Likewise, tryptophan applied topically had a considerable impact. The T0 (0 mg L^{-1}) and T2 (100 mg L^{-1}) treatments showed the lowest values, recording 49.35 and 49.40 leaf seedling^{-1}, respectively. The T1 (50 mg L^{-1}) treatment came next, recording 53.88 leaf seedling^{-1}. The interaction between the addition of biochar and spraying with tryptophan showed an effect that reached the level of significance, the B2T3 treatment had the largest increase in leaf number (68.94 leaf seedling^{-1}), which was substantially different from all other treatments except B2T1 and the interaction effect showed a similar pattern. Conversely, the B0T0 treatment had the lowest value, measuring 43.72 leaf per seedling^{-1}.

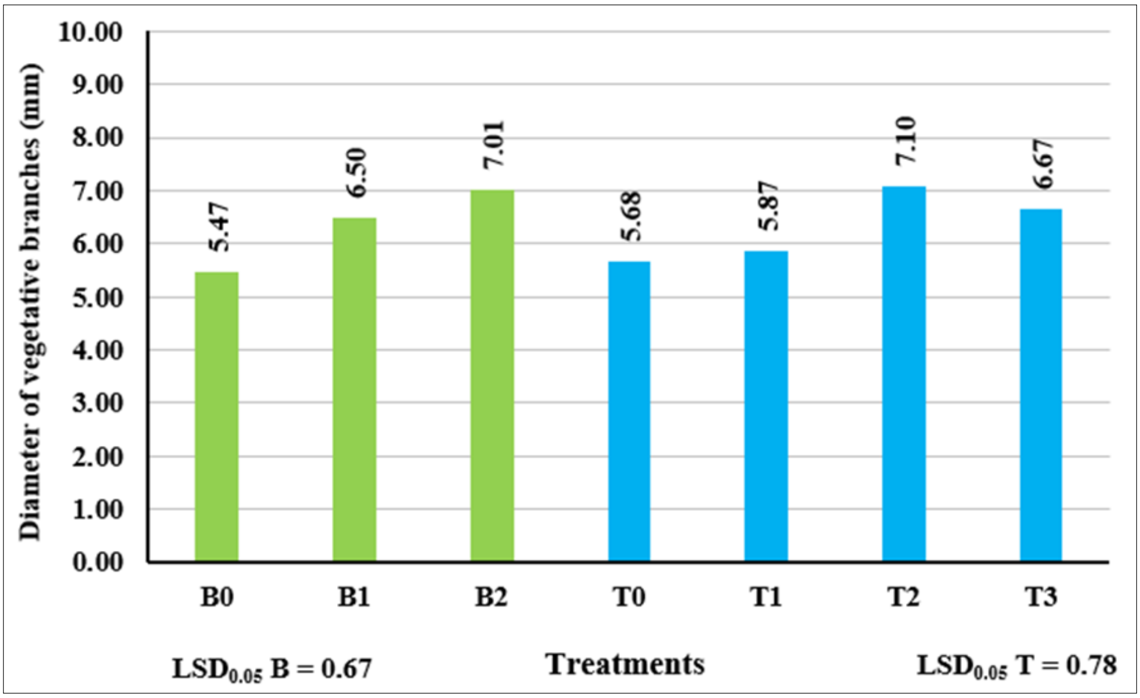

Fig. 4. Effect of biochar application and tryptophan foliar spray on diameter of vegetative branches (mm) of fig seedlings (cv. Aswad Diyala).

Table 3. Effect of biochar application and tryptophan foliar spray on some vegetative traits of fig seedlings (cv. Aswad Diyala)

(B) Biochar	(T) Tryptophan	Increase in seedling height (cm)	Increase in the number of vegetative branches (Branches seedling^{-1})	Increase in main stem diameter (mm)	Diameter of vegetative branches (mm)
B0 (0 %)	T0 (0 mg L^{-1})	28.74	4.23	3.64	4.28
	T1 (50 mg L^{-1})	30.91	5.79	4.37	5.86
	T2 (100 mg L^{-1})	34.87	6.43	3.65	6.62
	T3 (150 mg L^{-1})	43.03	6.81	4.98	5.14
B1 (2 %)	T0 (0 mg L^{-1})	36.62	6.48	3.96	6.73
	T1 (50 mg L^{-1})	33.35	5.67	4.56	5.50
	T2 (100 mg L^{-1})	32.18	6.31	5.39	6.87
	T3 (150 mg L^{-1})	35.96	6.04	4.40	6.91
B2 (4 %)	T0 (0 mg L^{-1})	35.54	6.82	5.04	6.03
	T1 (50 mg L^{-1})	50.36	6.24	4.87	6.24
	T2 (100 mg L^{-1})	42.27	7.15	4.12	7.82
	T3 (150 mg L^{-1})	54.48	7.47	5.84	7.95
	$LSD_{5\%}$	9.22	1.26	1.03	1.35

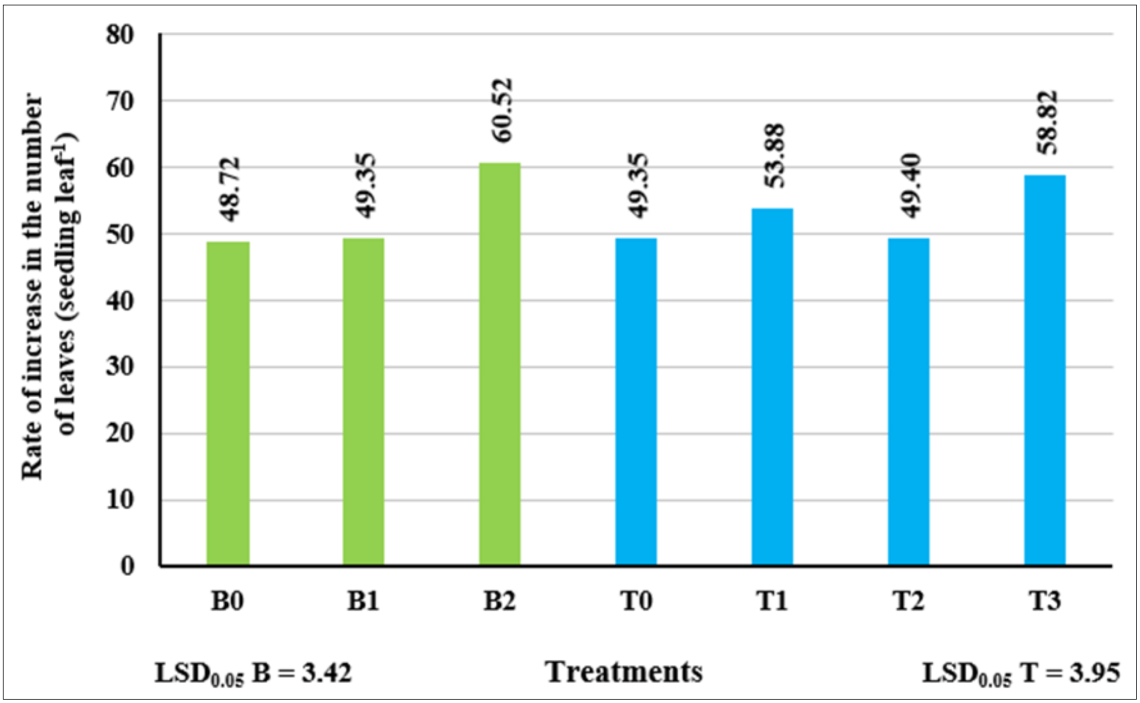

Fig. 5. Effect of biochar application and tryptophan foliar spray on rate of increase in the number of leaves (leaf seedling-1) of fig seedlings (cv. Aswad Diyala).

Dry weight of vegetative system (gm)

The application of biochar had a statistically significant impact on the vegetative system's dry weight, as evidenced by the B2 (4 %) treatment, which outperformed all other treatments with the highest value of 169.25 g. The B0 (0 %) treatment had the lowest value at 147.82 g, followed by the B1 (2 %) treatment, which recorded 156.16 g (Fig. 6). The T2 (100 mg L^{-1}) treatment achieved the maximum value of 165.08 g, which was significantly different from all other treatments. In the same way, the foliar application of tryptophan had a considerable impact on the dry weight of the vegetative system. The T1 (50 mg L^{-1}) and T3 (150 mg L^{-1}) treatments came next, with corresponding weights of 155.43 and 158.30 g. On the other hand, at 152.16 gm, the T0 (0 mg L^{-1}) therapy showed the lowest value. In terms of the interaction impact, the B2T3 treatment outperformed all other treatments by recording the highest dry weight of the vegetative system (178.64 g). On the other hand, the B0T0 therapy had the lowest value, measuring 144.56 g.

Dry weight of root system (gm)

According to the findings shown in Fig. 7, the dry weight of the root system of fig seedlings cv. Aswad Diyala increased significantly when biochar was added. With the highest value of 80.47 g, the B2 (4 %) treatment differed considerably from the B0 (0 %) and B1 (2 %) treatments. The B0 treatment had the lowest recorded value (64.71 g). The treatments had a substantial impact on the parameter under study about tryptophan applied topically. With a dry root weight of 75.38 g, the T3 (150 mg L^{-1}) treatment outperformed T0 (0 mg L^{-1})

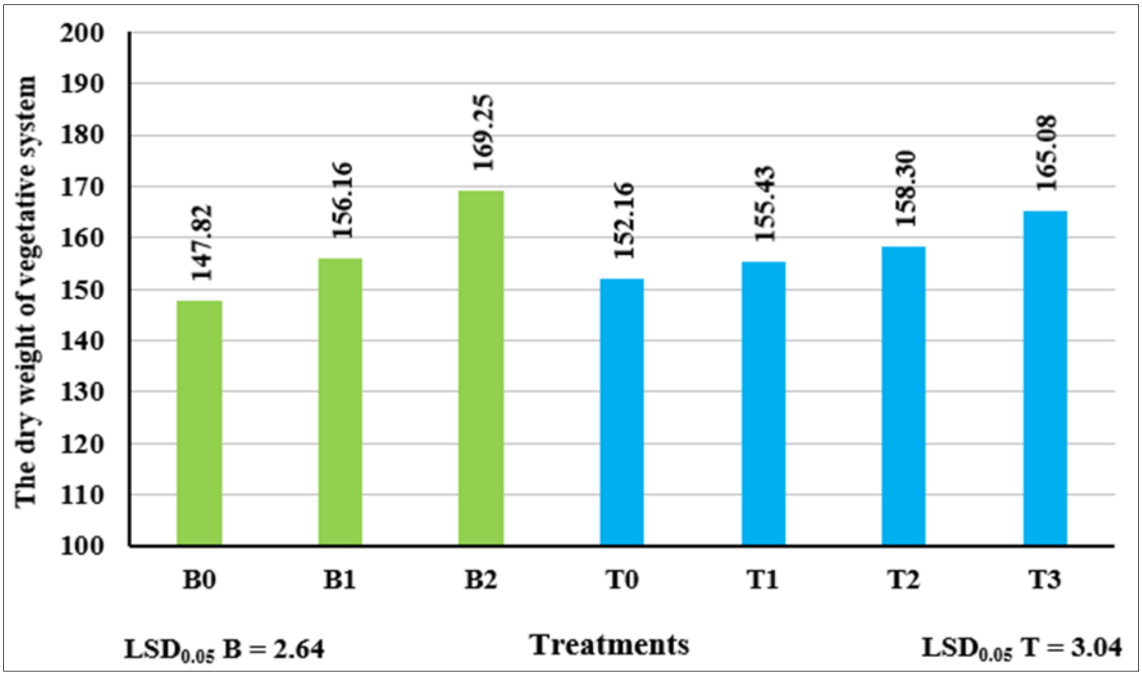

Fig. 6. Effect of biochar application and tryptophan foliar spray the dry weight of vegetative system (g) of fig seedlings (cv. Aswad Diyala).

and T1 (50 mg L^{-1}). T1 recorded 70.77 g, while T2 (100 mg L^{-1}) came in second with 75.27 g. The T0 therapy got the lowest value (68.75 g). With no discernible difference from B2T3, the B2T2 treatment recorded the highest value of 88.23 g, indicating that the interaction effect also had a substantial impact. However, the B0T1 therapy had the lowest value, measuring 63.04 g (Table 4).

Leaf area (cm^2)

Fig. 8 findings show that adding biochar to fig seedlings significantly increased their leaf area. In comparison to the B0 (0 %) treatment, which had the lowest value (126.78 cm^2), the B2 (4 %) treatment had the highest value (137.81 cm^2), indicating an 8.7 % increase. The intermediate leaf area produced by the B1 (2 %) treatment was 128.00 cm^2. Likewise, tryptophan applied topically had a major impact on leaf area. The T0 (0 mg L^{-1}) treatment had the lowest result (125.80 cm^2), while the T3 (150 mg L^{-1}) treatment had the maximum leaf area (138.77 cm^2), a 10.3 % increase. 127.93 cm^2 and 130.95 cm^2 were obtained for the T1 (50 mg L^{-1}) and T2 (100 mg L^{-1}) treatments, respectively. Conversely, when it came to affecting leaf area, the interaction effect between the application of biochar and tryptophan foliar spray did not reach statistical significance.

Discussion

The application of reed biochar has been shown to improve fig seedlings cv. Aswad Diyala's vegetative and root growth characteristics by increasing the area of their leaves (Fig. 8). By increasing the production of chlorophyll, this expansion improves the photosynthetic process and increases the synthesis of carbohydrates, which in turn supplies the energy required for vegetative development. Monosaccharides, the basic building blocks of plant tissues, are directly produced during photosynthesis (27). Additionally, biochar stimulates plant growth by enhancing root development, especially the elongation of absorptive roots, which improves the uptake and accumulation of nutrients in various plant tissues (28, 29). Among its many advantageous qualities are its low

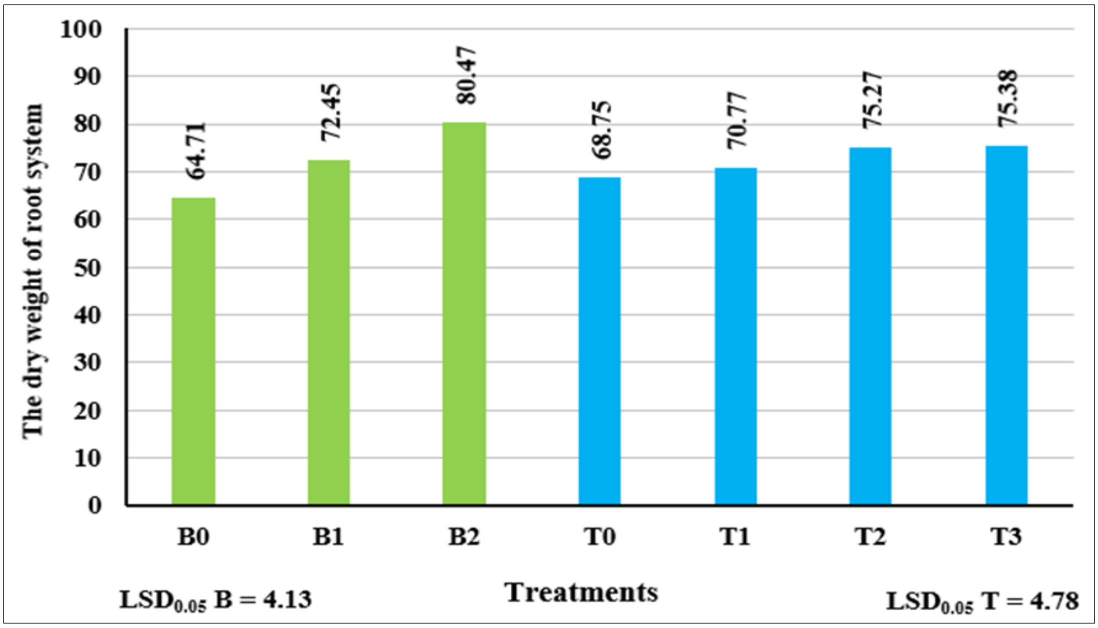

Fig. 7. Effect of biochar application and tryptophan foliar spray on the dry weight of root system (g) of fig seedlings (cv. Aswad Diyala).

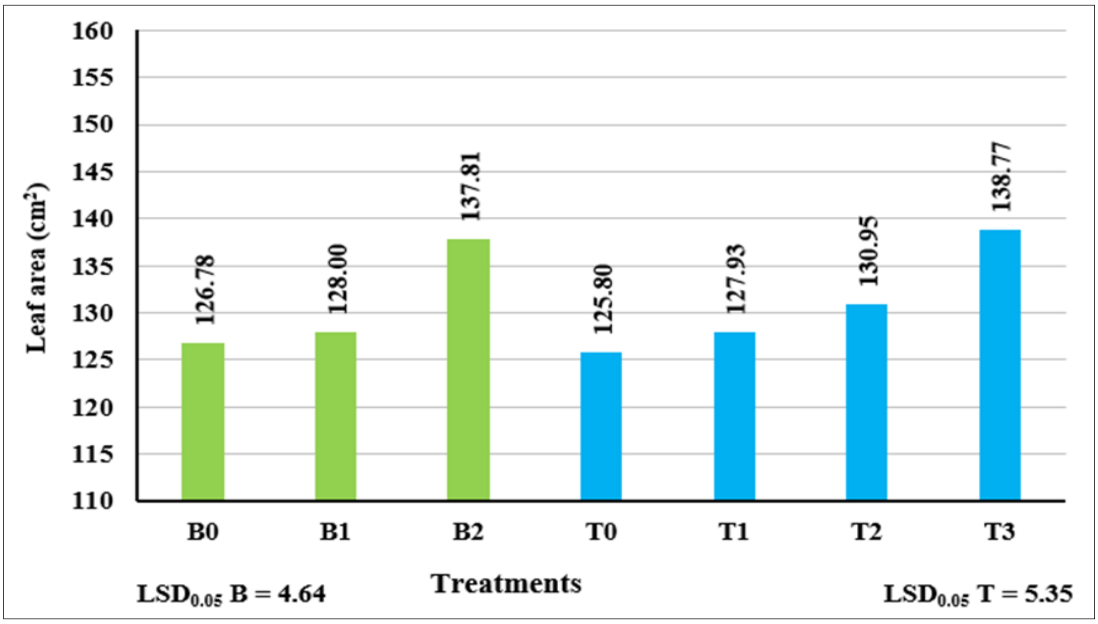

Fig. 8. Effect of biochar application and tryptophan foliar spray on leaf area (cm^2) of fig seedlings (cv. Aswad Diyala).

Table 4. Effect of biochar application and tryptophan foliar spray on some vegetative and root traits of fig seedlings (cv. Aswad Diyala).

(B) Biochar	(T) Tryptophan	Increase in the number of leaves (Leaves seedling^{-1})	Dry weight of vegetative system	Dry weight of root system (gm)	Leaf area (cm^2)
B0 (0 %)	T0 (0 mg L^{-1})	43.72	144.56	65.23	121.58
	T1 (50 mg L^{-1})	47.56	148.41	63.04	124.85
	T2 (100 mg L^{-1})	47.78	146.09	66.73	127.73
	T3 (150 mg L^{-1})	55.86	152.23	63.85	132.97
B1 (2 %)	T0 (0 mg L^{-1})	50.49	150.85	69.38	128.64
	T1 (50 mg L^{-1})	48.94	153.16	73.80	127.29
	T2 (100 mg L^{-1})	46.31	156.24	70.87	125.12
	T3 (150 mg L^{-1})	51.67	164.37	75.64	130.93
B2 (4 %)	T0 (0 mg L^{-1})	53.85	161.08	71.61	127.18
	T1 (50 mg L^{-1})	65.13	164.72	75.46	131.65
	T2 (100 mg L^{-1})	54.16	172.58	88.23	140.01
	T3 (150 mg L^{-1})	68.94	178.64	86.54	152.42
LSD 5 %		6.85	5.27	8.27	9.16

density, high porosity and high carbon content (30, 31). These micropores enhance the physical and chemical characteristics of soil, especially by reducing pH and boosting nutrient availability (32). Moreover, biochar enhances nutrient retention and supports the gradual release of nutrients, particularly phosphorus, which otherwise tends to bind with calcium carbonate and become immobilized (33, 34). By increasing its availability in the soil solution, this mechanism makes it easier for plant roots to absorb it, which benefits plant growth (35, 36). Additionally, by creating a well-aerated environment with many micropores that retain nutrients and prevent their fixation, biochar encourages microbial activity, which further enhances nutrient release and availability (37, 38). The results of the study are consistent with previous findings (39, 40).

The study's findings also show that tryptophan, an amino acid, had a substantial impact on all vegetative and root growth characteristics of fig seedlings when applied topically. Due to its direct penetration through stomata, the epidermis, or wounds, foliar fertilizer administration enables quick absorption and translocation. This results in a constant nutrient supply and metabolic processes, which eventually improve vegetative growth indices (41). The benefits of tryptophan administration are explained by the increased leaf area, which boosts the generation of chlorophyll, increases photosynthetic efficiency and boosts the synthesis of carbohydrates for the stimulation of overall plant growth (42). Tryptophan also acts as a precursor for enzyme activity and protein synthesis (43). Additionally, tryptophan is essential for the manufacture of indole-3-acetic acid (IAA), a vital plant hormone that promotes cell elongation and expansion by making cell walls more flexible, which enables cells to take up more water and nutrients (44, 45). In addition to facilitating the movement of nutrients from synthesis sites to storage or usage areas and controlling protein metabolism, auxins-including IAA-also aid in stem elongation by encouraging vascular tissue cell proliferation and differentiation (46, 47). Additionally, they contribute to apical dominance, tropic responses and root formation by preventing the growth of lateral buds by building up high auxin concentrations in the shoot apex. Auxins also inhibit chlorophyll degradation by decreasing chlorophyllase activity and postpone leaf senescence (48, 49). The results of the study are consistent with previous findings (50, 51).

Conclusion

The results demonstrated that fig seedlings cv. Aswad Diyala responded positively to the application of Reed biochar, with the highest level (B2, 4 %) yielding the most favourable growth parameters. Furthermore, all studied traits were significantly influenced by the foliar application of the amino acid tryptophan. The highest concentration (T3, 150 mg L^{-1}) produced the best results for most growth parameters. Based on these findings, it is recommended to apply Reed biochar and tryptophan at their highest tested concentrations to enhance the growth and development of fig seedlings. Future research could explore the long-term effects of these treatments under field conditions, assess their impact on fruit yield and quality and investigate their interactions with different soil types and environmental stress factors.

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Authors' contributions

AFZA was responsible for creating the initial research ideas and collecting the literature review to achieve the final idea for this research, as well as performing statistical analysis after collecting data to investigate the effect of individual factors solely or interaction between them, moreover comprehensive reading for the final manuscript. AYMA carried out experiments, data collection and interpretation of results; moreover, the initial writing of the manuscript also compared the findings with the literature and made the conclusions built into the output of this research.

Compliance with ethical standards

Conflict of interest: Authors have stated that there are no conflicts of interest.

Ethical issues: None

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