The North African Journal of Scientific Publishing (NAJSP)
مجلة شمال إفريقيا للنشر العلمي (NAJSP)
E-ISSN: 2959-4820
Volume 4, Issue 4, 2026
Page No: 110-117
Website: https://najsp.com/index.php/home/index
SJIFactor 2024: 5.49 معامل التأثير العربي (AIF) 2025: 0.69 ISI 2024: 0.696

Date-Palm Residue Biochar Effects on Rocket (Eruca sativa Mill.) Growth and Soil Chemical Properties

Thuraya E. Wahiba[1*], Ayada M. Hallab[2], Mohamed A. Finner[3], Mohamed T. Morghem[4], Abdusalam M. Benhmeda[5]
[1]Department of Horticulture, Faculty of Agriculture, University of Tripoli, Libya
[2]Libyan National Research Agency, Libya
[3,4]Department of Agricultural Engineering, Faculty of Agriculture, University of Tripoli, Libya.
[5]Agricultural Research Center, Tripoli Libya

تأثير إضافة الفحم الحيوي (بايوتشار) لمخلفات نخلة التمر على نمو نبات الجرجير (*Eruca sativa Mill.*) والخصائص الكيميائية للتربة

ثريا الصديق وهيبة[1*]، عيادة محمد هلاب[2]، محمد أبوصاع فنير[3]، محمد الطاهر مرغم[4]، عبد السلام محمد بن احميدة[5]
[1]قسم البستنة، كلية الزراعة، جامعة طرابلس، ليبيا
[2]الهيئة الليبية للبحث العلمي، ليبيا
[3،4]قسم الهندسة الزراعية، كلية الزراعة، جامعة طرابلس، ليبيا
[5]مركز البحوث الزراعية، ليبيا

*Corresponding author: T.wahiba@uot.edu.ly

Received: July 24, 2026	Accepted: October 03, 2026	Published: October 18, 2026

Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Abstract:
Biochar derived from date-palm residues could be considered a valuable resource for agricultural applications. However, its effect depends on application rates and growing conditions. The present study aimed to evaluate the effects of date-palm residue biochar incorporated into soil at 1%, 2%, and 3% (w/w), compared to an untreated control, on rocket (Eruca sativa Mill.) growth and changes in the chemical properties of the growing media. The experiment was laid out in a randomized complete block design (RCBD), comprising 32 planting bags distributed across three blocks, with eight bags per treatment and two plants initially established per bag. Each bag constituted one experimental unit. Plant height increments were analyzed using analysis of variance (ANOVA) in SPSS, and treatment means were compared using Duncan's multiple range test at the 5% significance level. Soil chemical measurements were summarized descriptively. Soil pH and electrical conductivity (EC) were measured before planting and at the end of the experiment using one representative sample per treatment at each sampling time. These measurements were summarized descriptively. All plants were irrigated with water having an EC of 2.90 mS cm^{-1}, and no fertilizer was applied. Plant height increase was significantly higher in the control (1.81 cm) than in the 1%, 2%, and 3% biochar treatments (0.83, 0.59, and 0.85 cm, respectively) during the first measurement period ($p < 0.001$), with no significant differences among biochar rates according to Duncan's multiple range test. Treatment effects were not significant during the second or third intervals ($p = 0.472$ and 0.919, respectively). Mean cumulative height increments were 2.49, 1.46, 1.06, and 1.48 cm for the control, 1%, 2%, and 3% treatments, respectively. Soil pH declined from 8.70, 8.04, 8.03, and 7.98 before planting to 7.30, 7.50, 7.50, and

7.41 at the end of the experiment for the control, 1%, 2%, and 3% treatments, respectively. Corresponding EC values increased from 0.70, 6.04, 10.02, and 15.95 to 10.60, 13.31, 18.31, and 22.40 mS cm^{-1}. In conclusion, the date-palm biochar application reduced rocket height increment during the first measurement interval, whereas no significant differences were observed among treatments during the second and third intervals.

Keywords: date-palm residues; biochar; rocket; height increment; soil electrical conductivity.

الملخص:
يعد الفحم الحيوي (بايوتشار) لمخلّفات نخلة التمر مصدراً قيّماً للتطبيقات الزراعية، إلا أن مدى تأثيره يتوقف على معدلات الإضافة وظروف النمو .هدفت هذه الدراسة إلى تقييم تأثير إضافة بايوشار مخلفات نخلة التمر إلى التربة بمعدلات 1%، و2%، و3% (وزن/وزن)، مقارنةً بمعاملة الشاهد (بدون إضافة)، على نمو نبات الجرجير (Eruca sativa Mill.) والتغيرات في الخواص الكيميائية لوسط النمو. نُفّذت التجربة وفق تصميم القطاعات العشوائية الكاملة(RCBD) باستخدام 32 أكياس زراعة مُوزّعة على ثلاثة قطاعات (بواقع 8 أكياس لكل معاملة وشتلتين لكل كيس في البداية، حيث مثّل كل كيس وحدة تجريبية واحدة) .حُللت قراءات الزيادة في طول النباتات باستخدام تحليل التباين (ANOVA) عبر برنامج SPSS، وقُورنت متوسطات المعاملات باستخدام اختبار دنكن متعدد المدى عند مستوى معنوية 5%، بينما لُخِّصت قياسات التربة الكيميائية وصفياً .قُيس الرقم الهيدروجيني (pH) والتوصيل الكهربائي (EC) للتربة قبل الزراعة وفي نهاية التجربة باستخدام عينة ممثلة واحدة لكل معاملة في كل موعد أخذ عينات .رُويت جميع النباتات بمياه ذات توصيل كهربائي بلغ 2 90.ميلي سيمنز/سم، دون إضافة أي سماد. أظهرت النتائج أن الزيادة في ارتفاع النبات كانت أعلى معنوياً في معاملة الشاهد (1 81.سم) مقارنة بمعاملات البايوشار 1%، و2%، و3% (830.، و590.، و0 85.سم على التوالي) خلال فترة القياس الأولى($p < 0.001$) ، دون وجود فروق معنوية بين معدلات البايوشار المختلفة وفقاً لاختبار دنكن .في المقابل، لم تكن تأثيرات المعاملات معنوية خلال الفترتين الثانية والثالثة (0.472 و$p= 0.919$) على التوالي .وبلغت متوسطات الزيادة التراكمية في الارتفاع 2.49، 1.06، 1.46 و1.48 سم لمعاملات الشاهد، و1%، و2%، و3% على التوالي. على صعيد الخواص الكيميائية، انخفض الرقم الهيدروجيني (pH) للتربة من 8.07، 8.04، 8.03 و7.98 قبل الزراعة إلى 7.30، 7.50، 7.05 و7.41 في نهاية التجربة لمعاملات الشاهد، و1%، و2%، و3% على التوالي .بينما ارتفعت قيم التوصيل الكهربائي (EC) المقابلة من 0.70، 6.04، 10.02 و15.95 إلى 10.60، 13.31، 18.31 و22.40 مللي سيمنز/سم لنفس العينات قبل وبعد الزراعة على التوالي. تخلص الدراسة إلى أن إضافة بايوشار مخلفات النخيل أدت إلى خفض معدل الزيادة في ارتفاع نبات الجرجير خلال فترة القياس الأولى، بينما لم تُظهِر الفترتان الثانية والثالثة أي فروق معنوية بين المعاملات.

الكلمات المفتاحية: مخلفات نخلة التمر، البايوشار، الجرجير، الزيادة في الطول، التوصيل الكهربائي للتربة.

Introduction:

represents a carbon sequestration material produced by the pyrolysis of various organic wastes via a thermochemical process under anoxic conditions (Jabborova et al., 2021; Vural et al., 2025; Kumari et al., 2023; Murtaza et al., 2023). It is a beneficial soil agent that potentially enhances its nutrient availability, serves as an adsorption medium for pollutants, and contributes to climate change mitigation (Abhishek et al., 2022; Nepal et al., 2023). In the arid and semi-arid areas there are several organic feedstocks depending on the local and domestic plant cover, which could be vitally a rich resource of biochar production. (Haddad et al., 2024). Date palm (*Phoenix dactylifera* L.) residues are considered as a potential biochar resource, which are available annually and consist of various parts: palm fronds, petiole bases, leaflets, trunk, date seeds, pits, palm fiber, mesh, spadix and empty fruit branches. (Tahir et al., 2022; Elhadioui et al., 2023). Date palm-derived biochars produced at temperatures ranging between 250 to 550 °C and incorporated into clay loam soil at 5% and 10% by weight modified soil properties during a 30-day incubation (Tahir, et al., 2022).

Recently, various studies have examined the date palm biochar and documented the efficacy of biochar as a vital amendment that ameliorates soil fertility and physical properties, thereby influencing plant growth and yield (Vural et al., 2025). Positive plant responses have also been reported. Mixed date biochar of stems and leaves in 2.5% with sandy loam soil is reported as a soil amendment that improves water holding capacity, plant growth, plant yield of cucumber under glasshouse conditions (Munir, et al., 2020). Hussein et al. (2022) reported that the spinach response under saline irrigation was improved by 1% dose of biochar. Elhadioui et al. (2023) indicated that 2% dosage of palm biochar revealed soil amelioration and it promoted hypocotyl growth of lettuce seeds without phytotoxic effect under the tested conditions.

However, date palm biochar could not consistently elicit positive plant responses. Biochar application doses of 4–32% negatively affected lettuce germination under saline irrigation, despite improvements in soil water-holding capacity (Elhadioui et al., 2023). In sandy soil under simulated arid

and semi-arid conditions, date palm residue biochar applied in combination with a nitrogen source led to reduce barley shoot dry matter and grain production of barley in the short term, although the yield reductions were not statistically significant (Le Guyader et al., 2025). These findings highlight the importance of evaluating application rates and growing conditions rather than assuming that improvements in soil properties necessarily translate into better crop performance.

Rocket (*Eruca sativa* Mill.) is a cool season annual leafy vegetable belonging to the Brassicaceae family and native to the Mediterranean region and adapted with arid areas. Its leaves are consumed fresh in salads and are valued for their characteristic pungent tasty, which are rich in glucosinolates and their breakdown products (Ashraf et al., 2026). Rocket is characterized by rapid germination and growth, making it ideal for short-cycle vegetable parameters and for assessing plant responses over relatively short experiments (Bell and Wagstaff, 2019). It can produce sufficient green volume under various growing conditions; however, its tolerance to salinity varies among ecotypes. (Al-Sulivany et al., 2024). Therefore, this study aimed to evaluate the effects of different application rates of date palm residue biochar on rocket plant growth over time, together with a descriptive assessment of the main measurements of the plant media in different treatments.

Materials and Methods:

Study Site and Experimental Duration:

The experiment was conducted at the Agricultural Research Station, Faculty of Agriculture, University of Tripoli, Tripoli, Libya (32°50'N, 13°13'E), during the period from March to July 2026.

Biochar Preparation, Washing, and Nutrient Charging:

To prepare the palm biochar, palm feedstocks (including palm fronds, petiole bases, and leaflets) were collected from palm trees in Souk El-Jouma, Tripoli. The pyrolysis process was conducted under slow pyrolysis conditions at a temperature range of 400–500 °C (Bridgwater, 2003). Subsequently, the resulting biochar was washed and soaked in water for 3 days, followed by drying and sieving through a 0.2 mm mesh. To charge the biochar, it was immersed in a liquid local compost extract for 48 hours under aerated conditions.

Experimental Setup and Design:

The prepared charged biochar was thoroughly mixed with sandy loam soil (w/w) at four application rates: 0%, 1%, 2%, and 3%, with 8 replicates per treatment. The experimental unit consisted of polyethylene bags (10 cm in diameter). Each plastic bag was transplanted with a one-month-old rocket seedling (*Eruca sativa Mill.*) having an average initial plant height of 12.46 cm.

Media Analysis and Plant Growth Measurements:

The physical and chemical properties of the four growing media were evaluated. Soil pH and electrical conductivity (EC) were measured using saturated soil paste extracts and a 1:4 (w/v) soil–distilled water suspension, following standard procedures (Sparks et al., 1996). Nitrogen was determined using the Kjeldahl method, while available phosphorus was extracted with sodium bicarbonate and determined calorimetrically using a spectrophotometer, following the procedures described by Sparks et al. (1996). Plant height increments were recorded over three successive measurement intervals. All plants were irrigated with water having an EC of 2.90 mS cm^{-1}. No fertilizer was applied during the experiment.

Table (1): Initial pH and electrical conductivity of the growing media before planting.

Biochar application rate (% w/w)	Control	1%	2%	3%
pH	8.70	8.04	8.03	7.98
EC (mS cm^{-1})	0.70	6.04	10.02	15.95

Note: EC = electrical conductivity. Values represent measurements of one representative sample per treatment before planting.

Statistical Analysis:

Collected data were subjected to Analysis of Variance (ANOVA) according to the RCBD design using SPSS software. Mean comparisons were performed using Duncan's Multiple Range Test at a significance level of 0.05

Results:

Growing-Media Chemical Properties and Visual Plant Symptoms:

Table 2 presents the chemical properties of the growing media at the end of the experiment. Biochar-amended media had pH values ranging from 7.41 to 7.50, compared with 7.30 in the control. EC increased with biochar application rate, from 10.60 mS cm^{-1} in the control to 22.40 mS cm^{-1} at 3% biochar. Reported available nitrogen concentrations also increased across application rates, from 56 to 4,760 mg kg^{-1}, while available phosphorus increased from 8.21 to 25.43 mg kg^{-1}. Visual observations during the experiment revealed purple discoloration and wilting in plants under the 2% and 3% biochar

treatments. Wilting appeared most pronounced at 3% biochar, followed by 2%, whereas plants in the control and 1% treatments appeared comparatively more vigorous. These observations were qualitative; symptom severity was not assessed using a standardized scoring scale.

Table (2): Chemical properties of the growing media at the end of the experiment under different date-palm biochar application rates.

Biochar application rate (% w/w)	pH	EC after cultivation (mS cm^{-1})	Available N (mg kg^{-1})	Available P (mg kg^{-1})
Control	7.30	10.60	56	8.21
1%	7.50	13.31	2,240	14.01
2%	7.50	18.31	3,500	24.73
3%	7.41	22.40	4,760	25.43

Note: EC = electrical conductivity; N = nitrogen; P = phosphorus. Values represent measurements of one representative sample per treatment at the end of the experiment and are presented descriptively

Plant Height Increment:

Biochar application significantly affected rocket height increment during the first measurement interval (Table 3; $p < 0.001$). The control recorded the highest mean increment (1.81 cm), exceeding those of the 1%, 2%, and 3% biochar treatments (0.83, 0.59, and 0.85 cm, respectively). No significant differences were detected among the three biochar rates. Treatment effects were not significant during the second or third measurement intervals ($p = 0.472$ and 0.919, respectively).

Table 3. Effect of date-palm biochar application rate on rocket plant height increment during three successive measurement intervals.

Treatments	D1	D2	D3
Control	1.81a	0.48a	0.19a
1% biochar	0.83b	0.41a	0.20a
2% biochar	0.59b	0.20a	0.26a
3% biochar	0.85b	0.38a	0.24a
F-Value	11.263***	0.862 ns	0.166 ns
p-Value	<0.001	0. 472	0.919

Note: D1, D2, and D3 represent the first, second, and third measurement intervals, respectively. Values are treatment means (n = 8 bags). Within each column, means sharing the same letter are not significantly different according to Duncan's multiple range test at $p < 0.05$.

Cumulative Plant Height Increment:

As shown in Figure 1A, the control recorded the highest cumulative height increase along the measurements period reaching 2.49 cm at the final assessment, compared with 1.46, 1.06, and 1.48 cm in the 1%, 2%, and 3% biochar treatments, respectively. Moreover, regarding Figure 1B, there is a substantial gap variation observed between the control and the other treatments at the first interval with 0.165 cm day^{-1} and seeking to 0.032 cm day^{-1} at the final record before death of all plants. In this regard, the initial mean daily elongation measurements for 1% and 3% were 0.076 and 0.077 cm day^{-1} and they decreased at the final interval to 0.034 and 0.041 cm day^{-1}, respectively, whereas the treatment 2% showed a slight decrease from 0.054 to 0.029 cm day^{-1} before increasing to 0.044 cm day^{-1} during the final interval.

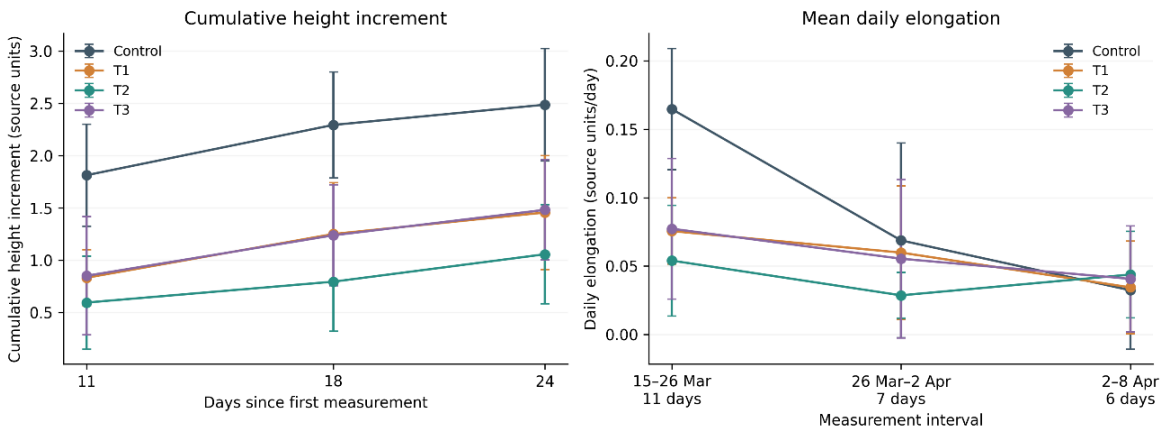


Figure (1): (A) Cumulative plant height increment and (B) mean daily elongation rate of rocket under different date-palm biochar application rates. Values are means ± SD (n = 8 bags per treatment)

Recorded Plant Mortality:

Plant death throughout trough the experiment recorded along the intervals reaching to the mortality of all plants. As shown in figure 2, the percentage of mortality was 0% in the control, 6.25% in the 1% biochar treatment, and 12.50% in both the 2% and 3% treatments. These percentages corresponded to zero, one, two, and two dead plants, respectively. Overall, five of the 64 initially established plants had died by the final height assessment, giving a recorded mortality of 7.81%. Following the final height assessment, all remaining plants were subsequently observed to have died. The exact timing of these deaths was not recorded; therefore, the mortality percentages presented in Figure 2 refer only to losses documented up to the final height assessment.

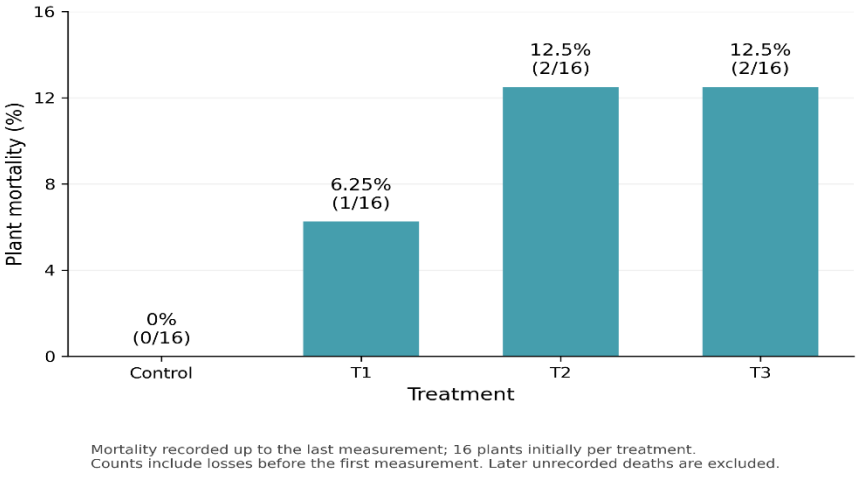


Figure (2): Plant mortality recorded up to the final height assessment

Discussion:

Biochar incorporation was associated with higher initial EC and lower pH than the control. The EC response agrees with Elhadioui et al. (2023), who reported increasing soil EC with increasing date-palm leaf biochar rates. Differences in soil–water extraction methods, however, prevent direct comparison of absolute values. The initial pH response contrasts with Tahir et al. (2022), who observed increased soil pH following date-palm biochar application at 5% and 10%. These contrasting findings highlight the influence of biochar characteristics, soil properties, and application conditions on growing-medium chemistry.

At the end of the experiment, measured nitrogen and available phosphorus concentrations increased with biochar application rate. These observations are consistent with the potential of biochar to influence nutrient supply and retention (Nepal et al., 2023; Murtaza et al., 2023). However, initial nitrogen and phosphorus concentrations were not determined, so the final measurements indicate differences among treatments rather than increases during cultivation. Higher residual nutrient concentrations also do not necessarily indicate greater nutrient uptake by plants.

The relatively similar available phosphorus concentrations at 2% and 3% biochar (24.73 and 25.43 mg kg^{-1}, respectively) may reflect a balance between phosphorus release and retention within the biochar–soil system. Sorption–desorption and precipitation–dissolution processes can regulate extractable phosphorus, potentially limiting further increases despite a higher biochar application rate (Zhang et al., 2025). Such buffering provides a possible explanation for the small additional increase observed at 3%; however, these processes were not directly investigated in the present study.

Purple discoloration and wilting were visually observed in the 2% and 3% biochar treatments, with wilting appearing most pronounced at 3%. In contrast, plants in the control and 1% treatments appeared comparatively more vigorous. Phosphorus deprivation can stimulate anthocyanin accumulation and purple pigmentation (Hasan et al., 2016); however, the observed discoloration does not independently confirm phosphorus deficiency. The higher extractable phosphorus concentrations measured after cultivation do not establish that phosphorus acquisition was adequate when the symptoms developed, particularly because plant tissue phosphorus was not determined.

The occurrence of wilting alongside higher growing-medium EC raises the possibility of restricted water uptake and associated nutritional stress. Salinity can affect plant water relations and nutrient acquisition, although these responses depend on crop species and growing conditions (Grattan and Grieve, 1999). Consequently, the coexistence of higher residual available nitrogen and phosphorus concentrations with visible stress symptoms suggests that nutrient accumulation in the medium did not necessarily translate into effective plant uptake. Nevertheless, inadequate water supply or other environmental stresses could also have contributed. These interpretations remain tentative because symptom severity, plant water status, and nutrient uptake were not quantified.

EC increased during cultivation in all treatments, including the control, indicating that biochar alone cannot explain the temporal change. Irrigation water with an EC of 2.90 mS cm^{-1} supplied a potential source of salts, which may have accumulated if leaching was limited. This interpretation follows the principles described by Ayers and Westcot (1985), although irrigation volumes and drainage losses were not quantified. Likewise, the decline in pH cannot be assigned to a specific mechanism from the available measurements.

The significantly lower first-interval height increments indicate that biochar did not promote early rocket elongation under the tested conditions. This contrasts with the improved lettuce root and hypocotyl elongation at 2% date-palm leaf biochar reported by Elhadioui et al. (2023). Conversely, Le Guyader et al. (2025) observed a non-significant tendency toward reduced barley yield following date-palm biochar application. These comparisons demonstrate that responses vary among crops and experimental conditions, and that higher soil nutrient concentrations do not necessarily translate into improved growth.

Cumulative height differences largely reflected the smaller first-interval increments in amended treatments. The absence of significant treatment effects during subsequent intervals does not establish recovery or equivalent performance. Similarly, the final-interval increase in daily elongation at 2% biochar cannot be interpreted as significant growth stimulation. Recorded plant losses during the assessment period occurred only in amended treatments, but all remaining plants subsequently died. The available observations therefore cannot establish biochar as the specific cause of mortality. Overall, the tested rates were associated with reduced early elongation, while the chemical measurements and visual symptoms suggest possible nutritional and environmental constraints that require further investigation.

Conclusion:

Date-palm residue biochar applied at 1–3% (w/w) reduced rocket height increment during the first measurement interval, while no significant treatment effects were detected during subsequent intervals. Biochar-amended media had higher initial EC than the control, and EC increased while pH declined in all treatments during cultivation. Final available nitrogen and phosphorus concentrations increased with application rate, although phosphorus values were numerically similar at 2% and 3%. These chemical measurements were descriptive and did not establish improved plant nutrient uptake. Purple discoloration and wilting were observed at 2% and 3% biochar, with wilting appearing most pronounced at 3%. The symptoms may indicate water or nutritional stress, but their causes were not confirmed. Under the tested conditions, the evaluated biochar rates provided no demonstrated benefit to rocket height increment. Biochar characterization, application-rate selection, and irrigation management therefore require further evaluation before recommending this material for rocket cultivation

References:

1. Abhishek, K., Shrivastava, A., Vimal, V., Gupta, A. K., Bhujbal, S. K., Biswas, J. K., Singh, L., Ghosh, P., Pandey, A., Sharma, P., & Kumar, M. (2022). Biochar application for greenhouse gas mitigation, contaminants immobilization and soil fertility enhancement: A state-of-the-art review. Science of the Total Environment, 853, 158562. https://doi.org/10.1016/j.scitotenv.2022.158562

2. Al-Sulivany, B. S. A., Ahmed, D. Y., Naif, R. O., Omer, E. A., & Saleem, P. M. (2024). Phytochemical profile of Eruca sativa and its therapeutic potential in disease prevention and treatment. Global Academic Journal of Agriculture and Biosciences, 6(3), 57–64. https://doi.org/10.36348/gajab.2024.v06i03.002
3. Ashraf, S. A., Banu, H., Al-Shammari, E., Haque, A., Shahanawaz, S., Alcantara, J. C., Mahmood, D., Patel, M., & Adnan, M. (2026). Eruca sativa as a nutraceutical resource rich in bioactive compounds with therapeutic potential and translational applications. Discover Food, 6, 254. https://doi.org/10.1007/s44187-026-00988-9
4. Ayers, R. S., & Westcot, D. W. (1985). Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/t0234e/t0234e00.htm
5. Bell, L., & Wagstaff, C. (2019). Rocket science: A review of phytochemical & health-related research in Eruca & Diplotaxis species. Food Chemistry: X, 1, 100002. https://doi.org/10.1016/j.fochx.2018.100002
6. Bridgwater, A. V. (2003). Renewable fuels and chemicals by thermal processing of biomass. Chemical Engineering Journal, 91(2-3), 87-102. https://doi.org/10.1016/S1385-8947(02)00142-0
7. Elhadioui, L., Harrouni, M. C., Koyro, H. W., Elhadioui, B., Ait Hammou, R., & Daoud, S. (2023). Evaluation of date palm biochar as oasis soil amendment under saline irrigation in Morocco. Trends in Agricultural Sciences, 2(4), 419–431. https://doi.org/10.17311/tas.2023.419.431
8. Grattan, S. R., & Grieve, C. M. (1999). Salinity–mineral nutrient relations in horticultural crops. Scientia Horticulturae, 78, 127–157. https://doi.org/10.1016/S0304-4238(98)00192-7
9. Haddad, N., Al Tawaha, A. R., Alassaf, R., Alkhoury, W., Abusalem, M., & Al-Sharif, R. (2024). Sustainable agriculture in Jordan—A review for the potential of biochar from agricultural waste for soil and crop improvement. Journal of Ecological Engineering, 25(9), 190–202. https://doi.org/10.12911/22998993/191186
10. Hasan, M. M., Hasan, M. M., Teixeira da Silva, J. A., & Li, X. (2016). Regulation of phosphorus uptake and utilization: Transitioning from current knowledge to practical strategies. Cellular & Molecular Biology Letters, 21, 7. https://doi.org/10.1186/s11658-016-0008-y
11. Hussein, Y. S., Hassan, M. A., Marzouk, E. R., & Ismail, S. A. (2022). Effect of biochar amendment on spinach (Spinacia oleracea L.) growth under salt stress conditions. Sinai Journal of Applied Sciences, 11(5), 891–908. https://doi.org/10.21608/sinjas.2022.148488.1127
12. Jabborova, D., Ma, H., Bellingrath-Kimura, S. D., & Wirth, S. (2021). Impacts of biochar on basil (Ocimum basilicum) growth, root morphological traits, plant biochemical and physiological properties and soil enzymatic activities. Scientia Horticulturae, 290, 110518. https://doi.org/10.1016/j.scienta.2021.110518
13. Kumari, K., Kumar, R., Bordoloi, N., Minkina, T., Keswani, C., & Bauddh, K. (2023). Unravelling the recent developments in the production technology and efficient applications of biochar for agro-ecosystems. Agriculture, 13(3), 512. https://doi.org/10.3390/agriculture13030512
14. Le Guyader, E., El Mazlouzi, M., Guillaneuf, A., Tandina, B., Gommeaux, M., Hubert, J., Miconnet, V., Marin, B., Abiven, S., Intrigliolo, D. S., Delgado-Iniesta, M. J., Girods, P., Sbih, M., Guimeur, K., Kavvadias, V., Zoghlami, R. I., Abid, A., & Morvan, X. (2025). Nitrogen budget and barley response to organic amendments in a sandy soil under simulated arid climate. Soil Use and Management, 41(1), e70008. https://doi.org/10.1111/sum.70008
15. Munir, M., Alhajhoj, M. R., Mohammed, M. E. A., Ghazzawy, H. S., Elgarawany, M. M., El-Habbab, M. S., Zeineldin, F. I., & Al-Bahigan, A. M. (2020). Effects of date palm biochar on growth, yield and photosynthetic capacity of cucumber (Cucumis sativus L.) under glasshouse conditions. Pakistan Journal of Life and Social Sciences, 18(1), 7–16. https://www.kfu.edu.sa/ar/Centers/WaterStudies/Documents/EffectsofDatePalmBiocharonGrowthYieldandPhotosynthetic.pdf
16. Murtaza, G., Ahmed, Z., Eldin, S. M., Ali, B., Bawazeer, S., Usman, M., Iqbal, R., Neupane, D., Ullah, A., Khan, A., Hassan, M. U., Ali, I., & Tariq, A. (2023). Biochar-soil-plant interactions: A cross talk for sustainable agriculture under changing climate. Frontiers in Environmental Science, 11, 1059449. https://doi.org/10.3389/fenvs.2023.1059449
17. Nepal, J., Ahmad, W., Munsif, F., Khan, A., & Zou, Z. (2023). Advances and prospects of biochar in improving soil fertility, biochemical quality, and environmental applications. Frontiers in Environmental Science, 11, 1114752. https://doi.org/10.3389/fenvs.2023.1114752
18. Sparks, D. L., Page, A. L., Helmke, P. A., Loeppert, R. H., Soltanpour, P. N., Tabatabai, M. A., Johnston, C. T., & Sumner, M. E. (Eds.). (1996). Methods of soil analysis: Part 3. Chemical methods (SSSA Book Series No. 5). Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin. https://doi.org/10.2136/sssabookser5.3

19. Tahir, A., Al-Ani, F., & Al Obaidy, A. (2022). Effect of date palm derived biochar on soil's bulk density, pH, and nitrogen content. Engineering and Technology Journal, 40(11), 1358–1364. https://doi.org/10.30684/etj.2021.132003.1082
20. Yılmaz Vural, G., Erdem, H., & Yıldız, K. (2025). Optimizing biochar applications for improved growth and nutritional quality of basil plants using rice and corn biochars. Turkish Journal of Agriculture–Food Science and Technology, 13(4), 941–945. https://doi.org/10.24925/turjaf.v13i4.941-945.7371
21. Zhang, L., Chang, L., Liu, H., Puy Alquiza, M. de J., & Li, Y. (2025). Biochar application to soils can regulate soil phosphorus availability: A review. Biochar, 7, 13. https://doi.org/10.1007/s42773-024-00415-1