

The role of mycorrhizal fungi and organic fertilization with pomegranate peels in enhancing the oil content of flax seeds

Hawraa Ali Abba¹, Itlal Hakim AL-Masoody¹, Atyaf Falih Salih^{2*}, Amira Hussein Ali¹, Nibras Al-Ibrahemi¹

¹Departments of Field Crops, College of Agriculture, University of Kerbala, Iraq

²College of Pharmacy, University of Kerbala, Karbala, Iraq

*atyaf.f@uokerbala.edu.iq

DOI: 10.66723/zjhms.2026.170970.1133

Received: 24 April 2026, Accepted: 24 June 2026. Published: 30 June 2026

ABSTRACT

The experiment was conducted in the field in the Al-Sadda district - Al-Muhannawiya village during the 2024-2025 agricultural. The experiment was designed according to the complete randomized block design as a factorial experiment, four concentration levels first factor organic fertilization with pomegranate peels (0 Just water, 10 g·L⁻¹, 25 g·L⁻¹, 50 g·L⁻¹) the extract was used to irrigate the soil directly at a rate of (100 - 200 mL/plant) depending on the size of the plant, with an interval of (10–14) days between each treatment, the two seconds he commercial mycorrhizal fungus inoculum (in powder form) was used, four concentration levels (0, 3 g. per plant, 5 g. plant, 10 g. plant Mycorrhizal fungi were added directly to the root zone during planting to ensure direct contact with the roots, and the use of fungicides was avoided during the trial period to ensure the effectiveness of the fungi. Indicate the results for the interaction between pomegranate peels at concentration 50 g·L⁻¹ and Mycorrhiza at concentration 10 g. plant, the highest average oleic acids, linolenic, oil percentage and oil yield compared with the control.

Key words: Mycorrhizal fungi, Pomegranate peels, Flax seeds, Oil content.

INTRODUCTION

Fax seeds (*Linum usitatissimum* L.) are considered Among the plant sources rich in bioactive compounds of nutritional and pharmaceutical importance, as they contain a wide range of chemical compounds that contribute to enhancing human health and preventing many diseases [1]. Among the most notable of these compounds are unsaturated

fatty acids, especially alpha-linolenic acid (ALA) from the omega-3 group, in addition to lignans [2], which are considered natural phytoestrogens, as well as phenolic compounds and flavonoids that are distinguished by their antioxidant properties [3,4].

Biofertilization using mycorrhizal fungi is considered one of the most prominent modern trends in sustainable agriculture, due to its pivotal role in enhancing nutrient absorption efficiency and improving both plant and soil health [5]. Mycorrhiza refers to a mutualistic symbiotic relationship between plant roots and certain types of fungi, where the fungi colonize the roots and form an extensive network of fungal hyphae that extend into the soil [6], increasing the effective surface area for the absorption of water and nutrients, especially poorly mobile elements such as phosphorus, zinc, and copper[7]. Mycorrhizal fungi are divided into several main types, the most important of which are arbuscular mycorrhizae (AM) that penetrate the root cortex cells and form specialized structures known as arbuscules, which are the sites of nutrient exchange between the fungus and the plant, in addition to vesicles that serve as nutrient storage [8]. There is also ectomycorrhiza, which forms a sheath around the roots without penetrating the cells, and is often found in forest trees [9]. The importance of mycorrhizal fungi lies in their ability to improve the efficiency of natural resource use, as they contribute to increased absorption of mineral elements, reduce the need for chemical fertilizers, and enhance the resistance of plants to environmental stresses such as drought, salinity, and high temperatures [10]. It also plays a role in improving soil structure by secreting compounds such as glomalin, which helps stabilize soil aggregates and increase their cohesion, thereby enhancing aeration and water retention capacity. In addition, mycorrhizae directly and indirectly affect the chemical composition of plants, including increased production of secondary metabolites of vital importance such as phenolics and flavonoids, which are associated with antioxidant and disease-resistant properties [11]. This is attributed to the activation of metabolic pathways within the plant as a result of the symbiotic interaction with the fungus, which enhances the nutritional and medicinal value of the crops [12]. Pomegranate peels (*Punica granatum* L.) are considered agricultural waste rich in phenolic compounds and antioxidants, making them a promising material for producing value-added organic fertilizers[13]. Their use can contribute to improving the nutritional content of cultivated plants, in addition to their role in reducing environmental pollution resulting from the accumulation of agricultural waste [14]. On the other hand, flaxseeds hold significant nutritional and health importance due to their content of active compounds such as unsaturated fatty acids, lignans, and phenolic compounds, which are associated with numerous health benefits[15].

Based on that, the importance of studying the effect of bio-fertilization and organic fertilization using pomegranate peels on the chemical composition of flax seeds emerges, especially concerning bioactive compounds. This study aims to evaluate the ability of these types of fertilization to enhance the content of flax seeds with bioactive compounds, which may contribute to improving their nutritional and medicinal value, and support the shift toward more sustainable and efficient agricultural practices.

MATERIAL AND METHODS

The experiment was conducted in the field in the Al-Sadda district - Al-Muhannawiya village during the 2024-2025 agricultural season at a latitude of 34.56 degrees, a longitude of 44.45 degrees, and an elevation of 24 meters above sea level. The experiment was designed according to the complete randomized block design as a factorial experiment[16].

Preparation of pomegranate peel extract

The peels of pomegranate fruits were collected. and air-dried at room temperature for (7–10) days until weight stabilization, then ground using an electric grinder to obtain a fine powder. to prepare the aqueous extract, specific amounts of the powder were soaked in distilled water and left for (24–48) hours at a temperature of (25°C), then the solution was filtered using filter paper to obtain the final extract [16]. Four concentration levels first factor organic fertilization with pomegranate peels (0 , 10 g·L⁻¹, 25 g·L⁻¹, 50 g·L⁻¹ the extract was used to irrigate the soil directly at a rate of (100–200 mL/plant) depending on the size of the plant, with an interval of (10–14) days between each treatment.

Method of preparing the dilutions for pomegranate peel extract

The control solution was prepared using only distilled water (0 g/L), while the other concentrations were prepared by dissolving 10 g, 25 g, and 50 g of pomegranate peel extract in one liter of distilled water to obtain concentrations of 10, 25, and 50 g/L, respectively.

The seconds factor he commercial mycorrhizal fungus inoculate (in powder form) was used, four concentration levels (0 , 3 g. per plant, 5 g. plant, 10 g. plant Mycorrhizal fungi were added directly to the root zone during planting to ensure direct contact with the roots, and the use of fungicides was avoided during the trial period to ensure the effectiveness of the fungi [17]. The flax plants were harvested on 1/5/2025 when *plant* reached physiological maturity [18].

Method of preparing the dilutions for mycorrhizal

The different concentrations of the root mycorrhizal inoculum (mycorrhiza) were prepared by dissolving the required amounts of the powder in distilled water to obtain the concentrations of 0 g/L (water only as a control treatment), 3 g/L, 5 g/L, and 10 g/L.

Extract the volatile oil from flax seeds using a soxlet device. A 500 mL round flask was filled with 100 mL of 70% chloroform and 100 g of flax powder for a full day [19]. Furthermore, the active chemical constituents (oleic and linolenic acids) were measured using high-performance liquid chromatography (HPLC) [20].

Statistical evaluation

The experiment was designed according to the Randomised Complete Block Design

(RCBD) with three replications for each treatment, and the results were analysed using the Least Significant Difference (LSD) test at a significance level of 0.05 [21].

RESULTS

The results of table 1 show a significant difference when using mycorrhizal fertilizer, as a concentration of 10 g. plant was recorded higher average (21.73%) compared with the control (15.025%). But showed a significant difference when using pomegranate peels fertilizer, as a concentration of 50 g·L⁻¹ was recorded higher average (19.98%) compared with the control (15.93%). As for the interaction between pomegranate peels at concentration 50 g·L⁻¹ and Mycorrhiza at concentration 10 g. plant, the highest average was 24.65% compared with the control 13.45%.

Table 1. The effect of mycorrhizal fungi and organic fertilization with pomegranate peels in enhancing the oleic acid% content of flax seeds.

Mycorrhiza g. plant	pomegranate peels g·L⁻¹				
	0	10 g·L ⁻¹	25 g·L ⁻¹	50 g·L ⁻¹	Mean %
0	13.45	14.65	15.35	16.65	15.025
3 g. plant	14.76	15.87	16.45	17.87	16.2375
5 g. plant	16.65	17.85	19.56	20.74	18.70
10 g. plant	18.87	20.65	22.75	24.65	21.73
LSD 0.05 for interaction	1.87				
Mean g·L ⁻¹	15.93	17.26	18.53	19.98	
LSD Mycorrhiza g. plant = 0.76					LSD pomegranate peels g·L ⁻¹ = 0.65

Based on the results in table 2, they show a significant difference when using mycorrhizal fertilizer, as a concentration of 10 g. plant was recorded higher average (26.46%) compared with the control (21.11%). but showed a significant difference when using pomegranate peels fertilizer, as a concentration of 50 g·L⁻¹ was recorded higher average (25.65%) compared with

the control (21.93%). As for the interaction between pomegranate peels at concentration $50 \text{ g} \cdot \text{L}^{-1}$ and Mycorrhiza at concentration $10 \text{ g} \cdot \text{plant}$, the highest average was 28.65% compared with the control 19.65%.

Table 2. The effect of mycorrhizal fungi and organic fertilization with pomegranate peels in enhancing the linolenic acid% content of flax seeds.

Mycorrhiza g. plant	pomegranate peels $\text{g} \cdot \text{L}^{-1}$				
Control	Control	$10 \text{ g} \cdot \text{L}^{-1}$	$25 \text{ g} \cdot \text{L}^{-1}$	$50 \text{ g} \cdot \text{L}^{-1}$	Mean g. plant
	19.65	20.67	21.45	22.65	21.11
3 g. plant	20.54	22.65	23.76	24.54	22.87
5 g. plant	22.65	23.76	24.87	26.76	24.51
10 g. plant	24.87	25.76	26.56	28.65	26.46
LSD 0.05 for interaction	1.87				
Mean $\text{g} \cdot \text{L}^{-1}$	21.93	21.93	24.16	25.65	
LSD Mycorrhiza g. plant = 0.97					LSD pomegranate peels $\text{g} \cdot \text{L}^{-1}$ = 0.84

Indicated to the results of table 3, they show a significant difference when using mycorrhizal fertilizer, as a concentration of $10 \text{ g} \cdot \text{plant}$ was recorded higher average (31.43%) compared with the control (25.18%), but they show a significant difference when using pomegranate peels fertilizer, as a concentration of $50 \text{ g} \cdot \text{L}^{-1}$ was recorded higher average (30.23%) compared with the control (26.43%). as for the interaction between pomegranate peels at concentration $50 \text{ g} \cdot \text{L}^{-1}$ and Mycorrhiza at concentration $10 \text{ g} \cdot \text{plant}$, the highest average was 33.65% compared with the control 23.54%.

Table 3. The effect of mycorrhizal fungi and organic fertilization with pomegranate peels in enhancing the oil percentage% content of flax seeds.

Mycorrhiza g. plant	pomegranate peels $\text{g} \cdot \text{L}^{-1}$				
Control	Control	$10 \text{ g} \cdot \text{L}^{-1}$	$25 \text{ g} \cdot \text{L}^{-1}$	$50 \text{ g} \cdot \text{L}^{-1}$	Mean
	23.54	24.65	25.76	26.76	25.18
3 g. plant	25.87	26.76	27.87	29.87	27.59
5 g. plant	26.65	27.45	28.76	30.65	28.38
10 g. plant	29.65	30.65	31.76	33.65	31.43

LSD 0.05 for interaction	2.76				
Mean g·L ⁻¹	26.43	27.38	28.54	30.23	
LSD Mycorrhiza g. plant =1.54					LSD pomegranate peels g·L ⁻¹ =1.76

Based on the results of table 4 showed a significant difference when using mycorrhizal fertilizer, as a concentration of 10 g.plant was recorded higher average (0.2568%) compared with the control (0.2388%). but showed a significant difference when using pomegranate peels fertilizer, as a concentration of 50 g·L⁻¹ was recorded higher average (0.264%) compared with the control (0.2468%). as for the interaction between pomegranate peels at concentration 50 g·L⁻¹ and Mycorrhiza at concentration 10 g. plant, the highest average was 0.231% compared with the control 0.223%.

Table 4. The effect of mycorrhizal fungi and organic fertilization with pomegranate peels in enhancing the oil yield content of flax seeds.

Mycorrhiza	pomegranate peels				
Control	Control	10 g·L ⁻¹	25 g·L ⁻¹	50 g·L ⁻¹	Mean g. plant
	0.223	0.234	0.244	0.254	0.2388
3 g. plant	0.239	0.256	0.265	0.275	0.2588
5 g. plant	0.254	0.275	0.288	0.296	0.2783
10 g. plant	0.271	0.295	0.230	0.231	0.2568
LSD 0.05 for interaction	2.76				
Mean g·L ⁻¹	0.2468	0.265	0.2568	0.264	
LSD Mycorrhiza g.plant=1.65					LSD pomegranate peels g·L ⁻¹ =1.85

DISCUSSION

The results of studies related to biofertilization using mycorrhizal fungi and organic fertilization with pomegranate peels indicate a clear effect on improving the biochemical content

of flax seeds, particularly active compounds such as unsaturated fatty acids, lignans, and phenolic compounds. These results can be explained by the complex interaction between the plant, the biocontrol agent, and organic fertilization, which directly reflects on the metabolic processes within the plant[22]. Mycorrhizal fungi significantly contribute to enhancing the efficiency of nutrient absorption, especially phosphorus, which is an essential element in building biomolecules and transferring energy within plant cells. This improvement in mineral nutrition leads to the activation of metabolic pathways responsible for the synthesis of secondary compounds, which explains the increase in the concentrations of phenolic compounds and lignans in flax seeds. The symbiotic relationship between the fungi and the roots also leads to an overall improvement in the plant's physiological state and an increase in photosynthetic efficiency, which positively reflects on the accumulation of active compounds [23]. On the other hand, organic fertilization using pomegranate peels contributes to improving soil properties by increasing its organic matter content and enhancing the activity of beneficial microorganisms. Pomegranate peels also contain phenolic compounds and antioxidants that may act as biostimulants, enhancing the plant's metabolic response. This effect may lead to an increased accumulation of plant defensive compounds such as phenolics, which are associated with the plant's ability to withstand various environmental stresses [24]. And when the biofertilization with mycorrhiza is combined with organic fertilization, a clear synergistic effect is observed, as each one enhances the other. While mycorrhiza improves nutrient absorption, organic fertilization provides a more stable and organic-rich soil environment, supporting the growth and activity of fungi. This integration creates a more efficient interactive ecosystem, ultimately reflected in the improved quality of flax seeds in terms of chemical content and nutritional value [25].

It can also be observed that the increase in active compounds, such as lignans and unsaturated fatty acids, is not only due to improved nutrition but also to the activation of plant defense mechanisms (Induced Systemic Resistance), which stimulate the plant to produce secondary compounds with a protective role. This aligns with what many recent studies indicate about the role of biofertilization in reprogramming plant metabolism toward the production of compounds with higher medicinal and nutritional value [27]. Based on that, the use of mycorrhiza and organic fertilization with pomegranate peels represents an effective agricultural strategy that not only improves productivity but also enhances the qualitative quality of crops, especially in terms of the content of bioactive compounds in flax seeds[28].

Conclusion

It can be concluded that the biological treatments used represent a promising alternative or complement to traditional fertilisers, due to their positive impact on improving plant growth and reducing reliance on chemical inputs, with the necessity of conducting additional studies to determine the optimal concentrations for each crop individually.

Acknowledgement

We thank the University of Kufa, College of Education for Girls, for their assistance in suggesting the title and conducting the statistical analysis.

References

1. Herchi, Wided; Arráez-Román, David; Trabelsi, Houda; Boukhchina, Slaheddine; Kallel, Hatem (2014). Phenolic compounds in flaxseed: A review of their properties and analytical methods. *Food Chemistry*, 151, 201–215. DOI: 10.1016/j.foodchem.2013.10.155
2. Touré, A., & Xueming, X. (2010). Flaxseed lignans: Source, biosynthesis, metabolism, antioxidant activity, bio-active components, and health benefits. *Comprehensive Reviews in Food Science and Food Safety*, 9(3), 261–269. DOI: 10.1111/j.1541-4337.2010.00105.x
3. Ganorkar, P. M., & Jain, R. K. (2013). Flaxseed — a nutritional punch. *International Food Research Journal*, 20(2), 519–525.
4. Koçak, Y. (2024). Phenolic profile and antioxidant activity of flaxseed (*Linum usitatissimum* L.). *Processes*, 12(4), 689. DOI: 10.3390/pr12040689.
5. Smith, S. E., & Read, D. J. (2008). *Mycorrhizal Symbiosis* (3rd ed.). Academic Press.
6. Begum, Nafeesah; Qin, Chunyan; Ahanger, Mohammad Aqil; Raza, Shahid; Ashraf, Mirza Hasanuzzaman; Ahmed, Nafees; Zhang, Liqun (2019). Role of arbuscular mycorrhizal fungi in plant growth regulation: implications in abiotic stress tolerance. *Frontiers in Plant Science*, 10, 1068. DOI: 10.3389/fpls.2019.01068.
7. Hazzoumi, Z., Moustakime, Y., & Joutei, K. A. (2015). Effect of arbuscular mycorrhizal fungi on phenolic compounds and antioxidant activity in plants. *Journal of Applied Botany and Food Quality*, 88, 1–6. DOI: 10.5073/JABFQ.2015.088.001
8. Kapoor, R., Giri, B., & Mukerji, K. G. (2002). Mycorrhization of coriander enhances the concentration and quality of essential oil. *Journal of the Science of Food and Agriculture*, 82(4), 339–342. DOI: 10.1002/jsfa.1036
9. Smith, S. E., & Read, D. J. (2008). *Mycorrhizal Symbiosis* (3rd ed.). Academic Press.
10. Viuda-Martos, M., Fernández-López, J., & Pérez-Álvarez, J. A. (2010). Pomegranate and its many functional components as related to human health: A review. *Comprehensive Reviews in Food Science and Food Safety*, 9(6), 635–654. DOI: 10.1111/j.1541-4337.2010.00131.x
11. Gullón, P., Pintado, M. E., Pérez-Álvarez, J. A., & Viuda-Martos, M. (2016). Assessment of polyphenolic profile and antibacterial activity of pomegranate peel. *Food Control*, 59, 94–98. DOI: 10.1016/j.foodcont.2015.06.038
12. Ambigaipalan, P., de Camargo, A. C., & Shahidi, F. (2017). Phenolic compounds of pomegranate peel: A review of their antioxidant and biological activities. *Food Chemistry*, 221, 160–169. DOI: 10.1016/j.foodchem.2016.10.043
13. Fischer, U. A., Carle, R., & Kammerer, D. R. (2011). Identification and quantification of phenolic compounds from pomegranate peel. *Journal of Agricultural and Food Chemistry*, 59(24), 12628–12636. DOI: 10.1021/jf203461g
14. Pomegranate peel as a rich source of polyphenols and natural antioxidants. *Food Bioscience* (2023).
15. Toussaint, J. P., Smith, F. A., & Smith, S. E. (2007). Arbuscular mycorrhizal fungi can induce the production of phytochemicals in plants. *Scientia Horticulturae*, 115(2), 110–115. DOI: 10.1016/j.scienta.2007.07.010
16. Al-Ibrahemi, N., Al-Asadi, Q. Th. Y., Hassan, S. F., Hamid, B. A., & Jawad, N. N. (2024). Response of flax (*Linum usitatissimum*) to nano-NPK and EMG-1 in growth, oil content, and active compounds. *SABRAO Journal of Breeding and Genetics*, 56(6), 2481–2487. <https://doi.org/10.54910/sabrao2024.56.6.29>
17. Al-Masaoodi, N. H., Al-Ibrahemi, N., Abdulmar, S. H., & Al-Yassiry, A. S. (2025). Fenugreek (*Trigonella graecum* L.) response to Azotobacter and orange peels in metabolism, growth, and yield traits. *SABRAO Journal of Breeding and Genetics*.

18. Al-Yasssiry, A. S., Aljenaby, H. K. A., Al-Masoody, I. H., & Al-Ibrahemi, N. (2024). Biofertilizers effects on the active compounds of sweet basil (*Ocimum basilicum* L.). *SABRAO Journal of Breeding and Genetics*, 56(1), 425–432. <https://doi.org/10.54910/sabrao2024.56.1.38>
19. Rabee, D. A., Al-Ani, S. H., Jasim, M. H., & Mohammed, A. H. (2023). Protective role of *Camellia sinensis* and nanoparticles. *Bionatura*, 8(4), 82. <https://doi.org/10.21931/RB/2023.08.04.82>
20. Srivastava, R.A.S.H.M.I., Joshi, M.A.M.T.A., Kumar, A.S.H.I.S.H., Pachari, S. and Sharma, A.K., (2010). Biofertilizers for sustainable agriculture. Diversification problems and perspectives. International Publishing House Pvt. Ltd., New Delhi, India, pp.58-73.
21. Al-Rawi, A.A., (2010). The effect of the organic materials addition on *Azotobacter* efficiency and nitrogen fixation in salinity soil. *Anbar Journal of Agriculture Sciences*. Special Issue, 8(4), pp.164-171.
22. Singh, J., Kaur, H., Kaur, N., Singh, S., & Singh, G. (2023). Pomegranate peel phytochemistry and applications. *ACS Omega*. <https://doi.org/10.1021/acsomega.3c02586>
23. Lina Abu-Niaaj , Ahmad M. Al-Qudah , Rasha S. Al-Tamimi , Mohammed I. Al-Natsheh (2024). Bioactivities of pomegranate peel. *Food Science & Nutrition*.
24. Tariq Aslam, Muhammad A. Khan, Hina Iqbal, Saeed Ahmed (2024). Bioactive metabolites of pomegranate peel. *Frontiers in Medicine*.
25. P. B. Rahul, K. V. Sharma, Anjali Verma , R. K. Singh (2025). Encapsulation of pomegranate peel extract. *Sustainable Food Technology*.
26. Siddiqui, S.A., Singh, S. and Nayik, G.A., (2024). Bioactive compounds from pomegranate peels-Biological properties, structure–function relationships, health benefits and food applications–A comprehensive review. *Journal of Functional Foods*, 116, p.106132.
27. Zhang, Y., Wang, L., Li, H., & Chen, X. (2023). Arbuscular mycorrhizal fungi enhance plant secondary metabolites. *Journal of Plant Physiology*.
28. Goyal, A., Mehta, R., Sharma , S., Gupta. P. (2024). Flaxseed bioactive compounds and health benefits. *Food Chemistry Advances*.