SPRINGER NATURE Link

Log in

UHPLC-DAD-ESI-MSn profiling and predictive modeling of polyphenols in *Ceratonia siliqua* flowers with cosmetic applications

Original Paper Published: 27 June 2026

Volume 20, pages 15174–15195 (2026) Cite this article



Journal of Food Measurement and Characterization

Aims and scope →

Submit manuscript →

Aida Mekhoukhe, Leila Deflaoui-Abdelfettah, Abderrahmane Mokrani, Zina Mouhoubi Tafinine, Lamia Medouni-Haroune, Sonia Medouni-Adrar, Yasmine Ait-Abbas, Celia Ourari, Ouahiba Soufi-Maddi, Lila Boulekbache-Makhlouf, Khodir Madani & Hayate Haddadi-Guemghar

94 Accesses Explore all metrics →

Abstract

This study explored the valorisation of carob (*Ceratonia siliqua*) flowers by optimizing the extraction of antioxidant compounds using Response Surface Methodology (RSM) with a Box Behnken Design (BBD). To the best of our knowledge, this represents the first report on carob flower polyphenols optimized with BBD model. Three variables were investigated: solvent concentration (50–80%), agitation speed (100–200 rpm), and extraction time (30–60 min). The optimized conditions were established at 80% ethanol, 200 rpm, and 50.96 min, resulting in a high global desirability score of 0.97. Under these optimal conditions, the experimental yields were 120.23 ± 1.16 mg GAE/g for total phenolic compounds (TPC), 26.44 ± 0.76 QE/g for flavonoids, 30.65 ± 0.85 mg TAE/g for tannins, and 17.77 ± 1.22 QE/g for flavanols. The data reported that all models developed exhibited

good agreement between predicted and experimental values (R^2 = 0.8681–0.9997) and were statistically significant (F-values ranging from 0.000 to 0.032). The results of optimized extract were charachterized using Ultra High Performance Liquid Chromatography coupled with Diode Array Detection and Electrospray Ionisation Mass Spectrometry (UHPLC-DAD-ESI-MS^n), revealing gallic acid and apigenin derivative as the most abundant compounds. Furthermore, the extracts demonstrated strong antioxidant and antidiabetic activities. Finally, five cosmetic body lotions were formulated using the optimized extract. Sensory evaluation revealed that formulation F3 received the highest overall score, indicating good consumer acceptability in terms of odor, spread ability, and skin feel.

This is a preview of subscription content, log in via an institution to check access.

Access this article

Log in via an institution

Subscribe and save

Springer+ from €37.37 /Month

Starting from 10 chapters or articles per month

Access and download chapters and articles from more than 300k books and 2,500 journals

Cancel anytime

View plans

Buy Now

Buy article PDF 39,95 €

Price includes VAT (Algeria)

Instant access to the full article PDF.

Institutional subscriptions →

Explore related subjects

Discover the latest articles, books and news in related subjects, suggested using machine learning.

Floriculture Flowering Lead Optimization Solid-phase microextraction

Natural Products Optimization

Antioxidant Activity and Bioactive Compound Extraction Techniques

Data availability

All data and materials are available.

Code Availability

Not applicable.

References

1. I. Boublenza, S. Ghezlaoui, M. Mahdad, F. Vasaï, F. Chemat, Algerian carob (*Ceratonia siliqua* L.) populations. Morphological and chemical variability of their fruits and seeds. Sci. Hortic. **256**, 108537 (2019). https://doi.org/10.1016/j.scienta.2019.05.064

2. M.E. Brassesco, A. Martins Vilas-Boas, T.R. Brandão, C.L. Silva, M. Azevedo, M. Pintado, Impact of roasting temperature and seed presence on carob flour (*Ceratonia*

siliqua L.): physical, chemical, and functional properties. ACS Food Sci & Technol. **3**(11), 1890–1902 (2023). https://doi.org/10.1021/acsfoodscitech.3c00263

3. J. Kassout, Y. Hmimsa, S. El Fatehi, A. El Ouahrani, K. Kadaoui, S. Chakkour, M. Ater, Image analysis of Moroccan carob seeds (*Ceratonia siliqua* L.) revealed substantial intraspecific variations depending on climate and geographic origin. Ecol. Process. **11**(1), 34 (2022). https://doi.org/10.1186/s13717-022-00378-w

4. A. Krokou, M. Stylianou, A. Agapiou, Assessing the volatile profile of carob tree (*Ceratonia siliqua* L.). Environ. Sci. Pollut. Res. **26**, 35365–35374 (2019). https://doi.org/10.1007/s11356-019-04664-7

5. P. Quezel, S. Santa, *Nouvelle Flore de l'Algérie et des régions désertiques méridionales. Tomes I et II* (Ed Centre National de la Recherche Scientifique, Paris, 1962)

6. A. Mekhoukhe, H. Kicher, A. Ladjouzi, L. Medouni-Haroune, F. Brahmi, S. Medouni-Adrar, K. Madani, Antioxidant activity of carob seeds and chemical composition of their bean gum by–products. J. Complement. Integr. Med. (2019). https://doi.org/10.1515/jcim-2017-0158

7. F.A. Ayaz, H. Torun, S.E.M.A. Ayaz, P.J. Correia, M. Alaiz, C. Sanz, M. Strnad, Determination of chemical composition of anatolian carob pod (*Ceratonia siliqua* L.): sugars, amino and organic acids, minerals and phenolic compounds. J. Food Qual. **30**(6), 1040–1055 (2007). https://doi.org/10.1111/j.1745-4557.2007.00176.x

8. I. Khelouf, I. Jabri Karoui, M. Abderrabba, Chemical composition, in vitro antioxidant and antimicrobial activities of carob pulp (*Ceratonia siliqua* L.) from Tunisia. Chem. Pap. **77**(10), 6125–6134 (2023). https://doi.org/10.1007/s11696-023-02926-w

9. O.A. Eldahshan, Isolation and structure elucidation of phenolic compounds of carob leaves grown in Egypt. Curr. Res. J. Biol. Sci. **3**(1), 52–55 (2011)

10. F.E. Mansouri, J.C.E. Silva, F. Cacciola, F. Asraoui, H. Tayeq, Y.M. Ben Amar, J.J. Brigui, Evaluation of different extraction methods on the phenolic profile and the antioxidant potential of *Ceratonia siliqua* L. pods extracts. Mol. **27**(19), 6163 (2022). https://doi.org/10.3390/molecules27196163

11. H. El Hajaji, N. Lachkar, K. Alaoui, Y. Cherrah, A. Farah, A. Ennabili, M. Lachkar, Antioxidant activity, phytochemical screening, and total phenolic content of extracts from three genders of carob tree barks growing in Morocco. Arab. J. Chem. **4**(3), 321–324 (2011). https://doi.org/10.1016/j.arabjc.2010.06.053

12. M. Balaban, Identification of the main phenolic compounds in wood of *Ceratonia siliqua* by GC-MS. Phytochemical Analysis: Int J of Plant Chem Biochem Tech **15**(6), 385–388 (2004). https://doi.org/10.1002/pca.792

13. C. Liyana-Pathirana, F. Shahidi, Optimization of extraction of phenolic compounds from wheat using response surface methodology. Food Chem. **93**(1), 47–56 (2005). https://doi.org/10.1016/j.foodchem.2004.08.050

14. S. Fotsing, M.P. Ngogang, N. Bérenger, L.J. Simo, J. Ngogang, Teneurs en polyphénols, en flavonoïdes et activités antioxydantes des rhizomes de Zingiber officinale récoltés dans cinq sites de culture du Cameroon. J. Cameroon Acad. Sci. **18**(2), 397–406 (2022). https://doi.org/10.4314/jcas.v18i2.1

15. K.D.P.P. Gunathilake, K.K.D.S. Ranaweera, H.V. Rupasinghe, Response surface optimization for recovery of polyphenols and carotenoids from leaves of *Centella asiatica* using an ethanol-based solvent system. Food Sci & nutr. **7**(2), 528–536 (2019). https://doi.org/10.1002/fsn3.832

16. M. Karamac, Fe [II], Cu [II] and Zn [II] chelating activity of buckwheat and buckwheat groats tannin fractions. Pol. J. Food Nutr. Sci. **57**(3), 357–362 (2007)

17. A.E. Hagerman, L.G. Butler, Protein precipitation method for the quantitative determination of tannins. Agri Food Chern **4**, 809–12 (1978). https://doi.org/10.1021/jf60218a027

18. A. Kumaran, R.J. Karunakaran, In vitro antioxidant activities of methanol extracts of five *Phyllanthus* species from India. LWT **40**(2), 344–352 (2007). https://doi.org/10.1016/j.lwt.2005.09.011

19. P. Prieto, M. Pineda, M. Aguilar, Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E1. E Anal Biochem **269**, 337–41 (1999). https://doi.org/10.1006/abio.1999.4019

20. K. Balan, P. Ratha, G. Prakash, P. Viswanathamurthi, S. Adisakwattana, T. Palvannan, Evaluation of invitro α-amylase and α-glucosidase inhibitory potential of N2O2 schiff base Zn complex. Arab. J. Chem. **10**(5), 732–738 (2017). https://doi.org/10.1016/j.arabjc.2014.07.002

21. L. Iglesias-Carres, A. Mas-Capdevila, L. Sancho-Pardo, F.I. Bravo, M. Mulero, B. Muguerza, A. Arola-Arnal, Optimized extraction by response surface methodology used for the characterization and quantification of phenolic compounds in whole red grapes (*Vitis vinifera*). Nutrients **10**(12), 1931 (2018). https://doi.org/10.3390/nu10121931

22. Z.E. Huma, V. Jayasena, S.M. Nasar-Abbas, M. Imran, M.K. Khan, Process optimization of polyphenol extraction from carob (*Ceratonia siliqua*) kibbles using microwave-assisted technique. J. Food Process. Preserv. **42**(2), e13450 (2018). https://doi.org/10.1111/jfpp.13450

23. R. Ayad, R. Ayad, H. Bourekoua, M. Lefahal, E.H. Makhloufi, S. Akkal, G. Nieto, Process optimization of phytoantioxidant and photoprotective compounds from carob pods (*Ceratonia siliqua* L.) using ultrasonic assisted extraction method. Mol **27**(24), 8802 (2022). https://doi.org/10.3390/molecules27248802

24. Y. Benchikh, H. Louailèche, Effects of extraction conditions on the recovery of phenolic compounds and in vitro antioxidant activity of carob (*Ceratonia siliqua* L.) pulp. Acta Bot. Gall. **161**(2), 175–181 (2014). https://doi.org/10.1080/12538078.2014.909325

25. A.N. Li, S. Li, H.B. Li, D.P. Xu, X.R. Xu, F. Chen, Total phenolic contents and antioxidant capacities of 51 edible and wild flowers. J. Funct. Foods **6**, 319–330 (2014). https://doi.org/10.1016/j.jff.2013.10.022

26. P. Kumari, D.V.S. Raju, K.V. Prasad, S. Saha, S. Panwar, S. Paul, S. Fogarasi, Characterization of anthocyanins and their antioxidant activities in Indian rose varieties (*Rosa× hybrida*) using HPLC. Antioxidants **11**(10), 2032 (2022). https://doi.org/10.3390/antiox11102032

27. Z. Xiang, H. Guan, X. Zhao, Q. Xie, Z. Xie, F. Cai, C. Wang, Dietary gallic acid as an antioxidant: a review of its food industry applications, health benefits, bioavailability, nano-delivery systems, and drug interactions. Food Res. Int. **180**(8), 114068 (2024). https://doi.org/10.1016/j.foodres.2024.114068

28. Ünal N, Kahraman O, Dögen A, & Binzet R. Investigation of the Chemical Composition, Antimicrobial, and Antioxidant Activity of Endemic Onosmahalophila Boiss. & Heldr. Curr Microbiol. **80**(8). (2023) https://doi.org/10.1007/s00284-023-03363-4

29. Cegledi E, Dobroslavić E, Zorić Z, Repajić M, Elez Garofulić I. Antioxidant Activity of Carob Tree (*Ceratonia siliqua L.*) Leaf Extracts Obtained by Advanced Extraction Techniques. Process. **12**(4), 658. (2024) https://doi.org/10.3390/pr12040658

30. Ioannou GD, Savva IK, Christou A, Stavrou IJ, & Kapnissi-Christodoulou CP. Polyphenols in carobs: A review on their composition, antioxidant capacity and cytotoxic effects, and health impact. Food chem **269**, 355–374. (2018) https://doi.org/10.1016/j.foodchem.2018.06.152

31. Ben Hamouda G, Bettaieb Rebey I, Zar Kalai F, Hammami M, & Ksouri R. Enhancing antioxidant yield from carob (Ceratonia siliqua L.): evaluating the efficacy of maceration and ultrasound-assisted methods. Int J Environ Health Res. **35**(7),1793–1805. (2025) https://doi.org/10.1080/09603123.2024.2407456

32. Hussain A, Batool S A, Sidrah Kabir K, Siddique T, Yaqub S, & Korma S A. Effects of spray drying and ultrasonic assisted extraction on the phytochemicals, antioxidant and antimicrobial activities of strawberry fruit. Food Chem Adv. **5**,100755. (2024) https://doi.org/10.1016/j.focha.2024.100755

33. Tourabi M, Metouekel A, Ghouizi A E, Jeddi M, Nouioura G, Laaroussi H, & Derwich E. Efficacy of various extracting solvents on phytochemical composition, and biological properties of Mentha longifolia L. leaf extracts. Sci Rep. **13**(1), 18028. (2023) https://doi.org/10.1038/s41598-023-45030-5

34. Kaczorová D, Karalija E, Dahija S, Bešta-Gajević R, Parić A, & Ćavar Zeljković S. Influence of extraction solvent on the phenolic profile and bioactivity of two Achillea species. Mol. **26**(6),1601. (2021) https://doi.org/10.3390/molecules26061601

35. Liu S X, White E. Extraction and characterization of proanthocyanidins from grape seeds. Open Food Sci J. **6**(1). (2012) https://doi.org/10.2174/1874256401206010005

36. Castillo-Correa M, Montalbán-Hernández C, Navarro-Hortal M D, Peña-Guzmán D, Badillo-Carrasco A, Varela-López A, & Romero Márquez J M. Exploring the Influence of Extraction Methods, Solvents, and Temperature on Total Phenolic Recovery and Antioxidant Capacity in Olive Leaf Extracts: A Systematic Review with Quantitative Synthesis. Separations. **12**(9), 236. (2025) https://doi.org/10.3390/separations12090236

37. S.C. Liu, J.T. Lin, C.K. Wang, H.Y. Chen, D.J. Yang, Antioxidant properties of various solvent extracts from lychee (*Litchi chinenesis* Sonn.) flowers. Food Chem. **114**(2), 577–581 (2009). https://doi.org/10.1016/j.foodchem.2008.09.088

38. A. Fernández-Agulló, E. Pereira, M.S. Freire, P. Valentao, P.B. Andrade, J. González-Álvarez, J.A. Pereira, Influence of solvent on the antioxidant and antimicrobial properties of walnut (*Juglans regia* L.) green husk extracts. Ind. Crops Prod. **42**, 126–132 (2013). https://doi.org/10.1016/j.indcrop.2012.05.021

39. H. Metrouh-Amir, C.M. Duarte, F. Maiza, Solvent effect on total phenolic contents, antioxidant, and antibacterial activities of *Matricaria pubescens*. Ind. Crops Prod. **67**, 249–256 (2015). https://doi.org/10.1016/j.indcrop.2015.01.049

40. M. Hebi, M. Eddouks, The promising role of plant tannins as bioactive antidiabetic agents. Curr. Med. Chem. **7**(1), 64–71 (2019). https://doi.org/10.2174/0929867325666180605124256

41. X.T. Le, V.L. Lan Vi, T.Q. Toan, L.G. Bach, T.T. Truc, P.T. Hai Ha, Extraction process of polyphenols from soybean (*Glycine max* L.) sprouts: optimization and evaluation of antioxidant activity. Processes **7**(8), 489 (2019). https://doi.org/10.3390/pr7080489

42. B. Wang, P. Chen, H. Zhang, Y. Chen, L. Chen, Optimization of polyphenols extraction by deep eutectic solvent from broccoli stem and characterization of their composition and antioxidative effects. Sci. Rep. **15**(1), 16066 (2015). https://doi.org/10.1038/s41598-025-00632-z

43. T. Sakdasukon, S. Thanachasai, Effect of agitation on extraction of phenolic compounds from ripe pericarp of *Wodyetia bifurcata*. Maejo Int J Energ Environ Comm. **4**(1), 44–48 (2022). https://doi.org/10.54279/mijeec.v4i1.246121

44. G.G. López, M.M. Brousse, M.L. Vergara, A.M. González, N.E. Cruz, A.R. Linares, Kinetic modelling of total phenolic compounds from *Ilex paraguariensis* (St. Hil.) leaves: conventional and ultrasound assisted extraction. Food Bioprod. Process. **139**, 75–88 (2023). https://doi.org/10.1016/j.fbp.2023.03.003

45. S. Shewale, V.K. Rathod, Extraction of total phenolic content from *Azadirachta indica* or (neem) leaves: kinetics study. Prep. Biochem. Biotechnol. **48**(4), 312–320 (2018). https://doi.org/10.1080/10826068.2018.1431784

46. N. Zainol, N.H. Aziz, A.S. Baharudin, Influence of agitation and solvent percentage on the extraction of phytochemical compound from *Asystasia gangetica*. Food Chem. Adv. **3**, 100538 (2023). https://doi.org/10.1016/j.focha.2023.100538

47. D. Tagliazucchi, E. Verzelloni, D. Bertolini, A. Conte, In vitro bio-accessibility and antioxidant activity of grape polyphenols. Food Chem. **120**(2), 599–606 (2010). https://doi.org/10.1016/j.foodchem.2009.10.030

48. J.J. Chan, R. Lim, G.C. Yusoff, A. Ngoh, A generalized energy-based kinetic model for microwave-assisted extraction of bioactive compounds from plants. Sep. Purif. Technol. **143**, 152–160 (2015). https://doi.org/10.1016/j.seppur.2015.01.041

49. O. Khedher, G. Rigane, R.B. Salem, Y. Moussaoui, Optimization of polyphenols recovery from *Schinus molle* L. peel using response surface methodology (RSM). Chem. Afr. **3**(3), 813–820 (2020). https://doi.org/10.1007/s42250-020-00170-3

50. M.H. Haido, A.H. Matti, S.M. Taher, M. Haido, Optimization of extraction conditions of bioactive compounds from Kurdistan species *Urtica dioica*. Cureus (2024). https://doi.org/10.7759/cureus.61146

51. F.J.A.A. Ekorong, G. Zomegni, S.C.Z. Desobgo, R. Ndjouenkeu, Optimization of drying parameters for mango seed kernels using central composite design. Bioresour. Bioprocess. **2**(1), 8 (2015). https://doi.org/10.1186/s40643-015-0036-x

52. M.C. Kyriacou, C. Antoniou, Y. Rouphael, G. Graziani, A. Kyratzis, Mapping the primary and secondary metabolomes of carob (*Ceratonia siliqua* L.) fruit and its postharvest antioxidant potential at critical stages of ripening. Antioxidants **10**(1), 57 (2021). https://doi.org/10.3390/antiox10010057

53. I.Y. Younis, A.F. Essa, S.A. El-Newary, A.M. Elgamal, M.A. Farag, E. Mohsen, Unravelling Egyptian blue lily (*Nymphaea nouchali*) organs' metabolome via UHPLC/PDA/ESI-QTOF-MS and in relation to their antioxidant and anti-cholinesterase effects. Sci. Rep. **15**, 44136 (2025). https://doi.org/10.1038/s41598-025-30937-y

54. K.M. Barry, N.W. Davies, C.L. Mohammed, Identification of hydrolysable tannins in the reaction zone of *Eucalyptus nitens* wood by high performance liquid chromatography–electrospray ionisation mass spectrometry. Phytochem. Anal. **12**(2), 120–127 (2001). https://doi.org/10.1002/pca.548

55. N.I. Kashchenko, D.N. Olennikov, N.K. Chirikova, Metabolites of *Geum aleppicum* and *Sibbaldianthe bifurca*: diversity and α-glucosidase inhibitory potential. Metabolites **13**(6), 689 (2023). https://doi.org/10.3390/metabo13060689

56. S. Djebari, M. Wrona, C. Nerín, O. Djaoudene, S. Guemouni, A. Boudria, K. Madani, Phenolic compounds profile of macerates of different edible parts of carob tree (*Ceratonia siliqua* L.) using UPLC-ESI-Q-TOF-MSE: phytochemical screening and biological activities. Fitoterapia **172**, 105696 (2024). https://doi.org/10.1016/j.fitote.2023.105696

57. I. Rached, L. Barros, I.P. Fernandes, C. Santos-Buelga, A.E. Rodrigues, A. Ferchichi, I.C. Ferreira, *Ceratonia siliqua* L. hydroethanolic extract obtained by ultrasonication: antioxidant activity, phenolic compounds profile and effects in yogurts functionalized with their free and microencapsulated forms. Food Funct. **7**, 1319–1328 (2016). https://doi.org/10.1039/c6fo00100a

58. D. Rico, A.B. Martín-Diana, C. Martínez-Villaluenga, L. Aguirre, J.M. Silván, M. Dueñas, A. Lasa, In vitro approach for evaluation of carob by-products as source bioactive ingredients with potential to attenuate metabolic syndrome (MetS). Heliyon (2019). https://doi.org/10.1016/j.heliyon.2019.e01175

59. T. Venianakis, N. Parisis, A. Christou, V. Goulas, N. Nikoloudakis, G. Botsaris, I.P. Gerothanassis, Phytochemical analysis and biological evaluation of carob leaf (*Ceratonia siliqua* L.) crude extracts using NMR and mass spectroscopic techniques. Molecules **29**, 5273 (2024). https://doi.org/10.3390/molecules29225273

60. M. Papagiannopoulos, H.R. Wollseifen, A. Mellenthin, B. Haber, R. Galensa, Identification and quantification of polyphenols in carob fruits (*Ceratonia siliqua* L.) and derived products by HPLC-UV-ESI/ MSn. J. Agric. Food Chem. **52**, 3784–3791 (2004). https://doi.org/10.1021/jf030660y

61. A.I. Owis, E.M.B. El-Naggar, Identification and quantification of the major constituents in Egyptian carob extract by liquid chromatography–electrospray ionization-tandem mass spectrometry. Pharmacogn. Mag. **12**(Suppl 1), S1 (2016). https://doi.org/10.4103/0973-1296.176108

62. R. Irada, L. Barros, I.P. Fernandes, C. Santos-Buelga, A.E. Rodrigues, A. Ferchichi, M. Filomena Barreiro, I.C.F.R. Ferreira, *Ceratonia siliqua* L. hydroethanolic extract obtained by ultrasonication: antioxidant activity, phenolic compounds profile and effects in yogurts functionalized with their free and microencapsulated forms. Food Funct. **7**, 1319–1328 (2016). https://doi.org/10.1039/C6FO00100A

63. Ferreres, F., Gil-Izquierdo, A., Andrade, PB, Valentão, P. et Tomás-Barberán, FA. Caractérisation des flavones C-glycosylées O-glycosylées par chromatographie liquide – spectrométrie de masse en tandem. Journal de Chromatographie A. **1161** (1–2), 214–223 (2007) https://doi.org/10.1016/j.chroma.2007.05.103

64. F. Ferreres, B.M. Silva, P.B. Andrade, R.M. Seabra, M.A. Ferreira, Approach to the study of C-glycosyl flavones by ion trap HPLC-PAD-ESI/MS/MS: application to seeds of quince (*Cydonia oblonga*). Phytochem. Anal. **14**(6), 352–359 (2003). https://doi.org/10.1002/pca.727

65. T. Levandi, T. Puessa, M. Vaher, A. Ingver, R. Koppel, M. Kaljurand, Principal component analysis of HPLC-MS/MS patterns of wheat (*Triticum aestivum*) varieties. Proc. Est. Acad. Sci. **63**(1), 86 (2014). https://doi.org/10.3176/proc.2014.1.11

66. F. Cuyckens, M. Claeys, Mass spectrometry in the structural analysis of flavonoids. J. Mass Spectrom. **39**, 1–15 (2004). https://doi.org/10.1002/jms.585

67. G. Dinelli, A. Segura-Carretero, R. Di Silvestro, I. Marotti, D. Arráez-Román, S. Benedettelli, A. Fernadez-Gutierrez, Profiles of phenolic compounds in modern and old common wheat varieties determined by liquid chromatography coupled with time-of-flight mass spectrometry. J. Chromatogr. A **1218**(42), 7670–7681 (2011). https://doi.org/10.1016/j.chroma.2011.05.065

68. A. Richane, B.M. Rim, K. Riadh, A. Khaoula, M. Nizar, B.I. Hanen, Variability of phenolic compounds and antioxidant activities of ten *Ceratonia siliqua* L.

provenances. Biochem. Syst. Ecol. **104**, 104486 (2022). https://doi.org/10.1016/j.bse.2022.104486

69. E. Rakib, H. Chicha, S. Abouricha, M. Alaoui, A.A. Bouli, M. Hansali, R.W. Owen, Determination of phenolic composition of carob pods grown in different regions of Morocco. Journal of Natural Products (India) **3**, 134–140 (2010)

70. V. Goulas, E. Georgiou, Utilization of carob fruit as sources of phenolic compounds with antioxidant potential: extraction optimization and application in food models. Foods **9**(1), 20 (2019). https://doi.org/10.3390/foods9010020

71. V. Goulas, A. Hadjisolomou, Dynamic changes in targeted phenolic compounds and antioxidant potency of carob fruit (*Ceratonia siliqua* L.) products during in vitro digestion. Lwt **101**, 269–275 (2019). https://doi.org/10.1016/j.lwt.2018.11.003

Acknowledgements

We are grateful to the Ministry of Higher Education and Scientific Research of Algeria. We would like to express our sincere gratitude to Prof. Soledad Rubio, head of the scientific field Chemical Science and Technology (CTQ) and leader of the Supramolecular Analytical Chemistry Group in Córdoba, Spain, for her scientific support and guidance throughout this work. Our heartfelt thanks also go to Dr. Noelia Caballero Casero, member of the same group, for her valuable help, availability, and active involvement in this study.

Funding

This work was supported by a grant from the Ministry of High Education and Scientific Research of Algeria.

Author information

Authors and Affiliations

Faculty of Natural and Life Sciences, Laboratory of Biochemistry Biophysics Biomathematics and Scientometry, University of Bejaia, Bejaia, 06000, Algeria
Aida Mekhoukhe, Abderrahmane Mokrani, Sonia Medouni-Adrar, Yasmine Ait-Abbas, Celia Ourari, Ouahiba Soufi-Maddi, Lila Boulekbache-Makhlouf, Khodir Madani & Hayate Haddadi-Guemghar

Faculty of Natural Sciences and Life, Applied Biochemistry Laboratory, University of Bejaia, Bejaia, 06000, Algeria
Leila Deflaoui-Abdelfettah & Zina Mouhoubi Tafinine

Centre de Recherche en Technologies Agro-alimentaires, Route de Targa Ouzemmour, Campus Universitaire, Bejaia, 06000, Algeria
Lamia Medouni-Haroune

Contributions

The first draft of the manuscript, Material preparation, data collection, analysis and validation were performed by Aida Mekhoukhe, Data Analysis by Leila Deflaoui-Abdelffetah, methodology by Abderrahmane Mokrani and Zina Mouhoubi tafinine, investigation by Yasmine Ait-Abbas, Celia Ourari, Sonia Medouni-Adrar, Lamia Medouni-Haroune and Ouahiba Soufi-Maddi, Supervision by Lila Boulekbache-Makhlouf [a], Khodir Madani [a], Hayate Haddadi-Guemghar. all authors have read and approved the final manuscript.

Corresponding author

Correspondence to Aida Mekhoukhe.

Ethics declarations

Ethics approval

Not applicable.

Conflicts of interest

There is no conflicts of interest regarding this article/the authors declare that they have no competing interests.

Additional information

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Rights and permissions

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Reprints and permissions

About this article

Cite this article

Mekhoukhe, A., Deflaoui-Abdelfettah, L., Mokrani, A. *et al.* UHPLC-DAD-ESI-MSn profiling and predictive modeling of polyphenols in *Ceratonia siliqua* flowers with cosmetic applications. *Food Measure* **20**, 15174–15195 (2026). https://doi.org/10.1007/s11694-026-04613-2

Received	Accepted	Published
07 May 2026	08 June 2026	27 June 2026

Version of record	Issue date
27 June 2026	August 2026

DOI

https://doi.org/10.1007/s11694-026-04613-2

Keywords

Carob flowers Box behnken Polyphenols Optimization

UHPLC-DAD-ESI-MSn