

DETERMINATION OF THE GEOGRAPHICAL ORIGINS OF OLIVE MILL WASTEWATER: FT-MIR SPECTROSCOPY AND CHEMOMETRIC ALGORITHMS FOR ACCURATE CLASSIFICATION

FAÏÇAL SBAI EL OTMANI; AIMEN EL ORCHE; MOUAD MOUHSIN; MERIEM KASBAJI;
AYOUB AIT OUMGHAR; MOHAMED MBARKI AND MUSTAPHA OUBENALI

References:

1. Hanafi, F.; Assobhei, O.; Mountadar, M. Detoxification and Discoloration of Moroccan Olive Mill Wastewater by Electrocoagulation. *J. Hazard. Mater.* **2010**, 174(1–3), 807–812. doi:10.1016/j.jhazmat.2009.09.124
2. Paredes, C.; Cegarra, J.; Roig, A.; Sánchez-Monedero, M. A.; Bernal, M. P. Characterization of Olive Mill Wastewater (Alpechin) and Its Sludge for Agricultural Purposes. *Bioresour. Technol.* **1999**, 67(2), 111–115. doi:10.1016/S0960-8524(98)00106-0
3. Fiestas Ros de Ursinos, J. A.; Borja Padilla, R. Use and Treatment of Olive Mill Wastewater: Current Situation and Prospects in Spain. *Grasas Aceites* **1992**, 43(2), 101–106. doi:10.3989/gya.1992.v43.i2.1182
4. Amaral, C.; Lucas, M. S.; Coutinho, J.; Crespi, A. L.; do Rosário Anjos, M.; Pais, C. Microbiological and Physicochemical Characterization of Olive Mill Wastewaters from a Continuous Olive Mill in Northeastern Portugal. *Bioresour. Technol.* **2008**, 99(15), 7215–7223. doi:10.1016/j.biortech.2007.12.058
5. Bouknana, D.; Hammouti, B.; Salghi, R.; et al. Physicochemical Characterization of Olive Oil Mill Wastewaters in the Eastern Region of Morocco. *J. Mater. Environ. Sci.* **2014**, 5(4), 1039–1058.
6. Mseddi, S.; Chaari, L.; Belaid, C.; Chakchouk, I.; Kallel, M. Valorization of Treated Olive Mill Wastewater in Fertigation Practice. *Environ. Sci. Pollut. Res.* **2016**, 23(16), 15792–15800. doi:10.1007/s11356-015-4353-6
7. Massadeh, M. I.; Modallal, N. Ethanol Production from Olive Mill Wastewater (OMW) Pretreated with *Pleurotus sajor-caju*. *Energy Fuels* **2008**, 22(1), 150–154. doi:10.1021/ef7004145
8. Ntougias, S.; Gaitis, F.; Katsaris, P.; Skoulika, S.; Iliopoulos, N.; Zervakis, G. I. Effects of Olive Harvest Period and Production Year on Olive Mill Wastewater Properties: Evaluation of *Pleurotus* Strains as Bioindicators of Effluent Toxicity. *Chemosphere* **2013**, 92(4), 399–405. doi:10.1016/j.chemosphere.2013.01.033
9. Sinigaglia, M.; Di Benedetto, N.; Bevilacqua, A.; Corbo, M. R.; Capece, A.; Romano, P. Yeasts Isolated from Olive Mill Wastewaters from Southern Italy: Technological Characterization and Potential Use for Phenol Removal. *Appl. Microbiol. Biotechnol.* **2010**, 87(6), 2345–2354. doi:10.1007/s00253-010-2684-2
10. Bleve, G.; Lezzi, C.; Chiriatti, M. A.; et al. Selection of Non-Conventional Yeasts and Their Use in Immobilized Form for the Bioremediation of Olive Oil Mill Wastewaters. *Bioresour. Technol.* **2011**, 102(2), 982–989. doi:10.1016/j.biortech.2010.09.059
11. Tsiamis, G.; Tzagkaraki, G.; Chamalaki, A.; et al. Olive-Mill Wastewater Bacterial Communities Display a Cultivar-Specific Profile. *Curr. Microbiol.* **2012**, 64(2), 197–203. doi:10.1007/s00284-011-0049-4
12. Martínez-Gallardo, M. R.; López, M. J.; López-González, J. A.; et al. Microbial Communities of the Olive Mill Wastewater Sludge Stored in Evaporation Ponds: A Resource for Sustainable Bioremediation. *J. Environ. Manage.* **2021**, 279 (Dec 2020). doi:10.1016/j.jenvman.2020.111810
13. Casa, R.; D'Annibale, A.; Pieruccetti, F.; Stazi, S. R.; Sermanni, G. G.; Lo Cascio, B. Reduction of Phenolic Components in Olive-Mill Wastewater by Enzymatic Treatment and Its Impact on Durum Wheat (*Triticum durum* Desf.) Germinability. *Chemosphere* **2003**, 50(8), 959–966. doi:10.1016/S0045-6535(02)00707-5
14. Aktas, E. S.; Imre, S.; Ersoy, L. Characterization and Lime Treatment of Olive Mill Wastewater. *Water Res.* **2001**, 35(9), 2336–2340. doi:10.1016/S0043-1354(00)00490-5
15. Fiorentino, A.; Gentili, A.; Isidori, M.; et al. Environmental Effects Caused by Olive Mill Wastewaters: Toxicity Comparison of Low-Molecular-Weight Phenol Components. *J. Agric. Food Chem.* **2003**, 51(4), 1005–1009. doi:10.1021/jf020887d
16. Ben Sassi, A.; Boularbah, A.; Jaouad, A.; Walker, G.; Boussaid, A. Comparison of Olive Oil Mill Wastewaters (OMW) from Three Different Processes in Morocco. *Process Biochem.* **2006**, 41(1), 74–78. doi:10.1016/j.procbio.2005.03.074
17. El Yamani, M.; Ghabbour, N.; Sakar, E. H.; Rharrabti, Y. Olive Oil Wastewaters from Northern Morocco: Physicochemical Characterization and Antibacterial Activity of Polyphenols. *J. Mater. Environ. Sci.* **2017**, 8(8), 2667–2378.
18. El Yamani, M.; Sakar, E. H.; Boussakouran, A.; Ghabbour, N.; Rharrabti, Y. Physicochemical and Microbiological Characterization of Olive Mill Wastewater (OMW) from Different Regions of Northern Morocco. *Environ. Technol.* **2020**, 41(23), 3081–3093. doi:10.1080/09593330.2019.1597926
19. Leouifoudi, I.; Zyad, A.; Amechrouq, A.; Oukerrou, M. A.; Mouse, H. A.; Mbarki, M. Identification and Characterization of Phenolic Compounds Extracted from Moroccan Olive Mill Wastewater. *Food Sci.*

Technol. **2014**, 34(2), 249–257. doi:10.1590/fst.2014.0051

20. Leouifoudi, I.; Harnafi, H.; Ziad, A. Olive Mill Waste Extracts: Polyphenols Content, Antioxidant, and Antimicrobial Activities. *Adv. Pharmacol. Sci.* **2015**, 2015, Article ID 714138. doi:10.1155/2015/714138
21. Leouifoudi, I.; Mbarki, M.; Tilaoui, M.; et al. Study of the *In Vitro* Anticancer Activity of Moroccan Phenolic Olive Cake Extracts. *J. Pharmacogn. Phytochem.* **2014**, 2(6), 154–165.
22. Elbir, M.; Es-Safi, N. E.; Amhoud, A.; Mbarki, M. Characterization of Phenolic Compounds in Olive Stones of Three Moroccan Varieties. *Maderas Cienc. Tecnol.* **2015**, 17(3), 479–492. doi:10.4067/S0718-221X2015005000043
23. El Orche, A.; Bouatia, M.; Yanisse, S.; Labjar, H.; Mouhsin, M.; Bouha, M.; Oubenali, M.; Mbarki, M. Evaluation of the Capability of Horizontal ATR-FTMIR and UV-Visible Spectroscopy in the Discrimination of Virgin Olive Oils from the Moroccan Region of Beni Mellal-Khenifra. *J. Spectrosc.* **2020**, Article ID 9317350, 1–9. doi:10.1155/2020/9317350
24. Olmo-García, L.; Bajoub, A.; Benlamaalam, S.; et al. Establishing the Phenolic Composition of *Olea europaea* L. Leaves from Cultivars Grown in Morocco as a Crucial Step Towards Their Subsequent Exploitation. *Molecules* **2018**, 23(10), 1–18. doi:10.3390/molecules23102524
25. El Orche, A.; Bouatia, M.; Mbarki, M. Rapid Analytical Method to Characterize the Freshness of Olive Oils Using Fluorescence Spectroscopy and Chemometric Algorithms. *J. Anal. Methods Chem.* **2020**, 2020, Article ID 8860161. doi:10.1155/2020/8860161
26. El Orche, A.; Bouatia, M.; Yanisse, S.; et al. Evaluation of the Capability of Horizontal ATR-FTMIR and UV-Visible Spectroscopy in the Discrimination of Virgin Olive Oils from the Moroccan Region of Beni Mellal-Khenifra. *J. Spectrosc.* **2020**, Article ID 9317350. doi:10.1155/2020/9317350
27. Laouni, A.; El Orche, A.; Elhamdaoui, O.; Karrouchi, K.; El Karbane, M.; Bouatia, M. Preliminary Study on the Potential of FT-IR Spectroscopy and Chemometrics for Tracing the Geographical Origin of Moroccan Virgin Olive Oils. *J. AOAC Int.* **2023**, 106(3), 804–812. doi:10.1093/jaoacint/qsac136
28. Hirri, A.; Bassbasi, M.; Platikanov, S.; Tauler, R.; Oussama, A. FTIR Spectroscopy and PLS-DA Classification and Prediction of Four Commercial Grade Virgin Olive Oils from Morocco. *Food Anal. Methods* **2016**, 9(4), 974–981. doi:10.1007/s12161-015-0255-y
29. Benlamaalam, S.; Chigr, M.; Hirri, A.; Auhmani, A.; Mbarki, M. Characterization and Discrimination of Virgin Olive Oils from Different Moroccan Geographical Areas Using MIR Spectroscopy Coupled to Chemometric Methods. *Int. J. Sci. Res.* **2015**, 4(6), 2443–2448. doi:10.13140/RG.2.1.4760.9443
30. Pretsch, E.; Bihlmann, P.; Affolter, C. *Structure Determination of Organic Compounds: Tables of Spectral Data*; 3rd ed.; Springer-Verlag: Berlin, Heidelberg, 2000. doi:10.1007/978-3-662-04201-4
31. Larkin, P. J. *Infrared and Raman Spectroscopy: Principles and Spectral Interpretation*; 2011. doi:10.1016/C2015-0-00806-1
32. El Orche, A.; Bouatia, M.; Labjar, H.; Maaouni, M.; Mbarki, M. Coupling Mid Infrared Spectroscopy to Mathematical and Statistical Tools for Automatic Classification, Qualification, and Quantification of Argan Oil Adulteration. *6th Int. Conf. Optim. Appl. ICOA 2020*, Proc. 1–4. doi:10.1109/ICOA49421.2020.9094456
33. Zaroual, H.; Chénè, C.; El Hadrami, E. M.; Karoui, R. Application of New Emerging Techniques in Combination with Classical Methods for the Determination of the Quality and Authenticity of Olive Oil: A Review. *Crit. Rev. Food Sci. Nutr.* **2022**, 62(16), 4526–4549. doi:10.1080/10408398.2021.1876624
34. Zaroual, H.; Chénè, C.; Mestafa El Hadrami, E.; Karoui, R. Comparison of Four Classification Statistical Methods for Characterising Virgin Olive Oil Quality During Storage up to 18 Months. *Food Chem.* **2022**, 370 (Aug 2021). doi:10.1016/j.foodchem.2021.131009
35. Zaroual, H.; El Hadrami, E. M.; Karoui, R. Preliminary Study on the Potential Application of Fourier-Transform Mid-Infrared for the Evaluation of Overall Quality and Authenticity of Moroccan Virgin Olive Oil. *J. Sci. Food Agric.* **2021**, 101(7), 2901–2911. doi:10.1002/jsfa.10922
36. Dupuy, N.; Galtier, O.; Ollivier, D.; Vanloot, P.; Artaud, J. Comparison between NIR, MIR, Concatenated NIR and MIR Analysis and Hierarchical PLS Model. Application to Virgin Olive Oil Analysis. *Anal. Chim. Acta* **2010**, 666(1–2), 23–31. doi:10.1016/j.aca.2010.03.034
37. Laroussi-Mezghani, S.; Vanloot, P.; Molinet, J.; et al. Authentication of Tunisian Virgin Olive Oils by Chemometric Analysis of Fatty Acid Compositions and NIR Spectra: Comparison with Maghrebien and French Virgin Olive Oils. *Food Chem.* **2015**, 173, 122–132. doi:10.1016/j.foodchem.2014.10.002
38. De Luca, M.; Terouzi, W.; Ioele, G.; et al. Derivative FTIR Spectroscopy for Cluster Analysis and Classification of Moroccan Olive Oils. *Food Chem.* **2011**, 124(3), 1113–1118. doi:10.1016/j.foodchem.2010.07.010
39. De Luca, M.; Terouzi, W.; Kzaiber, F.; Ioele, G.; Oussama, A.; Ragno, G. Classification of Moroccan Olive Cultivars by Linear Discriminant Analysis Applied to ATR-FTIR Spectra of Endocarps. *Int. J. Food Sci. Technol.* **2012**, 47(6), 1286–1292. doi:10.1111/j.1365-2621.2012.02972.x
40. El Mouftari, M.; Mahjoubi, F. Z.; Kzaiber, F.; et al. Study of Oleaster Oil's Falsification by ATR-FTIR and Chemometrics Tools. *Egypt. J. Chem.* **2021**, 64(6), 2747–2755. doi:10.21608/ejchem.2021.53644.3107
41. Terouzi, W.; Platikanov, S.; de Juan Capdevila, A.; Oussama, A. Classification of Olives from Moroccan Regions Using Direct FT-IR Analysis: Application of Support Vector Machines (SVM). *Int. J. Innov. Appl. Stud.* **2013**, 3(2), 493–503.