

AGASTACHE MEXICANA (LAMIACEAE) AS A MODEL FOR STUDY OF PLANT SECONDARY METABOLISM BY THE METABOLOMIC METHODS

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REFERECES

1. Hong J., Yang L., Zhang D., Shi J. 2016. Plant metabolomics: An indispensable system biology tool for plant science. — *Int. J. Mol. Sci.* 17: 767.
2. He C., Peng B., Dan Y., Peng Y., Xiao P. 2014. Chemical taxonomy of tree peony species from China based on root cortex metabolic fingerprinting. — *Phytochemistry*. 107(1): 69–79.
3. Matsuda F., Nakabayashi R., Yang Zh., Okazaki Y., Yonemaru J., Ebana K., Yano M., Saito K. 2015. Metabolome-genome-wide association study dissects genetic architecture for generating natural variation in rice secondary metabolism. — *Plant J.* 81(1): 13–23.
4. Piasecka A., Sawikowska A., Krajewski P., Kachlick P. 2015. Combined mass spectrometric and chromatographic methods for in-depth analysis of phenolic secondary metabolites in barley leaves. — *J. Mass Spectrom.* 50(3): 513–532.
5. Alseekh S., Tohge T., Wendenberg R., Scossa F., Omranian N., Li J., Kleessen S., Giavalisco P., Pleban T., Mueller-Roeber B., Zamir D., Nikoloski Z., Fernie A. R. 2015. Identification and mode of inheritance of quantitative trait loci for secondary metabolite abundance in Tomato. — *Plant Cell.* 27(3): 485–512.
6. Voroshilov V. N. 1982. *Opredelitel rasteniy Sovetskogo Dalnego Vostoka* [Key to plants of the Soviet Far East]. Moscow. 672 p. (In Russian)
7. *Rastitelnye resursy SSSR. Tsvetkovye rasteniya, ikh khimicheskij sostav, ispolzovanie*. 1991. Vol. 4: *Semeystva Hippuridaceae—Lobeliaceae* [Plant Resources of the SSSR: Flowering plants and their chemical composition, using. Vol. 4: Fam. Hippuridaceae—Lobeliaceae]. Ed. by P. D. Sokolov. St. Petersburg. 197 p. (In Russian)
8. *Dikorastushchiye poleznye rasteniya Rossii* 2001. [Wild useful plants of Russia]. Ed. by A. L. Budantsev, E. E. Lesiovskaya. St. Petersburg. 663 p. (In Russian)
9. *Rastitelnyye resursy Rossii: Dikorastushchiye tsvetkovye rasteniya, ikh komponentnyy sostav i biologicheskaya aktivnost*. 2011. Vol. 4: *Semeystva Caprifoliaceae—Lobeliaceae* [Plant Resources of Russia: Wild flowering plants and their component composition and biological activity. Vol. 4: Family Caprifoliaceae—Lobeliaceae]. Ed. by A. L. Budantsev. St. Petersburg; Moscow. 630 p. (In Russian)

10. Zielińska S., Matkowski A. 2014. Phytochemistry and bioactivity of aromatic and medicinal plants from the genus *Agastache* (Lamiaceae). — *Phytochem. Rev.* 13(2): 391–416.
11. Yakobson E. L., Danchul T. Yu., Terekhova T. A. 1994. *Agastache rugosa* (Fisch. et C. Mey.) O. Kuntze (Lamiaceae) – the source of bioactive compounds at introduction on the north-west of Russia. In: Tr. molodezhnoy conf. botanikov Sankt-Peterburga. Bot. inst. RAN-SPB. (In Russian).
12. Estrada-Reyes R., López-Rubalcava C., Ferreyra-Cruz O. A., Dorantes-Barrón A. M., Heinze G., Moreno Aguilar J., Martínez-Vázquez M. 2014. Central nervous system effect and chemical composition of two subspecies of *Agastache mexicana* an ethnomedicine of Mexico. — *J. Ethnopharmacol.* 153(1): 98–110.
13. González-Trujano M. E., Ponce-Muñoz H., Hidalgo-Figueroa S., Navarrete-Vázquez G., Estrada-Soto S. 2015. Depressant effects of *Agastache mexicana* methanol extract and one of major metabolites tilianin. — *Asian Pac. J. Trop. Med.* 8(3): 185–190.
14. Hernandez-Abreu O., Castillo-España P., León-Rivera I., Ibarra-Barajas M., Villalobos-Molina R., González-Christen J., Vergara-Galicia J., Estrada-Soto S. 2009. Antihypertensive and vasorelaxant effects of tilianin isolated from *Agastache mexicana* are mediated by NO/cGMP pathway and potassium channel opening. — *Biochem. Pharmacol.* 78(1): 54–61.
15. Hernandez-Abreu O., Durán-Gómez L., Best-Brown R., Villalobos-Molina R., Rivera-Leyva J., Estrada-Soto S. 2011. Validated liquid chromatographic method and analysis of content of tilianin on several extracts obtained from *Agastache mexicana* and its correlation with vasorelaxant effect. — *J. Ethnopharmacol.* 138(2): 487–491.
16. Hernandez-Abreu O. S., Torres-Piedra M., García-Jiménez S., Ibarra-Barajas M., Villalobos-Molina R., Montes S., Rembao D., Estrada-Soto S. 2013. Dose-dependent antihypertensive determination and toxicological studies of tilianin isolated from *Agastache mexicana*. — *J. Ethnopharmacol.* 146(1): 187–191.
17. Molina-Hernandez M., Tellez-Alcantara P., Martinez E. 2000. *Agastache mexicana* may produce angiogenic-like actions in the male rat. — *Phytomedicine.* 7(3): 199–203.
18. Ibarra-Alvarado C., Rojas A., Mendoza S. 2010. Vasoactive and antioxidant activities of plants used in Mexican traditional medicine for the treatment of cardiovascular diseases. — *Pharm. Biol.* 48(7): 732–739.
19. Xia J., Sinelnikov I., Han B., Wishart D. S. 2015. MetaboAnalyst 3.0 – making metabolomics more meaningful. — *Nucl. Acids Res.* 43: 251–257.
20. Wold S. 1987. Principal Component Analysis. — *Chemometr. Intellig. Lab. Syst.* 2: 37–52.
21. Eriksson L., Johansson E., Kettaneh-Wold K., Trygg J., Wikstrom C., Wold S. 2006. Multi- and Megavariate Data Analysis Umetrics. AB Umea.
22. Perez-Enciso M., Tenenhaus M. 2003. Prediction of clinical outcome with microarray data: a partial least squares discriminant analysis (PLS-DA) approach. — *Human Genet.* 112: 581–592.

23. Brieman L. 2001. Random forests. *Machine learning*. 45: 5–32.
24. <http://www.kegg.jp>
25. Kretovich V. L. 1980. *Biokhimiya rastenii [Biochemistry of plants]*. Moscow. Vyshaya shkola. 445 p. (In Russian)
26. Seigler D. S. 1998. *Plant secondary metabolism*. Boston. 75 p.
27. *Biochemistry of plant secondary metabolism*. 2010. — *Annual Plant Rev.* Oxford. 40. 434 p.
28. *Plant Metabolomics. Methods and Protocols*. 2012. Ed. by N. W. Hardy, R. D. Hall. 340 p.
29. *The Handbook of Plant Metabolomics*. 2013. Ed. by W. Weckwerth, G. Kahl. Wiley-Blackwell. 448 p.
30. Jernejc K. 2004. Comparison of different methods for metabolite extraction from *Aspergillus nigermycelium*. — *Acta Chim. Slov.* 51: 567–578.
31. Park C., Yun S., Lee S. Y., Park K., Lee J. 2012. Metabolic profiling of *Klebsiella oxytoca*: evaluation of methods for extraction of intracellular metabolites using UPLC/Q-TOF-MS. — *Appl. Biochem. Biotechnol.* 167(3): 425–438.
32. Villas-Bôas S. G., Højer-Pedersen J., Akesson M., Smedsgaard J., Nielsen J. 2005. Global metabolite analysis of yeast: evaluation of sample preparation methods. — *Yeast*. 22(14): 1155–1169.
33. Gravot A., Dittami S. M., Rousvoal S., Lugan R., Eggert A., Collén J., Boyen C., Bouchereau A., Tonon T. 2010. Diurnal oscillations of metabolite abundances and gene analysis provide new insights into central metabolic processes of the brown alga *Ectocarpus siliculosus*. — *New Phytol.* 188(1): 98–110.
34. Ito T., Tanaka M., Shinkawa H., Nakada T., Ano Y., Kurano N., Soga T., Tomita M. 2013. Metabolic and morphological changes of an oil accumulating trebouxiophycean alga in nitrogen-deficient conditions. — *Metabolomics*. 9(1): 178–187.
35. Liseč J., Schauer N., Kopka J., Willmitzer L., Fernie A. R. 2006. Gas chromatography mass spectrometry-based metabolite profiling in plants. — *Nat. Protoc.* 1(1): 387–396.
36. Tambellini N. P., Zarembeg V., Turner R. J., Weljie A. M. 2013. Evaluation of extraction protocols for simultaneous polar and non-polar yeast metabolite analysis using multivariate projection methods. — *Metabolites*. 3(3): 592–605.
37. Jones W. P., Kinghorn A. D. 2012. Extraction of plant secondary metabolites. — *Methods Mol. Biol.* 864: 341–366.
38. Schaller H. 2003. The role of sterols in plant growth and development. — *Prog. Lipid Res.* 42: 163–175.
39. Fridman Y., Savaldi-Goldstein S. 2013. Brassinosteroids in growth control: How, when and where. — *Plant Sci.* 209: 24–31.
40. Cacas J. L., Furt F., Le Guédard M., Schmitter J. M., Buré C., Gerbeau-Pisso P., Moreau P., Bessoule J. J., Simon-Plas F., Mongrand S. 2012. Lipids of plant membrane rafts. — *Prog. Lipid Res.* 51: 272–299.

41. Malinsky J., Opekarová M., Grossmann G., Tanner W. 2013. Membrane microdomains, rafts, and detergent-resistant membranes in plants and fungi. — *Ann. Rev. Plant Biol.* 64: 501–529.
42. Valitova Yu. N., Sulkarnayeva A. G., Minibayeva F. V. 2016. Plant sterols: the diversity, biosynthesis, and physiological functions. — *Biochemistry (Moscow)*. 81: 121–132.
43. Moses T., Papadopoulou K. K., Osbourn A. 2014. Metabolic and functional diversity of saponins, biosynthetic intermediates and semi-synthetic derivatives. — *Crit. Rev. Biochem. Mol. Biol.* 49: 439–462.