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PROSPECTS OF CURCUMIN USE IN NANOBIOTECHNOLOGY

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The aim of the work was a generalization of literature data on the prospects for curcumin usage in biotechnology as a component for biologically active nanocomplexes with anti-inflammatory and antioxidant activity creation. It is emphasized that their effectiveness depends on the solubility in aqueous medium and on the metabolism rate decreasing in the body. Current trend is the development of creation methods of hydrophilic curcumin-based nanostructures to increase the time of its biological action. Its nanostructures with silicium, polylysine, copolymers of lactic and glycolic acids and metal ions are the most promising in this respect. For multicomponent hybrid nanoparticles effective usage the substantiation of their component combined use features is necessary. The practical task is to create and to study the functional properties of such combined nanocomplexes. Curcumin complex with metal ions creation contributes to its water solubility and to increase the efficiency of biological action. These complexes have specific characteristics depending on the nature of metal ion. The creation of curcumin-based biocompatible nanocomposites with amplifiers of its action that are known pharmaceuticals is perspective. Such multifunctional nanocomplexes will facilitate the targeted medicines delivery to the places of pathological processes localization and the reduction of their side effects.

Key words: curcumin, multicomponent nanocomplexes.

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1. *Kanyuk M. I.* Use of nanodiamonds in biomedicine. *Biotechnologia Acta*. 2015, 8 (2), 9–25. https://doi.org/10.15407/biotech8.02.009

2. *Chekman I. S.* Nanopharmacology. *K.: Zadruga*. 2011, 424 p. (In Ukrainian).

3. *Prylutska S. V., Grynyuk I. I., Grebinyk S. M., Matyshevska O. P., Prylutskyy Yu. I., Ritter U., Siegmund C., Scharff P.* Comparative study of biological action of fullerenes C_{60} and carbon nanotubes in thymus cells.
Mat.-wiss. u. Werkstofftech
. 2009, 40, 238–241.

4. *Prylutska S. V., Burlaka A. P., Prylutskyy Yu. I., Ritter U., Scharff P.* Comparative study of antitumor effect of pristine C
60
fullerenes and doxorubicin.
Biotechnology.
2011, V. 4, P. 82–87.

5. *Prylutska S. V., Remeniak O. V., Honcharenko Yu. V., Prylutskyy Yu. I.* Carbon nanotubes as a new class of materials for nanobiotechnology.
Biotechnologiya.
2009, 2 (2), 55–66. (In Ukrainian).

6. *Prylutska S. V., Remenyak O. V., Burlaka A. P., Prylutskyy Yu. I.* Perspective of carbon nanotubes application in cancer therapy.
Oncologiya.
2010, 12 (1), 5–9. (In Ukrainian).

7. *Prylutska S. V.* Using of C_{60} fullerene complexes with antitumor medicianes in chemotherapy. *Biotechnologia Acta*. 2014, 7 (3), 9–20.

8. *Prylutska S. V., Didenko G. V., Kichmarenko Yu. M., Kruts O. O., Potebnya G. P., Cherepanov V. V., Prylutskyy Yu. I.* Effect of C_{60} fullerene, doxorubicin and their complex on tumor and normal cells of BALB/c mice. *Biot echnologia Acta*
. 2014, 7 (1), 60–65. (In Ukrainian).

9. *Golub A., Matyshevska O., Prylutska S., Sysoyev V., Ped L., Kudrenko V., Radchenko E., Prylutskyy Yu., Scharff P., Braun T.* Fullerenes immobilized at silica surface: topology,

structure and bioactivity. *J. Mol. Liq.* 2003, 105 (2–3), 141–147. https://doi.org/10.1016/S0167-7322(03)00044-8

10. *Moorthi C., Kathiresan K.* Curcumin–Piperine/Curcumin–Quercetin/Curcumin– Silibinin dual drug- loaded nanoparticulate combination therapy: A novel approach to target and treat multidrug-resistant cancers. *J. Med. Hypoth. Ideas*. 2013, 7(1), 15–20. https://doi.org/10.1016/j.jmhi.2012.10.005

11. *Nazarenko V. I., Demchenko O. P.* Nanodiamonds for fluorescent cell and sensor nanotechnology. *Biotechnologia. Acta.* 2013, 6 (5), 9–18. https://doi.org/10.15407/biotech6.05.009

12. *Priyadarsini K. I.* The Chemistry of Curcumin: From Extraction to Therapeutic Agent. *Molecules* . 2014, 19 (12), 20091–20112. https://doi.org/10.3390/molecules191220091

13. *Sagnou M., Benaki D., Triantis C., Tsotakos T., Psycharis V., Raptopoulou C. P., Pirmettis I., Papadopoulos M., Pelecanou M.* Curcumin as the OO bidentate ligand in “2+1” complexes with the $[M(CO)_3]^+$ (M = Re, ^{99m}Tc) tricarbonyl core for radiodiagnostic applications. *Inorg. Chem.* 2011, 50 (4), 1295–1303. https://doi.org/10.1021/ic102228u

14. *Asti M., Ferrari E., Groci S., Atti G., Rubagotti S., Lori M., Capponi P.C., Zerbini A., Saladini M., Versari A.* Synthesis and characterization of ^{68}Ga-labeled curcumin and curcuminoid Complexes as potential radiotracers for imaging of cancer and Alzheimer’s disease. *Inorg. Chem* . 2014, 53 (10), 4922–4933. https://doi.org/10.1021/ic403113z

15. *Yan H., Teh C., Sreejith S., Zhu L., Kwok A., Fang W., Ma X., Nguyen K. T., Korzh V., Zhao Y.* Functional Mesoporous Silica Nanoparticles for Photothermal-Controlled Drug Delivery *I n Vivo*
.
Angew Chem. Int. Ed
. 2012. 51 (33), 8373–7.
https://doi.org/10.1002/anie.201203993

16. *Mullaicharam A. R., Maheswaran A.* Pharmacological effects of curcumin.

Int. J. Nutr. Pharmacol. Neurol. Diseases. 2012, 2 (2), 92–100. https://doi.org/10.4103/2231-0738.95930

17. *Chin S. F., Iyer K. S., Saunders M., Tim G., Buckley C., Paskevicious M., Raston C. L.* Encapsulation and sustained release of curcumin using superparamagnetic silica reservoirs.
Chemistry
. 2009, 15 (23), 5661–5665.
https://doi.org/10.1002/chem.200802747

18. *Jin D., Park K. W., Lee J. H., Song K., Kim J. G., Seo M. L., Jung J. H*. The selective immobilization of curcumin onto the internal surface of mesoporous hollow silica particles by covalent bonding and its controlled release.
J. Mat. Chem
. 2011, 21 (11), 3641–3645.
https://doi.org/10.1039/c0jm03846f

19. *Dinda A. K., Prashant C. K., Naqvi S.* Curcumin loaded organically modified silica (ORMOSIL) nanoparticle; A novel agent for cancer therapy. Int.
J. Nanotechnol
. 2012, 9 (10-12), 862–871.
https://doi.org/10.1504/IJNT.2012.049451

20. *Yan H., Teh C., Sreejith S., Zhu L., Kwok A., Fang W., Ma X., Nguyen K. T., Korzh V., Zhao Y.* Functional mesoporous silica nanoparticles for photothermal-controlled drug delivery *in*

vivo
.
Angew. Chem. Int. Ed.
2012, 51 (33):8373–7.
https://doi.org/10.1504/IJNT.2012.049451

21. *Jin D., Lee J., Seo M.L., Jaworski J., Jung, J.H.* Controlled drug delivery from mesoporous silica using a pH response release. *New J. Chem.*
2012, 36 (8), 1616–1620.
https://doi.org/10.1039/c2nj20976d

22. *Patra D., Sleem F.* A new method for pH triggered curcumin release by applying poly(l-lysine) mediated nanoparticle-congregation. *Anal. Chim. Acta*.
2013, V. 795, P. 60–68.
https://doi.org/10.1016/j.aca.2013.07.063

23. *Gangwar R. K., Tomar G. B., Dhumale V. A., Zinjarde S., Sharma R. B., Datar S.* Curcumin conjugated silica nanoparticles for improving bioavailability and its anticancer applications. J. *Agric. Food Chem.*
2013, 61 (40), 9632–9637.
https://doi.org/10.1021/jf402894x

24. *Singh S. P., Sharma M., Gupta P. K.* Enhancement of phototoxicity of curcumin in human oral cancer cells using silica nanoparticles as delivery vehicle.
Lasers Med. Sci.
2014, 29 (2), 645–652.
https://doi.org/10.1007/s10103-013-1357-7

25. *Ma'Mani L., Nikzad S., Kheiri-Manjili H., Al-Musawi S., Saeedi M., Askaralou S.* Curcumin-loaded guanidine functionalized PEGylated mesoporous silica nanoparticles KIT-6: Practical strategy for the breast cancer therapy.
Eur. J. Med. Chem.
2014, V. 83C, P. 646–654.
https://doi.org/10.1016/j.ejmech.2014.06.069

26. *Mathew A., Fukuda T., Nagaoka Y., Hasumura T., Morimoto H., Yoshida Y., Maekawa T., Venugopal K., Kumar D.S* . Curcumin loaded-PLGA nanoparticles conjugated with Tet-1 peptide for potential use in Alzheimer's disease. *PLoS One*. 2012, 7 (3), e32616.
https://doi.org/10.1371/journal.pone.0032616

27. *Makadia H. K., Siegel S.J.* Poly Lactic-co-Glycolic Acid (PLGA) as Biodegradable Controlled Drug Delivery Carrier. *Polymers (Basel).* 2011, 3 (3), 1377–1397.
https://doi.org/10.3390/polym3031377

28. *Xing Z. H., Wei J.H., Cheang T. Y., Wang Z. R., Zhou X., Wang S. S., Chen W., Wang S. M., Luo J. H., Xu A. W.* Bifunctional pH-sensitive Zn(II)–curcumin nanoparticles/siRNA effectively inhibit growth of human bladder cancer cells *in vitro* and *in vivo*
.
J. Mater. Chem.
B. 2014, V. 2, P. 2714–2724.
https://doi.org/10.1039/c3tb21625j

**29. *Shulga S. M.* Obtaining and characteristic of curcumin liposomal form. *Biotechnologia Acta.* 2014, 7 (5), 55–61.
https://doi.org/10.15407/biotech7.05.055**

30. *Sokolik V. V.* Effect of curcumin liposomal form on angiotensin converting activity, cytokines and cognitive characteristics of the rats with Alzheimer’s disease model. *Biotechnologia Acta.*
2015, 8 (6), 48–55.
https://doi.org/10.15407/biotech8.06.048

31. *Goel A , Kunnumakkara A. B, Aggarwal B. B*. Curcumin as “Curecumin”: From kitchen to clinic. *Biochem. Pharmacol.* 2008, 75 (4), 787-809. https://doi.org/10.1016/j.bcp.2007.08.016

32. *Aggarwal B. B., Sundaram C., Malani N., Ichikawa H.* Curcumin: the Indian solid gold. *Adv. Exp. Med. Biol.*
2007, V. 595, P. 1–75.
https://doi.org/10.1007/978-0-387-46401-5_1

33. *Gupta S. C., Patchva S., Koh W., Aggarwal B. B.* Discovery of Curcumin, a Component of the Golden Spice, and Its Miraculous Biological Activities.
Clin. Exp. Pharmacol. Physiol
. 2012, 39 (3), 283–299.
https://doi.org/10.1111/j.1440-1681.2011.05648.x

34. *Anand P., Sundaram C., Jhurani S., Kunnumakkara A. B., Aggarwal B. B.* Curcumin and cancer: An ‘‘old-age” disease with an ‘‘age-old” solution.
Cancer Lett
. 2008, 267 (1), 133–164.
https://doi.org/10.1016/j.canlet.2008.03.025

35. *Goel A., Aggarwal B. B.* Curcumin, the golden spice from Indian saffron, is a chemosensitizer and radiosensitizer for tumors and chemoprotector and radioprotector for normal organs. *Nutr. Cancer.* 2010, 62 (7), 919–30. https://doi.org/10.1080/01635581.2010.509835
.

36. *Dhandapani K. M., Mahesh V. B., Brann D. W*. Curcumin suppresses growth and chemoresistance of human glioblastoma cells via AP-1 and NFkappaB transcription factors.
J. Neurochem.
2007, 102 (2), 522–38.
https://doi.org/10.1111/j.1471-4159.2007.04633.x

37. *Li M., Zhang Z., Hill D. L., Wang H., Zhang R.* Curcumin, a dietary component, has anticancer, chemosensitization, and radiosensitization effects by down-regulating the MDM2 oncogene through the PI3K/mTOR/ETS2 pathway.
Cancer Res.
2007, 67 (5), 1988–96.

https://doi.org/10.1158/0008-5472.CAN-06-3066

38. *Javvadi P., Segan A. T., Tuttle S. W., Koumenis C.* The chemopreventive agent curcumin is a potent radiosensitizer of human cervical tumor cells via increased reactive oxygen species production and overactivation of the mitogen-activated protein kinase pathway.
Mol. Pharmacol.
2008, 73 (5), 1491–501.
https://doi.org/10.1124/mol.107.043554

39. *Khafif A., Hurst R., Kyker K., Fliss D. M., Gil Z., Medina J. E.* Curcumin: a new radio-sensitizer of squamous cell carcinoma cells.
Otolaryngol. Head Neck Surg.
2005, 132 (2), 317–21.
https://doi.org/10.1016/j.otohns.2004.09.006

40. *Kim E.J., Kim J.H., Azad A.M, Chang Y.S.* Facile Synthesis and Characterization of Fe/FeS Nanoparticles for Environmental Applications.
ACS Appl. Mater. Interfaces
, 2011,
3
(5), pp 1457–1462.
https://doi.org/10.1021/am200016v

41. *Patel B. B., Sengupta R., Qazi S., Vachhani H., Yu Y., Rishi A.K., Majumdar A. P*. Curcumin enhances the effects of 5-fluorouracil and oxaliplatin in mediating growth inhibition of colon cancer cells by modulating EGFR and IGF-1R.
Int. J. Cancer
. 2008, 122 (2), 267–73
https://doi.org/10.1002/ijc.23097

42. *Zimmermann G. R., Lehar J., Keith C. T.* Multi-target therapeutics: When the whole is greater than the sum of the parts. *Drug Discov. Today* . 2007, 12 (1-2), 34–42.
https://doi.org/10.1016/j.drudis.2006.11.008

43. *Mohammadi-Bardbori A., Bengtsson J., Rannug U., Rannug A., Wincent E*. Chem. Quercetin, Resveratrol, and Curcumin Are Indirect Activators of the Aryl Hydrocarbon Receptor (AHR). *Res. Toxicol.*
2012, 25 (9), pp 1878–1884.
https://doi.org/10.1021/tx300169e

44. *Baum L., Ng A*. Curcumin interaction with copper and iron suggests one possible mechanism of action in Alzheimer's disease animal models. *J. Alzheimer's Dis*. 2004, 6 (4), 367–377. PMID: 15345806.

45. *Si X., Wang Y., Wong J., Zhang J., McManus B.M., Luo H.* Dysregulation of the ubiquitinproteasome system by curcumin suppresses coxsackievirus B3 replicat. *J. Virol*. 2007, 81 (7), 3142–3150.
https://doi.org/10.1128/JVI.02028-06

46. *Neelofar K., Shreaz S., Rimple B., Muralidhar S., Nikhat M., Khan L.A.* Curcumin as a promising anticandidal of clinical interest. *Can. J. Microbiol.*
2011, 57 (3), 204–10.
https://doi.org/10.1139/W10-117

47. *Zandi K., Ramedani E., Mohammadi K., Tajbakhsh S., Deilami I., Rastian Z., Fouladvand M., Yousefi F., Farshadpour F.* Evaluation of antiviral activities of curcumin derivatives against HSV-1 in Vero cell line. *Nat. Prod. Commun*. 2010, 5 (12), 1935–8.

48. *Garcia-Alloza M., Borrelli L. A., Rozkalne A., Hyman B. T., Bacskai B. J.* Curcumin labels amyloid pathology in vivo, disrupts existing plaques, and partially restores distorted neurites in an Alzheimer mouse model. *J. Neurochem.*
2007, 102 (4), 1095–104.

https://doi.org/10.1111/j.1471-4159.2007.04613.x

49. *Sokolik V. V., Shulga S. M.* Influence of curcumin on cytokines content and angiotensin-converting activity under intrahippocampus administration of β-amyloid peptide in rats. *Biotechnologia Acta* . 2015, 8 (3), 78–88. https://doi.org/10.15407/biotech8.03.078

50. *Jagatha B., Mythri R. B., Vali S., Bharath M. M.* Curcumin treatment alleviates the effects of glutathione depletion *in vitro* and *in vivo*: therapeutic implications for Parkinson's disease explained via in silico studies. *Free Rad. Biol. Med* . 2008, 44 (5), 907–17. https://doi.org/10.1016/j.freeradbiomed.2007.11.011

51. *Rajeswari A., Sabesan M.* Inhibition of monoamine oxidase-B by the polyphenolic compound, curcumin and its metabolite tetrahydrocurcumin, in a model of Parkinson's disease induced by MPTP neurodegeneration in mice. *Inflammopharmacology.* 2008, 16 (2), 96–9. https://doi.org/10.1007/s10787-007-1614-0

52. *Kumar A., Bora U.* Interactions of Curcumin and Its Derivatives with Nucleic Acids and their. *Mini-Rev. Med. Chem*. 2013, 13 (2), 256–264. https://doi.org/10.2174/1389557511313020007

53. *Ramanjaneyulu P. S.; Sayi Y. S., Raman V. A. Ramakumar K. L.* Spectrophotometric determination of boron in nuclear grade uranium compounds with curcumin and studies on effect of HNO_3. *J. Rad. Anal. Nucl. Chem.* 2007, 274 (1), 109–114. https://doi.org/10.1007/s10967-006-6913-1

54. *Wanninger S., Lorenz V., Subhan A., Edelmann F. T.* Metal complexes of curcumin – synthetic strategies, structures and medicinal applications.
Chem. Soc. Rev.
2015, 44 (15), 4986–5002.
https://doi.org/10.1039/C5CS00088B

55. *Refat M.S.* Synthesis and characterization of ligational behavior of curcumin drug towards some transition metal ions: Chelation effect on their thermal stability and biological activity.
Spectrochim. Acta. A Mol. Biomol. Spectrosc.
2013, 15 (105), 326-37.
https://doi.org/10.1016/j.saa.2012.12.041

56. *Kim Y. J., Lee H. J., Shin Y.* Optimization and validation of high-performance liquid chromatography method for individual curcuminoids in turmeric by heat-refluxed extraction.
J. Agric. Food Chem.
2013, 61 (46), 10911–10918.
https://doi.org/10.1021/jf402483c

57. *Paulucci V. P., Couto R. O., Teixeira C. C. C., Freitas L. A. P.* Optimization of the extraction of curcumin from *Curcuma longa* rhizomes.
Braz. J. Pharmacogn
. 2013, 23 (1), 94–100.
https://doi.org/10.1590/S0102-695X2012005000117

58. *Li M., Ngadi M. O., Ma Y.* Optimisation of pulsed ultrasonic and microwave-assisted extraction for curcuminoids by response surface methodology and kinetic study.
Food Chem.
2014, V. 165, P. 29–34.
https://doi.org/10.1016/j.foodchem.2014.03.115

59. *Baumann W., Rodrigues S. V., Viana L. M.* Pigments and their solubility in and extractability by supercritical CO_2- The case of curcumin. *Braz*

. J. Chem. Eng.
2000, 17 (3), 323–328.
https://doi.org/10.1590/S0104-66322000000300008

60. *Priyadarsini K. I.* Photophysics, Photochemistry and Photobiology of Curcumin: Studies from organic solutions, biomimetics and living cells. *J. Photochem. Photobiol. C. Photochem. Rev.*
2009, 10 (2), 81–96.
https://doi.org/10.1016/j.jphotochemrev.2009.05.001

61. *Singh U., Verma S., Ghosh H. N., Rath M. C., Priyadarsini K. I., Sharma A., Pushpa K. K., Sarkar S. K., Mukherjee T.* Photo-degradation of curcumin in the presence of TiO_2 nanoparticles: Fundamentals & application.
J. Mol. Catal. A. Chemical
. 2010, 318 (1-2) , 106–111. doi: 10.1016/j.molcata.2009.11.018.05.001.

62. *Priyadarsini K. I., Maity D. K., Naik, G. H., Kumar M. S., Unnikrishnan M. K., Satav J. G., Mohan H.* Role of phenolic O-H and methylene hydrogen on the free radical reactions and antioxidant activity of curcumin. *Free Rad. Biol. Med.* 2003, 35 (5), 475–484. https://doi.org/10.1016/S0891-5849(03)00325-3

63. *Mishra B., Priyadarsini K. I., Bhide M. K., Kadam R. M., Mohan H.* Reactions of superoxide radicals with curcumin: Probable mechanisms by optical spectroscopy and EPR.
Free Rad. Res.
2004, 38 (4), 355–362.
https://doi.org/10.1080/10715760310001660259

64. *Kim J. E., Kim A. R., Chung H. Y., Ha S. Y., Kim B. S., Choi J. S. In vitro* peroxynitrite scavenging activity of diarylheptanoids from
Curcumia longa
.
Phytother. Res
. 2003, 17 (5), 481–484.
https://doi.org/10.1002/ptr.1179

65. *Tiyaboonchai W, Tungpradit W, Plianbangchang P*. Formulation and characterization of curcuminoids loaded solid lipid nanoparticles.
Int. J. Pharmacol
. 2007; 337 (1-2), 299–306.
https://doi.org/10.1016/j.ijpharm.2006.12.043

66. *Li L., Braiteh F. S., Kurzrock R.* Liposome-encapsulated curcumin: in vitro and in vivo effects on proliferation, apoptosis, signaling, and angiogenesis.
Cancer.
2005, 104 (6),1322–31.
https://doi.org/10.1002/cncr.21300

67. *Suresh D, Srinivasan K*. Studies on the in vitro absorption of spice principles--curcumin, capsaicin and piperine in rat intestines. *Food Chem. Toxicol.* 2007, 45 (8),1437–42.
https://doi.org/10.1016/j.fct.2007.02.002

68. *Shoba G., Joy D., Joseph T., Majeed M., Rajendran R., Srinivas P. S.* Influence of piperine on the pharmacokinetics of curcumin in animals and human volunteers.
Planta Med.
1998, 64 (4), 353–6.
https://doi.org/10.1055/s-2006-957450

69. *Zebib B., Mouloungui Z., Noirot V.* Stabilization of Curcumin by Complexation with Divalent Cations in Glycerol/Water System. *Bioinorg. Chem. Appl.* 2010, Article ID 292760, *Volume* 8 pages
https://doi.org/10.1155/2010/292760

70. *Borsari M., Ferrari E., Grandi R., Saladini, M.* Curucminoids as potential new iron-chelating agents: Spectroscopic, polarographic and potentiometric study on their Fe(III) complexing ability. *Inorg. Chim. Acta.* 2002, 328 (1), 61–68. https://doi.or

g/10.1016/S0020-1693(01)00687-9

71. *Jiang T., Wang L., Zhang S., Sun P. C., Ding C. F., Chu Y. Q., Zhou P.* Interaction of curcumin with Al(III) and its complex structures based on experiments and theoretical calculations. *J. Mol. Struct* .
2011, 1004 (1-3), 163–173.
https://doi.org/10.1016/j.molstruc.2011.07.059

72. *Ali I., Saleem K., Wesselinova D., Haque A.* Synthesis, DNA binding, hemolytic, and anti-cancer assays of curcumin I-based ligands and their ruthenium(III) complexes.
Med. Chem. Res.
2013, 22 (3), 1386-1398.
https://doi.org/10.1007/s00044-012-0133-8

73. *Pucci D., Bellini T., Crispini A., D'Agnano I., Liquori P. F., Garcia-Orduna P., Pirillo S., Valentini A., Zanchetta G.* DNA binding and cytotoxicity of fluorescent curcumin-based Zn(II) Complexes. *Med. Chem. Commun.* 2012, 3 (4), 462–468.
https://doi.org/10.1039/c2md00261b

74. *Hussain A., Somyajit K., Banik B., Banerjee S., Nagaraju G., Chakravarthy A. R.* Enhancing the photocytotoxic potential of curcumin on terpyridyl-lanthanide(III) complex formation.
Dalton Trans.
2013, 42 (1), 182–95.
https://doi.org/10.1039/C2DT32042H

75. *Zhou S. X., Xuan W., Jia-Feng D., Dong Y., Jiang B., Wei D., Wan M. L., Jia Y*. Synthesis, optical properties and biological imaging of the rare earth complexes with curcumin and pyridine. *J. Mater. Chem.*
2012, 22 (42) , 22774–22780.
https://doi.org/10.1039/c2jm34117d

76. *Song Y. M., Xu J. P., Ding L., Hou Q., Liu J. W., Zhu Z. L.* Syntheses, characterisation and biological activities of rare earth metal complexes with curcumin and 1,10-phenanthroline-5,6-dione. *J. Inorg. Biochem.* 2009, 103 (3), 396–400. https://doi.org/10.1016/j.jinorgbio.2008.12.001

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