Potentiality of Nanoenzymes for Cancer Treatment

Subjects: Oncology
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Definition

Nanozyme synthesis is an innovative technology since it connects nanoparticles with biological activities and framework. Various assays have been implemented for the enzymes of proteins that also implement nanozymes, which could also have the potential for performing the catalysis of similar substrates. Due to such different functions of nanozymes, they are used for the treatment of the environment, biosensing, agents that act against microbes, cytoprotection of different cell biomolecules with management, diagnosis of diseases, etc..

1. Introduction

Enzymes are considered natural biocatalysts which catalyze many biochemical reactions with good catalytic efficiency, biocompatibility, and substrate specificity. Recently, these reactions have been extensively used in various food industries and other biomedical applications. Their use in the agri-food industry promotes proper processing, storage activities and the functionalization of food products [1][2][3][4][5][6]. Enzymes play a significant role in enhancing the safety of food products [7]. Nanotechnology is believed to have a major part in advanced drug formulation, targeting a specific part of the body and controlled release of the drug. Nanotechnology is stated to communicate with the barrier of physical and organic sciences by putting forward nanospheres and structures in numerous scientific fields [8][9] other than nanomedicines and their delivery [10][11]. Nanotechnology engages the therapeutic agents at nanoscale levels for the development of medicines that are nano. Biomedicine including nanobiotechnology, biosensors, and tissue designing is done by the nanoparticles [12]. Recently, nanomedicines have become very much refreshing as nanostructures act as delivery agents by giving medication examples [13][14]. Using conveyance nano-drugs for the treatment depends upon various properties of targeted drugs such as biochemical functions [15]. Over the past few years, scientists have made an extraordinary attempt in developing artificial enzymes for various types of applications. Consider the examples that the chemical complexes based on porphyrin [16][17], hematin [18], cyclodextrin [19], hemin [20][21], and the specially designed biomolecules proteins successively imitate the function of the naturally occurring enzymes [22,23].The intrinsic limitations of the natural enzymes such as low stability, high cost, and storage difficulty have led to the introduction of artificial enzymes that imitate the activity of the naturally occurring enzymes [22]. As another sort of promising artificial enzyme, nanozymes have demonstrated a wide range of uses because of their evident favorable circumstances, including low cost, high stability, the large surface area for functionalization, high catalytic activity, and tuneable activity [23]. Various obstacles and constraints of further developing therapeutic applications are of significant interest, as well as a future direction for the usage of modified nanozymes with better biomedical and diagnostic applications. Nanozymes are defined as artificial nanomaterials possessing intrinsic enzyme-like activities. Scientists have worked toward their enhancing utility as they have many advantages over natural enzymes. Nanozymes are believed to act by mimicking the action of the natural enzymes [24][25][26]. The concept of nanozyme has reformed our essential comprehension of chemistry and biology, encouraging plenty of uses in the fields of biosensing, science, and medication [24]. Nanozyme synthesis is an innovative technology since it connects nanoparticles with biological activities and framework. Various assays have been implemented for the enzymes of proteins that also implement nanozymes, which could also have the potential for performing the catalysis of similar substrates. Due to such different functions of nanozymes, they are used for the treatment of the environment, biosensing, agents that act against microbes, cytoprotection of different cell biomolecules with management, diagnosis of diseases, etc. [27][28][29][30][31]. Various sources, properties, mimicking types, and analytical capabilities are shown in **Figure 1** [1].

2. Types of Nanozymes

There are various nanomaterials based on noble metals such as gold [32][33][34][35][36][37][38][39][40][41][42][43], silver [44][45][46][47][48][49], platinum [50][51][52][53][54][55][56][57][58][59][60][61][62][63], Pd [64][65][66], and multi-metallic NPs which are known as peroxidase imitates and are utilized for antibodies, therapy, and biosensing.

Carbon is another typical nanomaterial as peroxidase-like activities with pH, temp, and hydrogen peroxide concentration dependent functions have been possessed by nanotubes which have a single wall and oxides of graphene [67][68]. Propelled by these findings, there are various other carbon-based peroxidase mimics such as carbon dots [69][70][71][72][73][74][75][76], Fe/N doped carbon [77][78][79][80][81][82] , carbon nitrides [83][84][85], etc., which have been explored.

Furthermore, Chmielewski et al. revealed that the assembly of electrostatics, the peptide parts of trimethylammonium working AuNPs, could advance the ligating of peptides that are two in number, which resulted in inorganic implemented nanoparticles favorable in the biopolymers polymerization [86]. Morse et al. also illustrated the monolayer AuNPs functionalization which could mimic silicatein.

The nanozymes showing a single substrate mechanism generally include: Hydrolase; Peroxidase; Superoxide dismutase; Oxidase; Catalase [24].

3. Synthesis of Nanozymes

The nanomaterials which are catalytic possess different properties in comparison with natural enzymes [87]. The activities of the nanozymes depend on the size of the particle, structure, and its shape which is affected by the coatings, charges, and external fields [88][89].

Electrochemical observation of glucose and fructose formed on gold nanoparticles (AuNPs) placed onto graphene paper has lately been presented. These nanostructures were formed by two techniques: thermal and laser de-wetting processes [90]. Gold nanostructures acquired by both methods exhibited major differences in their particle morphology. Both types of AuNPs were investigated by their capacity to oxidize glucose and fructose [91].

Chemical reduction is a method which is used very frequently because of its rapidity and simplicity. This tool enables the formation of NPs in which the morphology and the size of particle distribution are managed by changing the molar concentration of the reactants, the reductant type, and the reaction temperature [92]. The important factor in achieving very high chemical reduction is choosing the suitable reductants. The reduction of metal salts needs reactivity of the agent which causes reduction to the redox potential of the metal. The procured particles are small if the reaction rate during the synthesis procedure is too fast [93]. Nevertheless, if the reaction rate is too slow, particle aggregation may happen [94]. The synthesis of hollow copper sulfidenanocubes (h-CuS NCs) was done via the chemical reduction method [95]. This method has been utilized for the synthesis of peroxidase (PO)-like nanozyme-based AuNPs along with Pseudomonas aeruginosa-specific aptamer [96].

Electrochemical deposition is a minimal-effort strategy for acquiring metalnanocatalysts. In any case, it is normally utilized less regularly than synthetic decrease strategies. The interaction is straightforward and incorporates a drenching of a conductive surface into an answer containing particles of the material to be saved and the use of a voltage across the strongelectrolyte interface. Throughout this strategy, a reaction of charge transfer causes the deposition of film [97][98].

4. Future Perspectives for Nanozymes

Intending to peruse nanozymes, one has to have a vital source of innovation through productively conquering disadvantages of enzymes which are natural, and accompanying proposals are offered. There is a requirement of the advancement of fresh nanozymes comprised of high movement and customary examination functions; further has exploration followed a technique of screening of sound action dependent on the nuclear arrangements which were conceived for catalyzing the response of enzyme. The process to prepare normal composites for identifying the present significant limitations by adjusting synergistic effects for facilitating electron transfer between composite materials during redox reaction has also been started. Bioinspired synthesis of nanozymes additionally gives an alternative to prepare non-toxic nanozymes by successfully going around the utilization of poisonous synthetic compounds in traditional substance combination, accordingly quickening their use in therapeutic application. At last, the turn of events of novel surface designing innovation could specifically target the substrates by nanozymes and would be of great significance [99]. More of these developments would open up new avenues for single-stage sensors and theragnostic, which could be helpful in various biosensing and biomedical applications. The vast majority of the nanozymes are accounted for to show their synergist movement by redox action by surface iotas. Be that as it may, the reactant movement might be additionally improved by controlling the center of the nanozymes by doping with some uncommon earth components. Such procedures would add more redox "problem areas" for synergist action and along these lines upgrade the action of nanozymes. In contrast to characteristic catalysts, the size and synthesis of most nanozymes are not uniform, except for fullerene-based nanozymes. Further, group to-cluster variety fit as a fiddle of nanoparticles/nanozymes, and consequently adjustments in physicochemical properties, requires expanded spotlight on improving the union convention to create the monodispersed nanozymes with molecularly exact designs [100].

References

1. Sindhu, R.K.; Kaur, H.; Kumar, M.; Sofat, M.; Yapar, E.A.; Esenturk, I.; Kara, B.A.; Kumar, P.; Keshavarzi, Z. The ameliorating approach of nanorobotics in the novel drug delivery systems: A mechanistic review. J. Drug Target 2021, 29, 822–833.
2. Cheng, M.H.; Rosentrater, K.A.; Sekhon, J.; Wang, T.; Jung, S.; Johnson, L.A. Economic feasibility of soybeanoil production by enzyme-assisted aqueous extraction processing. Food Bioprocess Technol. 2019, 12, 539–550.
3. Kasar, S.S.; Giri, A.P.; Pawar, P.K.; Maheshwari, V.L. A Protein α-amylase inhibitor from Withania somnifera and its role in overall quality and nutritional valuei mprovement of potato chips during processing. Food Bioprocess Technol. 2019, 12, 636–644.
4. Osete-Alcaraz, A.; Bautista-Ortín, A.B.; Ortega-Regules, A.E.; Gómez-Plaza, E. Combined use of pectolytic enzymes and ultra sounds for improving the extraction of phenolic compounds during vinification. Food Bioprocess Technol. 2019, 12, 1330–1339.
5. Wubshet, S.G.; Wold, J.P.; Afseth, N.K.; Böcker, U.; Lindberg, D.; Ihunegbo, F.N.; Måge, I. Feed-Forward Prediction of Product Qualities in Enzymatic Protein Hydrolysis of Poultry By-products: A Spectroscopic Approach. Food Bioprocess Technol. 2018, 11, 2032–2043.
6. Zhang, L.; Li, C.-Q.; Jiang, W.; Wu, M.; Rao, S.-Q.; Qian, J.-Y. Pulsed Electric Field as a Means to Elevate Activity and Expression of α-Amylase in Barley (Hordeum vulgare L.) Malting. Food Bioprocess Technol. 2019, 12, 1010–1020.
7. Sun, D.W. (Ed.) Handbook of Food Safety Engineering; Wiley Blackwell: Hoboken, NJ, USA, 2011.
8. Patra, J.K.; Das, G.; Fraceto, L.F.; Campos, E.V.R.; del Pilar Rodriguez-Torres, M.; Acosta-Torres, L.S.; Diaz-Torres, L.A.; Grillo, R.; Swamy, M.K.; Sharma, S.; et al. Nano based drug delivery systems: Recent developments and future prospects. J. Nanobiotechnol. 2018, 16, 71.
9. Liu, Z.; Tabakman, S.; Welsher, K.; Dai, H. Carbon nanotubes in biology and medicine: In vitro and in vivo detection, imaging and drug delivery. Nano Res. 2009, 2, 85–120.
10. Orive, G.; Gascon, A.R.; Hernández, R.M.; Domínguez-Gil, A.; Pedraz, J.L. Techniques: New approaches to the delivery of biopharmaceuticals. Trends Pharmacol. Sci. 2004, 25, 382–387.
11. Razzacki, S.Z.; Thwar, P.K.; Yang, M.; Ugaz, V.M.; Burns, M.A. Integrated microsystems for controlled drug delivery. Adv. Drug Deliv. Rev. 2004, 56, 185–198.
12. Mirza, A.Z.; Siddiqui, F.A. Nanomedicine and drug delivery: A mini review. Int. Nano Lett. 2014, 4, 94.
13. Jahangirian, H.; Lemraski, E.G.; Webster, T.J.; Rafiee-Moghaddam, R.; Abdollahi, Y. A review of drug delivery systems based on nanotechnology and green chemistry: Green nanomedicine. Int. J. Nanomed. 2017, 12, 2957–2978.
14. Lam, P.-L.; Wong, W.-Y.; Bian, Z.; Chui, C.-H.; Gambari, R. Recent advances in green nanoparticulate systems for drug delivery: Efficient delivery and safety concern. Nanomedicine 2017, 12, 357–385.
15. Antonescu (Mintas), A.-I.; Miere (Groza), F.; Fritea, L.; Ganea, M.; Zdrinca, M.; Dobjanschi, L.; Antonescu, A.; Vicas, S.I.;

Bodog, F.; Sindhu, R.K.; et al. Perspectives on the Combined Effects of Ocimumbasilicum and Trifolium pratense Extracts in Terms of Phytochemical Profile and Pharmacological Effects. Plants 2021, 10, 1390.
16. Rodrigues, T.; Reker, D.; Schneider, P.; Schneider, G. Counting on natural products for drug design. Nat. Chem. 2016, 8, 531–541.
17. Siddiqui, A.A.; Iram, F.; Siddiqui, S.; Sahu, K. Role of natural products in the drug discovery process. Int. J. Drug Dev. Res. 2014, 6, 172–204.
18. Silva, P.; Bonifácio, B.; Ramos, M.; Negri, K.; Bauab, T.M.; Chorilli, M. Nanotechnology-based drug delivery systems and herbal medicines: A review. Int. J. Nanomed. 2013, 9, 1–15.
19. Mohanty, S.K.; Swamy, M.K.; Sinniah, U.R.; Anuradha, M. Leptadeniareticulata (Retz.) Wight & Arn. (Jivanti): Botanical, agronomical, phytochemical, pharmacological, and biotechnological aspects. Molecules 2017, 22, 1019.
20. Beutler, J.A. Natural products as a foundation for drug discovery. Curr. Prot. Pharmacol. 2009, 46, 9–11.
21. Thilakarathna, S.H.; Rupasinghe, H.P.V. Flavonoid Bioavailability and Attempts for Bioavailability Enhancement. Nutrients 2013, 5, 3367–3387.
22. Liu, X.; Wu, J.; Liu, Q.; Lin, A.; Li, S.; Zhang, Y.; Wang, Q.; Li, T.; An, X.; Zhou, Z.; et al. Synthesis temperature regulated multi enzyme mimicking activities of ceria nanozymes. J. Mater. Chem. B 2021, 9, 7238.
23. Wang, P.; Wang, T.; Hong, J.; Yan, X.; Liang, M. Nanozymes: A New Disease Imaging Strategy. Front. Bioeng. Biotechnol. 2020, 8, 15.
24. Jiang, D.; Ni, D.; Rosenkrans, Z.T.; Huang, P.; Yan, X.; Cai, W. Nanozyme: New horizons for responsive biomedical applications. Chem. Soc. Rev. 2019, 48, 3683–3704.
25. Zhang, X.; Li, G.; Chen, G.; Wu, D.; Wu, Y.; James, T.D. Enzyme Mimics for Engineered Biomimetic Cascade Nanoreactors: Mechanism, Applications, and Prospects. Adv. Funct. Mater. 2021, 2106139.
26. Wu, J.; Wang, X.; Wang, Q.; Lou, Z.; Li, S.; Zhu, Y.; Qin, L.; Wei, H. Nanomaterials with enzyme like characteristics (nanozymes): Next-generation artificial enzymes(II). Chem. Soc. Rev. 2019, 48, 1004–1076.
27. Munir, S.; Shah, A.A.; Rahman, H.; Bilal, M.; Rajoka, M.S.R.; Khan, A.A.; Khurshid, M. Nanozymes for medical biotechnology and its potential applications in biosensing and nanotherapeutics. Biotechnol. Lett. 2020, 42, 357–373.
28. Li, J.; Zhang, C.; Lin, J.; Yin, J.; Xu, J.; Chen, Y. Evaluating the bioavailability of heavy metals in natural-zeolite-amended aquatic sediments using thin-film diffusive gradients. Aquac. Fish. 2018, 3, 122–128.
29. Mutharaian, V.N.; Kamalakannan, R.; Mayavel, A.; Makesh, S.; Kwon, S.H.; Kang, K.-S. DNA polymorphisms and genetic relationship among populations of Acacia leucophloea using RAPD markers. J. For. Res. 2017, 29, 1013–1020.
30. Qiu, H.; Pu, F.; Ran, X.; Liu, C.; Ren, J.; Qu, X. Nanozyme as Artificial Receptor with Multiple Readouts for Pattern Recognition. Anal. Chem. 2018, 90, 11775–11779.
31. Yan-Yan, H.; You-Hui, L.; Fang, P.; Jin-Song, R.; Xiao-Gang, Q. The current progress of nanozymes indisease treatments. Prog. Biochem. Biophys. 2018, 45, 256–267.
32. Wu, Y.S.; Huang, F.F.; Lin, Y.W. Fluorescent Detection of Lead in Environmental Water and Urine Samples Using Enzyme Mimics of Catechin Synthesized Au Nanoparticles. ACS Appl. Mater. Interfaces 2013, 5, 1503–1509.
33. Zhu, R.; Zhou, Y.; Wang, X.-L.; Liang, L.-P.; Long, Y.-J.; Wang, Q.-L.; Zhang, H.-J.; Huang, X.-X.; Zheng, H.-Z. Detection of Hg2+ based on the selective inhibition of peroxidase mimetic activity of BSAAu clusters. Talanta 2013, 117, 127–132.
34. Deng, H.H.; Li, G.W.; Hong, L.; Liu, A.-L.; Chen, W.; Lin, X.-H.; Xia, X.-H. Colorimetric sensor based on dual-functional gold nanoparticles: Analyte-recognition and peroxidase-like activity. Food Chem. 2014, 147, 257–261.
35. Han, T.H.; Khan, M.M.; Lee, J.; Cho, M.H. Optimization of positively charged gold nanoparticles synthesized using a stainless-steel mesh and its application for colorimetric hydrogen peroxide detection. J. Ind. Eng. Chem. 2014, 20, 2003–2009.
36. Liu, Y.; Wang, C.; Cai, N.; Long, S.; Yu, F. Negatively charged gold nanoparticles as an intrinsicper oxidase mimic and their applications in the oxidation of dopamine. J. Mater. Sci. 2014, 49, 7143–7150.
37. Kaur, B.; Chaterjee, J.G.; Bruno, T.K. Sharma, Defining Target Product Profiles (TPPs) for AptamerBased Diagnostics. Adv. Biochem. Eng. Biotechnol. 2020, 174, 195–209.
38. Drozd, M.; Pietrzak, M.; Parzuchowski, P.; Mazurkiewicz-Pawlicka, M.; Malinowska, E. Peroxidase like activity of gold nanoparticles stabilized by hyperbranched poly glycidol derivatives over a wide pH range. Nanotechnology 2015, 26, 495101.
39. Jiang, X.; Sun, C.; Guo, Y.; Nie, G.; Xu, L. Peroxidase like activity of apoferritin paired gold clusters for glucose detection. Biosens. Bioelectron. 2015, 64, 165–170.
40. Drozd, M.; Pietrzak, M.; Parzuchowski, P.; Malinowska, E. Pitfalls and capabilities of various hydrogen donors in evaluation of peroxidase-like activity of gold nanoparticles. Anal. Bioanal. Chem. 2016, 408, 8505–8513.
41. Jiang, C.; Zhu, J.; Li, Z.; Luo, J.; Wang, J.; Sun, Y. Chitosan–gold nanoparticles as peroxidase mimic and their application in glucose detection in serum. RSC Adv. 2017, 7, 44463–44469.
42. Zhu, X.; Mao, X.; Wang, Z.; Feng, C.; Chen, G.; Li, G. Fabrication of nanozymeDNA hydrogel and its application in biomedical analysis. Nano Res. 2017, 10, 959–970.
43. Singh, R.; Belgamwar, R.; Dhiman, M.; Polshettiwar, V. Dendritic fibrous nano-silica supported gold nanoparticles as an

artificial enzyme. J. Mater. Chem. B 2018, 6, 1600–1604.
44. Sun, Z.; Zhang, N.; Si, Y.; Li, S.; Wen, J.; Zhu, X.; Wang, H. High-throughput colorimetric assays for mercury(ii) in blood and wastewater based on the mercury-stimulated catalytic activity of small silver nanoparticles in a temperature-switchable gelatin matrix. Chem. Commun. 2014, 50, 9196–9199.
45. Priyadarshini, N.E. Pradhan, Gold nanoparticles as efficient sensors incolorimetric detection of toxic metal ions: A review. Sens. Actuators B Chem. 2017, 238, 888–902.
46. Hu, J.; Ni, P.; Dai, H.; Sun, Y.; Wang, Y.; Jiang, S.; Li, Z. Aptamer-based color imetric biosensing of abrinusing catalytic gold nanoparticles. Analyst 2015, 140, 3581–3586.
47. Sloan-Dennison, S.; Laing, S.; Shand, N.C.; Graham, D.; Faulds, K. A novel nanozyme assay utilizing the catalytic activity of silver nanoparticles and SERRS. Analyst 2017, 142, 2484–2490.
48. Karim, M.N.; Anderson, S.R.; Singh, S.; Ramanathan, R.; Bansal, V. Nanostructured silver fabricasa free-standing Nano Zyme for colorimetric detection of glucose inurine. Biosens. Bioelectron. 2018, 110, 8–15.
49. Fu, Y.; Zhang, H.; Dai, S.; Zhi, X.; Zhang, J.; Li, W. Glutathione-stabilized palladium nanozyme for colorimetric assay of silver(i) ions. Analyst 2015, 140, 6676–6683.
50. Chansuvarn, W.; Tuntulani, T.; Imyim, A. Colorimetric detection of mercury (II) based on gold nanoparticles, fluorescent gold nanoclusters and other gold-based nanomaterials. TRAC Trend Anal Chem. 2015, 65, 83–96.
51. Li, W.; Zhang, J.; Fu, Y. Synthesis and sensing application of glutathione-capped platinum nanoparticles. Anal. Methods 2015, 7, 4464–4471.
52. Sindhu, R.K.; Chitkara, M.; Sandhu, I.S. Nanotechnology: Principles and Applications, 1st ed.; Jenny Stanford Publishing: Singapore, 2021; pp. 41–70.
53. Lin, X.-Q.; Deng, H.-H.; Wu, G.-W.; Peng, H.-P.; Liu, A.-L.; Lin, X.-H.; Xia, X.-H.; Chen, W. Platinum nanoparticles/grapheneoxide hybrid with excellent peroxidaselike activity and its application for cysteine detection. Analyst 2015, 140, 5251–5256.
54. Cai, K.; Lv, Z.; Chen, K.; Huang, L.; Wang, J.; Shao, F.; Wang, Y.; Han, H.-Y. Aqueous synthesis of porous platinum nanotubes at room temperature and their intrinsic peroxidaselike activity. Chem. Commun. 2013, 49, 6024–6026.
55. Gao, Z.; Xu, M.; Hou, L.; Chen, G.; Tang, D. Irregular-shaped platinum nanoparticles as peroxidase mimics for highly efficient colorimetric immunoassay. Anal. Chim. Acta 2013, 776, 79–86.
56. He, S.B.; Deng, H.H.; Liu, A.L.; Li, G.W.; Lin, X.H.; Chen, W.; Xia, X.H. Synthesis and Peroxidase Like Activity of Salt Resistant Platinum Nanoparticles by Using Bovine Serum Albumin as the Scaffold. ChemCatChem 2014, 6, 1543–1548.
57. Liu, Y.; Wu, H.; Li, M.; Yin, J.J.; Nie, Z. pH dependent catalytic activities of platinum nanoparticles with respect to the decomposition of hydrogen peroxide and scavenging of superoxide and singlet oxygen. Nanoscale 2014, 6, 11904–11910.
58. Wang, Z.; Yang, X.; Feng, J.; Tang, Y.; Jiang, Y.; He, N. Label-free detection of DNA by combining gated mesoporous silica and catalytic signal amplification of platinum nanoparticles. Analyst 2014, 139, 6088–6091.
59. Ju, Y.; Kim, J. Dendrimerencapsulated Pt nanoparticles with peroxidase-mimetic activity as biocatalytic labels for sensitive colorimetric analyses. Chem. Commun. 2015, 51, 13752–13755.
60. Raynal, M.; Ballester, P.; VidalFerran, A.; van Leeuwen, P.W.N.M. Supramolecular catalysis. Part 2: Artificial enzyme mimics. Chem Soc Rev. 2014, 43, 1734–1787.
61. Wang, Z.; Yang, X.; Yang, J.; Jiang, Y.; He, N. Peroxidase-like activity of mesoporous silica encapsulated Pt nanoparticle and its application in colorimetric immunoassay. Anal. Chim. Acta 2015, 862, 53–63.
62. Jin, L.; Meng, Z.; Zhang, Y.; Cai, S.; Zhang, Z.; Li, C.; Shang, L.; Shen, Y. Ultrasmall Pt Nanoclusters as Robust Peroxidase Mimics for Colorimetric Detection of Glucose in Human Serum. ACS Appl. Mater. Interfaces 2017, 9, 10027–10033.
63. Ye, H.; Liu, Y.; Chhabra, A.; Lilla, E.; Xia, X. Poly vinylpyrrolidone (PVP) Capped Ptnanocubes with superior peroxidase-Like activity. ChemNanoMat 2017, 3, 33–38.
64. Lan, J.; Xu, W.; Wan, Q.; Zhang, X.; Lin, J.; Chen, J.; Chen, J. Colorimetric determination of sarcosine in urine samples of prostatic carcinoma by mimic enzyme palladium nanoparticles. Anal. Chim. Acta 2014, 825, 63–68.
65. Liu, Y.; Purich, D.L.; Wu, C.; Wu, Y.; Chen, T.; Cui, C.; Zhang, L.; Cansiz, S.; Hou, W.; Wang, Y.; et al. Ionic function alization of hydrophobic colloidal nanoparticles to formionic nanoparticles with enzymelike properties. J. Am. Chem. Soc. 2015, 137, 14952–14958.
66. Wei, J.; Chen, X.; Shi, S.; Mo, S.; Zheng, N. An investigation of the mimetic enzyme activity of two-dimensional Pd-based nanostructures. Nanoscale 2015, 7, 19018–19026.
67. Hu, L.Z.; Liao, H.; Feng, L.Y.; Wang, M.; Fu, W.S. Accelerating the peroxidase-like activity of gold nanoclusters at neutral pH for colorimetric detection of heparin and heparinase activity. Anal Chem. 2018, 90, 6247–6252.
68. Song, Y.; Qu, K.; Zhao, C.; Ren, J.; Qu, X. Graphene oxide: Intrinsic per oxidase catalytic activity and its application to glucose detection. Adv. Mater. 2010, 22, 2206–2210.
69. Wu, D.; Deng, X.; Huang, X.; Wang, K.; Liu, Q. Low-cost preparation of photoluminescent carbon nanodots and application as peroxidase mimetics in colorimetric detection of H2O2and glucose. J. Nanosci. Nanotechnol. 2013, 13, 6611–6616.

70. Mohammadpour, Z.; Safavi, A.; Shamsipur, M. A new label free colorimetric chemosensor for detection of mercury ion with tunable dynamic range using carbon nanodots as enzyme mimics. Chem. Eng. J. 2014, 255, 1–7.
71. Shamsipur, M.; Safavi, A.; Mohammadpour, Z. Indirect colorimetric detection of glutathione based on its radical restoration ability using carbon nanodots as nanozymes. Sens. Actuators B Chem. 2014, 199, 463–469.
72. Zhu, W.; Zhang, J.; Jiang, Z.; Wang, W.; Liu, X. High-quality carbon dots: Synthesis, peroxidase-like activity and their application in the detection of H2O2, Ag+ and Fe3+. RSC Adv. 2014, 4, 17387–17392.
73. Garg, B.; Bisht, T. Carbon Nanodots as Peroxidase Nanozymes for Biosensing. Molecules 2016, 21, 1653.
74. Tang, D.; Liu, J.; Yan, X.; Kang, L. Graphene oxide derived graphene quantum dots with different photoluminescence properties and peroxidase-like catalytic activity. RSC Adv. 2016, 6, 50609–50617.
75. Nirala, N.R.; Khandelwal, G.; Kumar, B.; Prakash, R.; Kumar, V. One step electro-oxidative preparation of graphene quantum dots from wood charcoal as a peroxidase mimetic. Talanta 2017, 173, 36–43.
76. Vázquez-González, M.; Liao, W.C.; Cazelles, R.; Wang, S.; Yu, X.; Gutkin, V.; Willner, I. Mimicking Horseradish Peroxidase Functions Using Cu2+-Modified Carbon Nitride Nanoparticles or Cu2+-Modified Carbon Dots as Heterogeneous Catalysts. ACS Nano 2017, 11, 3247–3253.
77. Dong, Y.; Li, J.; Shi, L.; Guo, Z. Iron impuritiesas theactive sites for peroxidase like catalytic reaction on graphene and its derivatives. ACS Appl. Mater. Interfaces 2015, 7, 15403–15413.
78. Dong, Y.; Li, J.; Shi, L.; Xu, J.; Wang, X.; Guo, Z.; Liu, W. Grapheneoxide–iron complex: Synthesis, characterization and visible-light-driven photo catalysis. J. Mater. Chem. A 2013, 1, 644–650.
79. Gayathri, P.; Kumar, A.S. An Iron Impurity in Multiwalled Carbon Nanotube Complexes with Chitosan that Biomimics the Heme-Peroxidase Function. Chem.-A Eur. J. 2013, 19, 17103–17112.
80. Lin, L.; Song, X.; Chen, Y.; Rong, M.; Zhao, T.; Wang, Y.; Jiang, Y.; Chen, X. Intrinsic peroxidase-like catalytic activity of nitrogen-doped graphene quantum dots and their application in the colorimetric detection of H2O2 and glucose. Anal. Chim. Acta 2015, 869, 89–95.
81. Zhang, R.; He, S.; Zhang, C.; Chen, W. Three-dimensional Fe- and N-incorporated carbon structures as peroxidase mimics for fluorescence detection of hydrogen peroxide and glucose. J. Mater. Chem. B 2015, 3, 4146–4154.
82. Yang, W.; Huang, T.; Zhao, M.; Luo, F.; Weng, W.; Wei, Q.; Lin, Z.; Chen, G. High peroxidase-like activity of iron and nitrogen co-doped carbon dots and its application in immunosorbent assay. Talanta 2017, 164, 1–6.
83. Tian, J.; Liu, Q.; Asiri, A.M.; Qusti, A.H.; Al-Youbi, A.O.; Sun, X. Ultrathin graphitic carbon nitride nanosheets: A novel peroxidase mimetic, Fe doping-mediated catalytic performance enhancement and application to rapid, highly sensitive optical detection of glucose. Nanoscale 2013, 5, 11604–11609.
84. Lin, T.; Zhong, L.; Wang, J.; Guo, L.; Wu, H.; Guo, Q.; Fu, F.; Chen, G. Graphite-like carbon nitrides as peroxidase mimetics and their applications to glucose detection. Biosens. Bioelectron. 2014, 59, 89–93.
85. Qiao, F.; Wang, J.; Ai, S.; Li, L. As an ewperoxidasemimetic: The synthesis of selenium doped graphitic carbon nitride nanosheets and applications on colorimetric detection of H2O2 and xanthine. Sens. Actuators B Chem. 2015, 216, 418–427.
86. Fillon, Y.; Verma, A.; Ghosh, P.; Ernenwein, D.; Rotello, V.M.; Chmielewski, J. Peptideligation catalyzed by functionalized gold nanoparticles. J. Am. Chem. Soc. 2007, 129, 6676–6677.
87. Qin, L.; Hu, Y.; Wei, H. Nanozymes: Preparation and Characterization. In Nanostructure Science and Technology; Yan, X., Ed.; Springer: Singapore, 2020.
88. Li, J.; Wu, Q.; Wu, J. Synthesis of Nanoparticlesvia Solvothermal and Hydrothermal Methods. In Handbook of Nanoparticles; Aliofkhazraei, M., Ed.; Springer International Publishing: Cham, Switzerland, 2016; pp. 295–328.
89. Wang, H.; Wan, K.; Shi, X. Recent Advances in Nanozyme Research. Adv. Mater. 2019, 31, e1805368.
90. Wang, C.; Liu, C.; Li, J.; Sun, X.; Shen, J.; Han, W.; Wang, L. Electrospun metal–organic framework derived hierarchical carbon nanofibers with high performance for supercapacitors. Chem. Commun. 2017, 53, 1751–1754.
91. Scandurra, A.; Ruffino, F.; Sanzaro, S.; Grimaldi, M.G. Laserand Thermal Dewetting of Gold Layer onto Graphene Paperforn on Enzymatic Electrochemical Detection of Glucose and Fructose. Sens. Actuators B Chem. 2019, 301, 127113.
92. Chou, K.-S.; Ren, C.-Y. Synthesis of nanosized silver particles by chemical reduction method. Mater. Chem. Phys. 2000, 64, 241–246.
93. Rane, A.V.; Kanny, K.; Abitha, V.K.; Sabu, T.C. Methods for Synthesis of Nanoparticles and Fabrication of Nanocomposites. In Synthesis of Inorganic Nanomaterials Advances and Key Technologies Micro and Nano Technologies, 1st ed.; Woodhead Publishing Company: Sawston, UK, 2018; pp. 121–139.
94. Suriati, G.M.; Mariatti, M.; Azizan, A. Synthesis of silver nanoparticles buchemical reduction method: Effect of reducing agent and surfactant concentration. Int. J. Automot. Mech. Eng. 2014, 10, 1920–1927.
95. Zhu, J.; Peng, X.; Nie, W.; Wang, Y.; Gao, J.; Wen, W.; Wang, S. Hollow copper sulfide nanocubesas multifunctional nanozymes for colorimetric detection of dopamine and electrochemical detection of glucose. Biosens. Bioelectron. 2019, 141, 111450.
96. DAS, R.; Dhiman, A.; Kapil, A.; Bansal, V.; Sharma, T.K. Aptamer-mediated colorimetric and electrochemical detection of Pseudomonas aeruginosa utilizing peroxidase-mimic activity of gold NanoZyme. Anal. Bioanal. Chem. 2019, 411,

1229–1238.
97. Tonelli, D.; Scavetta, E.; Gualandi, I. Electrochemical Deposition of Nanomaterials for Electrochemical Sensing. Sensors 2019, 19, 1186.
98. Al-Bat'hi, S.A.M. Electrode position of nanostructure materials. In Electroplating of Nanostructures; Aliofkhazraei, M., Ed.; InTech: Rijeka, Croatia, 2015; pp. 3–25.
99. Shin, H.Y.; Park, T.J.; Kim, M.I. Recent Research Trends and Future Prospects in Nanozymes. J. Nanomater. 2015, 2015, 1–11.
100. Li, W.-P.; Su, C.-H.; Chang, Y.-C.; Lin, Y.-J.; Yeh, C.-S. Ultrasound-Induced Reactive Oxygen Species Mediated Therapy and Imaging Using a Fenton Reaction Activable Polymersome. ACS Nano 2016, 10, 2017–2027.

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