



A Comprehensive Review on Nano scale and Carrier-Mediated Strategies for alpha-Amylase Modulation: From Industrial Bio-catalysis to Biomedical Therapeutics

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Abstract

Alpha-Amylase plays a crucial role in carbohydrate metabolism, with widespread applications ranging from industrial starch processing to heritage conservation and clinical diagnostics (Abdel-Mageed & Radwan, 2025; El-Shishtawy et al., 2021; Hameed et al., 2022). However, the operational instability, sensitivity to harsh environmental conditions, and non-reusability of the native enzyme pose significant challenges. Recent advances in nanotechnology and material science have enabled the development of functionalized carrier matrices and nanoparticle systems that modulate alpha-amylase activity. This comprehensive review provides a comparative synthesis of five distinct carrier systems: functionalized acrylic fabric (El-Shishtawy et al., 2021), layered double hydroxides (Abdel-Mageed & Radwan, 2025), noble metal nanoparticles (Abdel-Mageed & Radwan, 2025), green-synthesized gold nanoparticles (Hameed et al., 2022), and inorganic-organic hybrid nanocomposites (Bahri et al., 2022). We evaluate their mechanism of action, kinetic impacts, operational stability, and target applications.

Keywords: endo-hydrolase; mechanism of action, kinetic impacts, operational stability

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1. Introduction

Alpha-Amylase is an endo-hydrolase that cleaves alpha {-1,4-glucosidic} linkages in starch and related polysaccharides (Abdel-Mageed & Radwan, 2025). Despite its high catalytic efficiency, the application of free alpha-amylase in continuous industrial processes is limited by thermal denaturation, pH sensitivity, and difficult recovery (Abdel-Mageed & Radwan, 2025; El-Shishtawy et al., 2021). Immobilization on nano- and micro-structured supports offers a viable solution to enhance catalytic stability, enable reuse, and optimize kinetics (Abdel-Mageed & Radwan, 2025; El-Shishtawy et al., 2021). Conversely, in clinical contexts such as Type-2 Diabetes Mellitus management, the deliberate, controlled inhibition of alpha-amylase is desirable to regulate postprandial hyperglycemia (Hameed et al., 2022). This manuscript evaluates recent comparative advances in carrier-mediated modulation of alpha-amylase across catalytic enhancement, structural preservation, and therapeutic inhibition.

2. Solid-Support Immobilization Systems

2.1 Functionalized Textile Supports: Acrylic Fabric with Cu-Nanomaterials

El-Shishtawy et al. developed an operational system utilizing acrylic fabric functionalized with hexamethylenediamine (Table 1) and loaded with copper nanoparticles {CuNPs} or copper ions (Cu²⁺) (El-Shishtawy et al., 2021). Physical and dynamic bonding onto amine-functionalized copper active sites on a flexible substrate (El-Shishtawy et al., 2021). Yields optimal catalytic activity at pH of 7.0 with high structural durability (El-Shishtawy et al., 2021). Replaces conventional centrifugation or filtration recovery with simple physical withdrawal of the bio-catalytic textile, ideal for large-scale food processing (El-Shishtawy et al., 2021).

2.2 Experimental Inorganic Nano-sheets: Layered Double Hydroxides {Zn-Al/LDH}

The investigated synthesized (Zn-Al-CO) Layered Double Hydroxide (LDH) nanoparticles approximately. 185nm for *Bacillus* sp. alpha-amylase immobilization. Immobilization occurs through electrostatic adsorption, inducing a Zeta potential shift from 26mV to 18mV. Achieved an immobilization yield of 97% and a loading capacity of 54.81mg/g. The maximum reaction velocity (V_{max}) increased from 40.98U/mg (free) to 59.88U/mg (immobilized), alongside a minor increase in K_m from 2.798 mg/mL to 3.089 mg/mL. Thermal activation energy of denaturation was reduced to 64.01kJ/mol. Maintained 90% activity after 5 cycles 84% after 10 cycles and retained 97.6% activity after 25 days of storage at 4° (Abdel-Mageed & Radwan, 2025).

2.3 Inorganic-Organic Hybrids: {ZnS-Chitosan} (ZnS-CS) Nanoparticles

This study examined the entrapment/adsorption of alpha-amylase extracted from *Sillago sihama* onto ZnS-Chitosan hybrid nanoparticles. Significantly broadens thermal and pH tolerance windows without altering optimum operational parameters. While a decrease in overall catalytic efficiency k_{cat} , K_m and an increase in K_m were observed due to steric constraints, the enhanced physical longevity outweighs kinetic trade-offs in continuous processing setups (Bahri et al., 2022).

3. Solution-Phase Modulation: Activation and Inhibition

3.1 Enzyme Activation for Art Restoration (AuNPs), (AgNPs)

The In paper artifact conservation, biosynthesized gold (AuNPs) and silver (AgNPs) nanoparticles derived from local fungal isolates were evaluated as co-catalytic additives. Addition of 20L AgNPs increased enzymatic activity up to 160%, while 5 L AuNPs yielded a 140% activity enhancement. Colorimetric and SEM analysis showed efficient removal of starch stains from paper artifacts without structural surface distortion.

3.2 Therapeutic Non-Competitive Inhibition (AuNPs)

While this study evaluated green-synthesized gold nanoparticles 39-57 nm using *Myrtus communis* leaf extract for clinical management of postprandial glucose (Hameed et al., 2022). A clear non-competitive inhibition pattern against alpha-amylase, significantly reducing V_{max} from 1000 U/L to 250U/L (Hameed et al., 2022). Demonstrated 72% enzymatic inhibition in diabetic serum compared to 45% in healthy controls, paired with dual antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* (Hameed et al., 2022).

Table (1) Comparative Synthesis among studies which investigated here

Matrix / Support System	Primary Interaction Mechanism	Kinetic Shift	Key Advantage	Primary Application Target	References
HMDA-Cu Acrylic Fabric	Covalent / Coordination	Preserved activity at pH 7.0	Rapid macro-level recovery without centrifugation	Industrial Food Processing	(El-Shishtawy et al., 2021)
Zn-Al-CO ₃ LDH	Electrostatic adsorption	Increased V_{max} minor K_m increase	97.6% retention over 25 days	Starch Hydrolysis / Biotechnology	(Abdel-Mageed & Radwan, 2025)
Fungal AgNPs/AuNPs	Co-factor activation	Up to 160% rate gain	Non-destructive cleaning of delicate matrices	Cultural Heritage Conservation	Abdel-Nasser et al., 2022)
<i>M. communis</i> AuNPs	Allosteric/Non-competitive inhibition	Reduced V_{max} 1000 - 250U/L	High serum inhibition 72%	Type-2 Diabetes Therapeutics	(Hameed et al., 2022)
ZnS-Chitosan (ZnS-CS)	Nano-entrapment	Increased K_m ; reduced k_{cat}/K_m	Extended thermal/pH stability	Continuous Bioprocessing	(Bahri et al., 2022)

4. Conclusion

Carrier-mediated modification of alpha-amylase demonstrates significant potential across both industrial and biomedical domains (Abdel-Mageed & Radwan, 2025; El-Shishtawy et al., 2021; Hameed et al., 2022). Solid supports like Zn-Al LDH and acrylic textiles provide operational stability and easy reusability essential for

biocatalysis. Conversely, precise nanoscale formulations of gold and silver can be tuned either to boost activity for delicate conservation work or to act as therapeutic inhibitors for metabolic regulation (Hameed et al., 2022). Future efforts should focus on scaling hybrid nanocomposites for industrial deployment and validating bio-functionalized metal nanoparticles in clinical trials (El-Shishtawy et al., 2021; Hameed et al., 2022).

References

- Abdel-Nasser M., Abdel-Maksoud G., Abdel-Aziz M. S., Darwish S. S., Hamed A. A., Youssef A. M. (2022) Evaluation of the efficiency of nanoparticles for increasing α -amylase enzyme activity for removing starch stain from paper artifacts. *J Cult Herit.* 53:14–23 .
- Abdel-Mageed, H. M., & Radwan, R. A. (2025). Fabrication of robust layered double-hydroxide nanoparticles for alpha-amylase immobilization: Enhancing catalytic performance, stability, and prospective sustainable biocatalysis applications. *International Journal of Biological Macromolecules*, 280, 135000.
- Bahri, S., Homaei, A., & Mosaddegh, E. (2022). Immobilization of alpha-amylase onto ZnS-chitosan hybrid nanoparticles to improve catalytic performance and stability. *Colloids and Surfaces B: Biointerfaces*, 218, 112754. <https://doi.org/10.1016/j.colsurfb.2022.112754>
- El-Shishtawy, R. M., Asiri, A. M., & Abdel-Mageed, H. M. (2021). Development of functionalized acrylic fabric modified with copper nanoparticles for enzyme immobilization. *Journal of Applied Polymer Science*, 138(15), 50210.
- Hameed, R. Y., Nathir, I., Abdulsahib, W. K., & Almashhadani, H. A. (2022). Study the effect of biosynthesized gold nanoparticles on the enzymatic activity of alpha-Amylase. *Research Journal of Pharmacy and Technology*, 15(8), 3459–3465. <https://doi.org/10.52711/0974-360X.2022.00579>
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