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NANOTECHNOLOGY-BASED THERAPIES IN THE TREATMENT OF TYPE 2 DIABETES: A NARRATIVE REVIEW

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ABSTRACT

Type 2 diabetes mellitus (T2DM) remains a major global health burden, driven by insulin resistance, progressive β-cell dysfunction, chronic inflammation, and metabolic dysregulation. Conventional pharmacotherapies often exhibit limited bioavailability, suboptimal targeting, and insufficient capacity to modulate the underlying mechanisms of disease progression. In recent years, nanotechnology has emerged as a highly promising therapeutic strategy capable of addressing these limitations. This narrative review evaluates current advancements in nanotechnology-based interventions for T2DM, with a focus on nanocarrier design, mechanisms of action, and translational potential.

Across the analyzed studies, diverse nanoplatforms—including polymeric nanoparticles, lipid-based nanocarriers, nanomicelles, PLGA systems, bilosomes, gold nanoparticles, and stimulus-responsive Pickering emulsions—demonstrated significant improvements in drug stability, controlled release, intestinal absorption, and metabolic outcomes. Notably, nanocarriers enhanced the therapeutic performance of incretin-based agents (GLP-1, liraglutide), enabled progress toward oral insulin delivery, and increased the bioavailability of conventional antidiabetic drugs such as metformin and glimepiride. Additionally, nanostructures encapsulating natural bioactive compounds (e.g., naringenin, oleanolic acid, resveratrol) exhibited potent antioxidant, anti-inflammatory, and metabolic benefits. Several innovative systems further demonstrated glucose- or pH-responsive behavior, enabling intelligent and targeted drug release.

Preclinical evidence consistently showed improved glycemic control, enhanced β-cell protection, reduced inflammatory markers, and favorable effects on lipid metabolism and body weight. However, the predominance of in vitro and in vivo animal studies underscores the need for robust clinical investigations to evaluate long-term safety, pharmacokinetics, and real-world therapeutic efficacy.

Overall, nanotechnology offers a promising avenue for the development of more effective, precise, and multidimensional treatments for T2DM. Continued translational and clinical research is essential to support its integration into future diabetes management.

KEYWORDS

Diabetes Mellitus Type 2, Nanotechnology, Nanoparticles, Drug Delivery Systems, Nanomedicine Diabetes, Nanoparticle-Based Therapy Diabetes

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1. Introduction

Type 2 diabetes mellitus (T2DM) is an escalating global health challenge, and the limitations of conventional therapies underscore the need for more precise and effective treatment strategies. Progressive β-cell dysfunction, insulin resistance, chronic inflammation, and lipid metabolism disturbances highlight the necessity for therapeutic approaches capable of targeted delivery of bioactive agents and modulation of cellular processes [1,2].

In recent years, nanotechnology has emerged as one of the most promising therapeutic directions in diabetology. Nanocarriers have been shown to enhance β-cell function [1,2,15], reduce inflammation and oxidative stress [1,13], modulate lipid metabolism [1,12,13], and improve insulin sensitivity [6,7]. A broad array of nanomaterial platforms—including liposomes, lipid-based nanocarriers, nanomicelles, PLGA nanoparticles, bilosomes, gold nanoparticles, and Pickering emulsions—provides improved drug stability, enhanced bioavailability, and controlled release profiles [3,4,6,7,10,11,12,14,15,16,20].

Significant advancements have been achieved particularly in the development of oral incretin delivery systems (liraglutide, GLP-1) [6,10,11], innovative micellar formulations [18], and nanocarriers for established antidiabetic drugs such as metformin [7,14], glimepiride [16], and naturally derived anti-inflammatory compounds, including naringenin and resveratrol [9,12,13]. Modern stimulus-responsive systems, triggered by changes in pH or glucose concentration, enable targeted and efficient intestinal drug delivery [20].

Preclinical studies demonstrate that nanotherapeutics can effectively improve glycemic control, reduce body weight gain, and enhance metabolic parameters in T2DM models [1,18,19]. Their capacity to act upon key pathophysiological mechanisms positions nanotechnologies as promising candidates for future therapeutic applications.

The aim of this narrative review is to summarize current advancements in the use of nanomaterials in the treatment of T2DM, with particular emphasis on their characteristics, mechanisms of action, and clinical translation potential [1–20].

2. Materials and Methods

Search Strategy

A systematic literature search was conducted in the PubMed database using a combination of MeSH terms and free-text keywords related to nanotechnology and the treatment of type 2 diabetes mellitus. The following search query was applied:

("Diabetes Mellitus, Type 2"[MeSH] AND ("Nanotechnology"[MeSH] OR "Nanoparticles"[MeSH] OR "Drug Delivery Systems"[MeSH] OR "nanomedicine diabetes" OR "nanoparticle-based therapy diabetes"))

The search was performed in January 2025. Articles published between 2024 and 2025 were included, covering:

- preclinical studies (in vitro, in vivo),
- translational research,
- and advanced nanocarrier systems for antidiabetic drugs.

Reference lists of all eligible publications were additionally screened to identify complementary studies.

Eligibility Criteria

Inclusion Criteria

Studies were included if they met the following criteria:

- Investigated the application of nanotechnology in the treatment or modulation of the pathophysiology of type 2 diabetes mellitus (T2DM).
- Described:
  - nanocarriers for antidiabetic drugs (e.g., GLP-1, insulin, metformin, glimepiride),
  - naturally derived nanomaterials with metabolic activity,
  - stimulus-responsive delivery systems triggered by glucose or pH.
- Included in vitro or in vivo studies, review articles, or papers reporting the development of therapeutic nanoplatforms.
- Published in English.
- Full-text availability.

Exclusion Criteria

Studies were excluded if they met any of the following:

- Did not concern T2DM (e.g., T1DM without nanotechnology components).
- Focused solely on diagnostics, insulin delivery technologies, or CGM systems without nanomaterial involvement.
- Addressed nanomaterial toxicity without therapeutic application.
- Examined nanotechnologies in diseases unrelated to metabolic disorders.
- Conference abstracts, letters to the editor, and non–peer-reviewed preprints.

PICOS Framework

Element	Description
P (Population)	Animal models of type 2 diabetes (e.g., db/db mice), in vitro models (β-cells, HepG2), zebrafish models, and translational references.
I (Intervention)	Nanotechnology-based therapies: nanoliposomes, nanomicelles, PLGA nanoparticles, nanoemulsions, bilosomes, gold nanoparticles, polysaccharide nanocarriers, Pickering emulsions, polyzwitterionic oral systems.
C (Comparison)	Standard therapy, free drug form, or no intervention (in preclinical studies).
O (Outcomes)	Glycemic control, metabolic improvements, β-cell function, inflammatory markers, bioavailability, lipid profile, body weight, and safety parameters.
S (Study Type)	In vitro studies, in vivo studies, translational research, nanocarrier-focused reviews, and physicochemical nanoparticle characterization analyses.

Data Extraction

Data extraction was performed manually according to a predefined protocol. For each included study, the following information was collected:

- authors, year of publication, journal,
- type of nanocarrier used,
- type of drug or bioactive compound delivered,
- research model (in vitro, in vivo),
- major outcomes related to glycemic control, β-cell function, inflammation, and metabolic parameters,
- safety and cytotoxicity data,
- key conclusions on therapeutic potential.

All extracted data were compiled into a unified table to enable cross-study comparison.

Outcomes & Measures

The primary outcomes assessed included:

- Glycemic parameters – glucose levels, glucose tolerance, HbA1c (when reported).
- β-cell function – markers of oxidative stress, apoptosis, and auto-inflammation.
- Insulin resistance – HOMA-IR, insulin sensitivity, glucose uptake in cells.
- Lipid parameters – triglycerides (TG), total cholesterol (TC), LDL-C, hepatic lipid metabolism.
- Inflammation and oxidative stress – pro-inflammatory cytokines, ROS markers.
- Body weight and metabolic parameters – weight gain, thermogenesis, energy metabolism.
- Bioavailability and pharmacokinetics – absorption, retention, stability in gastrointestinal conditions.
- Safety – cytotoxicity (e.g., HepG2, β-cells) and adverse effects in animal models.

Data Synthesis

Due to the heterogeneity of study designs (in vitro, in vivo) and nanocarrier types, a narrative synthesis was performed.

The analysis:

- grouped studies according to nanocarrier type (liposomes, PLGA, micelles, nanoemulsions, polysaccharide nanocarriers, Pickering emulsions, etc.),
- assessed proposed mechanisms of action,
- compared the effectiveness of nanocarriers in glycemic control, anti-inflammatory activity, lipid metabolism modulation, and β-cell protection,
- identified domains where nanotechnology demonstrated the strongest translational potential.

Findings were summarized narratively and accompanied by a tabular overview of the key characteristics and outcomes of each study.

3. Results

An analysis of the twenty selected publications confirms that nanotechnology represents one of the most promising therapeutic tools in the treatment of type 2 diabetes mellitus (T2DM). These studies present a broad spectrum of modern nanoplatforms, including polymeric nanoparticles, nanostructured lipid carriers, nanomicelles, nanoemulsions, liposomes, bilosomes, gold nanoparticles, polysaccharide-based systems, and intelligent Pickering emulsions. Collectively, they demonstrate that nanomaterials can target key pathophysiological mechanisms of T2DM, such as β-cell dysfunction, insulin resistance, chronic inflammation, and lipid metabolism disturbances.

Studies by Wang X et al. and Liu Z et al. showed that biomimetic and sequentially targeted nanoplatforms effectively reduce autoimmune and inflammatory damage to β-cells and improve insulin resistance, resulting in marked improvements in glycemic regulation (1,2). Equally important are the works focused on nanocarriers for antidiabetic drugs. Systems designed for incretin delivery—including liraglutide nanomicelles, sublingual GLP-1 nanoliposomal hydrogels, and oral GLP-1 bilosomes—demonstrated significantly enhanced bioavailability and therapeutic efficacy (6,10,11). A particularly advanced platform is the polyzwitterionic oral insulin nanocarrier described by Zhang W et al., which successfully penetrated the mucus barrier and provided long-lasting glycemic control in animal models (18).

Nanotechnology has also markedly improved the pharmacokinetic properties of oral antidiabetic medications. Nanostructured lipid carriers for metformin developed by Qushawy M et al. and PLGA nanoparticles providing sustained intracellular release described by Sun Q et al. produced significant glucose-lowering effects along with strong anti-inflammatory activity (7,14). In the case of sulfonylureas, nanoencapsulated glimepiride in chitosan nanoparticles prepared by Karthick V et al. showed controlled release and superior efficacy in T2DM models (16).

A substantial group of studies focused on nanocarriers for natural bioactive compounds. Liposomal oleanolic acid, zein nanoparticles loaded with naringenin, resveratrol–selenium nanoparticles, and green-synthesized nanomaterials described by Loyola-Leyva et al. exhibited beneficial metabolic, antioxidant, and anti-inflammatory effects (3,12,13,9). Of particular significance were the polysaccharide nanomicelles derived from soy hulls, which—as shown by Xu M et al.—demonstrated strong hypoglycemic activity dependent on sonication parameters determining particle size (19).

Among the most innovative technologies were stimulus-responsive delivery systems capable of reacting to physiological cues. Chen Q et al. presented a Pickering emulsion responsive to changes in glucose concentration and pH, enabling targeted intestinal release—an important step toward personalized diabetes therapy (20). Similarly, polysaccharide nanomicelles exhibited enhanced stability and therapeutic performance following structural modification (19).

Several studies applied nanotechnology to modulate complex disease mechanisms. Research by Forgham H et al.demonstrated that amyloid-targeting gold nanoparticles were capable of removing toxic islet amyloid deposits, thereby restoring β-cell function (15). Moreover, multiple nanotherapeutic platforms—including those presented in studies (1,3,13,18)—showed improvements in lipid profiles, reductions in body weight, and attenuation of inflammatory markers.

In summary, the analysis of twenty publications clearly indicates that nanotechnology enables precise, multidirectional modulation of the processes underlying the development and progression of T2DM. Most studies reported improved glycemic control, reduced lipid abnormalities, attenuation of inflammation, and enhanced β-cell metabolic function. The nanoplatforms examined demonstrated high stability, biocompatibility, and translational potential, highlighting their promise as future therapeutic approaches for type 2 diabetes.

4. Discussion

The reviewed studies demonstrate that nanomaterials not only facilitate drug delivery but also actively modulate key pathophysiological mechanisms of the disease, including insulin resistance, β-cell dysfunction, chronic inflammation, and lipid metabolism disturbances.

In particular, the studies by Wang X et al. and Liu Z et al. highlight that advanced biomimetic nanoplatforms can act directly on pancreatic β-cells, improving their function and reducing mitochondrial stress and auto-inflammatory damage (1,2). This is of major significance, as therapies aimed at protecting and regenerating β-cells remain one of the most challenging goals in diabetology. These findings suggest that nanotechnology holds potential that extends beyond drug delivery alone — it may modulate disease processes at both the cellular and subcellular levels.

A substantial proportion of the included research focused on improving the bioavailability of antidiabetic medications. Nanocarriers for liraglutide and GLP-1 presented by Subedi et al., Khopade et al., and Vidhate et al. markedly enhanced the therapeutic efficacy of incretin peptides by protecting them from enzymatic degradation and improving absorption (6,10,11). Particularly noteworthy are the findings of Zhang W et al., where polyzwitterionic nanocarriers enabled oral insulin administration — a long-standing goal in pharmacology (18). The ability of this platform to overcome mucus barriers and stabilize the hormone strongly suggests that oral insulin could become a viable alternative to injectable formulations in the future.

Studies focusing on metformin and glimepiride further confirm that nanotechnology can enhance the effectiveness of well-established antidiabetic drugs. Nanostructured lipid carriers for metformin described by Qushawy et al., as well as PLGA nanoparticles reported by Sun Q et al., improved bioavailability, prolonged therapeutic effects, and demonstrated additional anti-inflammatory benefits (7,14). Similarly, nanoencapsulated glimepiride in chitosan nanoparticles showed controlled release and superior efficacy compared with the conventional formulation, suggesting potential dose reduction and fewer adverse effects (16).

A significant number of studies evaluated nanocarriers for natural bioactive compounds, including oleanolic acid (Yuan M et al.), naringenin (Guo Y et al.), resveratrol and selenium nanoparticles (Soliman AY et al.), and plant-derived polysaccharides (Xu M et al.) (3,12,13,19). Although these compounds exhibit strong antioxidant, anti-inflammatory, and metabolic effects, their clinical use is often limited by poor bioavailability. Nanocarriers substantially improved their stability, release characteristics, and therapeutic efficacy in T2DM models. Additionally, the systematic review by Loyola-Leyva et al. confirms that "green-synthesized" nanoparticles may serve as eco-friendly and potent therapeutic alternatives, although the findings require cautious interpretation (9).

Advanced responsive drug-delivery systems, such as glucose- and pH-sensitive nanoplatforms described by Chen Q et al., enable precise and intelligent drug release in response to metabolic changes (20). Such approaches are vital for the development of long-acting, personalized therapies that reduce the risk of hypoglycemia and improve patient comfort. Structural modifications of polysaccharide nanomicelles further enhanced their therapeutic performance and gastrointestinal stability, as demonstrated by Xu M et al. (19).

One particularly innovative direction is represented by Forgham et al., whose study demonstrated that amyloid-targeting gold nanoparticles were able to eliminate toxic pancreatic amyloid deposits and restore β-cell function (15). This links nanotechnology with emerging therapeutic approaches directed at islet amyloid pathology, offering a potentially groundbreaking avenue in T2DM treatment.

Several studies — including (1), (3), (13), and (18) — also confirmed additional benefits of nanotherapies, such as reductions in body weight, improvements in lipid profiles, and decreases in inflammatory markers. These findings demonstrate that nanotechnology not only improves glycemic parameters but also exerts multifaceted effects on metabolic syndrome components, providing a more holistic therapeutic approach.

Nevertheless, most of the studies included in this review were conducted in preclinical models, underscoring the need for further clinical research to evaluate the efficacy and safety of these technologies in humans. Despite promising outcomes, key challenges remain, including long-term toxicity, nanoparticle biodegradation, metabolic fate, and potential interactions with existing antidiabetic medications.

In conclusion, nanotechnology substantially expands the therapeutic possibilities for T2DM by offering effective, multidirectional, and innovative treatment approaches. The evidence gathered to date highlights its potential not only to improve drug delivery but also to directly modulate pathophysiological processes such as oxidative stress, inflammation, and β-cell dysfunction. However, comprehensive translational and clinical studies are essential to fully harness its potential and ensure its safety for clinical use.

5. Limitations

This review has several important limitations. First, the majority of the analyzed studies were preclinical in nature (in vitro or in vivo), meaning that the efficacy and safety of nanotherapies reported in articles [1–3,6–7,10–16,18–20] may not fully translate to clinical settings. The absence of human studies limits the ability to evaluate the true therapeutic potential of these nanotechnologies.

Second, the included studies involved highly heterogeneous types of nanomaterials and diverse disease models, which complicates direct comparison of outcomes and precludes quantitative synthesis. Differences in particle size, composition, surface charge, and functionalization strategies significantly influence biological performance, thereby limiting the generalizability of conclusions.

Moreover, most studies focused primarily on short-term therapeutic effects without assessing long-term safety, nanoparticle accumulation, or potential immunological interactions—factors of particular relevance for non-biodegradable nanomaterials such as gold nanoparticles [15].

Additionally, this review was restricted to a single database (PubMed) and to publications from 2024–2025, which may have resulted in the omission of valuable studies indexed elsewhere.

Despite promising findings, further translational and clinical research is essential to confirm the safety, efficacy, and feasibility of implementing nanotechnology-based therapies in the treatment of T2DM.

6. Conclusions

The evidence gathered in this review clearly indicates that nanotechnology offers novel and highly promising therapeutic opportunities for the treatment of type 2 diabetes mellitus (T2DM). The analyzed studies show that a wide range of nanomaterials—including liposomes, polymeric and lipid-based nanoparticles, and advanced stimulus-responsive delivery systems—can effectively enhance glycemic control, improve drug bioavailability, protect pancreatic β-cells, and reduce inflammation and metabolic dysfunction. Particularly noteworthy are incretin-based nanoplatforms, oral insulin delivery systems, and nanocarriers for natural bioactive compounds, all of which demonstrated multidirectional metabolic benefits and strong translational potential.

Despite these encouraging findings, the current body of evidence is based primarily on preclinical studies, warranting caution in interpretation. The absence of clinical trials, the heterogeneity of nanomaterials used, and limited data regarding long-term safety represent significant barriers to the clinical adoption of nanotechnology-based therapies.

In summary, nanotechnology holds substantial promise for the development of innovative, more effective, and highly targeted therapeutic approaches for T2DM. Further translational and clinical research is essential to evaluate the feasibility of introducing these solutions into patient care and to fully realize their therapeutic potential.

Disclosure

Author's contributions:

Conceptualization: Jagoda Józefczyk, Łukasz Krzystek
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REFERENCES

1. Wang, X., Tian, R., Liang, C., Jia, Y., Zhao, L., Xie, Q., Huang, F., & Yuan, H. (2025). Biomimetic nanoplatform with microbiome modulation and antioxidant functions ameliorating insulin resistance and pancreatic β-cell dysfunction for T2DM management. *Biomaterials*, *313*, 122804. https://doi.org/10.1016/j.biomaterials.2024.122804
2. Liu, Z., Chen, W., Zhang, J., Huang, T., Hong, Y., Zhao, T., Liu, M., Chen, Q., Yang, Y., Wang, S., Wang, J., Ying, X., Li, Y., Huang, Q., & Ai, K. (2025). UCP2 inhibition eliminates pancreatic β cell autoinflammation in T2DM with islet-mitochondrial sequential targeting nanomedicines. *Nature communications*, *16*(1), 6840. https://doi.org/10.1038/s41467-025-61883-y
3. Yuan, M., Wang, Y., Wan, Y., Li, S., Tang, J., Liang, X., Zeng, B., Li, M., Wei, X., Li, X., Guo, L., & Guo, Y. (2024). Novel sodium tauroursodeoxycholate-based multifunctional liposomal delivery system for encapsulation of oleanolic acid and combination therapy of type 2 diabetes mellitus. *International journal of pharmaceutics*, *666*, 124803. https://doi.org/10.1016/j.ijpharm.2024.124803
4. Low, C. Y., Gan, W. L., Lai, S. J., Tam, R. S., Tan, J. F., Dietl, S., Chuah, L. H., Voelcker, N., & Bakhtiar, A. (2025). Critical updates on oral insulin drug delivery systems for type 2 diabetes mellitus. *Journal of nanobiotechnology*, *23*(1), 16. https://doi.org/10.1186/s12951-024-03062-7
5. Pandey, A., Rath, G., Chawala, R., & Goyal, A. K. (2025). A comprehensive review on liraglutide and novel nanocarrier-based systems for the effective delivery of liraglutide. *Naunyn-Schmiedeberg's archives of pharmacology*, *398*(7), 8241–8258. https://doi.org/10.1007/s00210-025-03918-1
6. Subedi, L., Bamjan, A. D., Phuyal, S., Shim, J. H., Cho, S. S., Seo, J. B., Chang, K. Y., Byun, Y., Kweon, S., & Park, J. W. (2025). An oral liraglutide nanomicelle formulation conferring reduced insulin-resistance and long-term hypoglycemic and lipid metabolic benefits. *Journal of controlled release : official journal of the Controlled Release Society*, *378*, 637–655. https://doi.org/10.1016/j.jconrel.2024.12.039
7. Qushawy, M., Alanazi, M. A., Hikal, W. M., Amirthalingam, P., Abu-Gharbieh, E., Almanzalawi, W. S., Mortagi, Y., Elsherbiny, N., & Elsherbini, A. M. (2025). Optimized Nanostructured Lipid Carriers for Metformin: Enhanced Anti-Inflammatory Activity and Protection Against Type 2 Diabetes-Induced Organ Damage. *International journal of nanomedicine*, *20*, 3765–3788. https://doi.org/10.2147/IJN.S506631
8. Guo, S., & Li, H. (2025). Chitosan-Derived Nanocarrier Polymers for Drug Delivery and pH-Controlled Release in Type 2 Diabetes Treatment. *Journal of fluorescence*, *35*(6), 3895–3904. https://doi.org/10.1007/s10895-024-03810-w
9. Loyola-Leyva, A., Hernandez-Vidales, K., Ruiz-Garcia, J., & Loyola-Rodriguez, J. P. (2025). Characterization of Green Synthesized Nanoparticles with Anti-diabetic Properties. A Systematic Review. *Current diabetes reviews*, *21*(7), 67–85. https://doi.org/10.2174/0115733998306451240425135229
10. Khopade, S., Agnihotri, T. G., Baviskar, S., Pavar, B., Gomte, S. S., Maskar, T., Sharma, N., Kumar, H., Behera, S. K., & Jain, A. (2025). Sublingual Delivery of Human GLP-1 Loaded Nanoliposomal Hydrogel for Treatment of Type 2 Diabetes Mellitus. *AAPS PharmSciTech*, *26*(5), 155. https://doi.org/10.1208/s12249-025-03152-1
11. Vidhate, M. K., Gomte, S. S., Singh, N., Suthar, D., & Jain, A. (2025). Exploring the hypoglycemic potential of HuGLP-1-loaded bilosomes in controlling type 2 diabetes mellitus. *Therapeutic delivery*, *16*(10), 907–922. https://doi.org/10.1080/20415990.2025.2557183
12. Guo, Y., Xu, M., Chen, J., Che, J., Zhu, W., Zheng, Y., Huang, W., Dai, W., Chen, H., Zhai, L., Zhang, L., & Guan, Y. Q. (2025). Preparation and characterization of glutamine/chito-oligosaccharide modified zein nanoparticles: Controlled release naringin and anti-diabetes. *Food chemistry*, *493*(Pt 1), 145615. https://doi.org/10.1016/j.foodchem.2025.145615
13. Soliman, A. Y., Elguindy, N. M., Saleh, A. M., & Balbaa, M. (2025). Biochemical and molecular evaluation of resveratrol and selenium nanoparticles in managing type 2 diabetes and its complications. *Scientific reports*, *15*(1), 25565. https://doi.org/10.1038/s41598-025-11156-x
14. Sun, Q., Man, J., Zhang, Y., Ji, M., Song, X., Li, J., & Li, J. (2025). Poly (lactic-co-glycolic acid) (PLGA) nanoparticles for sustained release of metformin hydrochloride within cells: A therapy for Type 2 diabetes mellitus. *Colloids and surfaces. B, Biointerfaces*, *256*(Pt 1), 114998. https://doi.org/10.1016/j.colsurfb.2025.114998
15. Forgham, H., Matre, S. V., Karen Chung, K. H., Tahir, M. S., Ali, S. A., Kikuchi, K., Kaur, A., Qiao, R., Kakinen, A., Qamar, A. Z., Davis, T. P., & Javed, I. (2025). Amyloid Targeting-Gold Nanoparticles-Assisted X-ray Therapy Rescues Islet β-Cells from Amyloid Fibrils and Restores Insulin Homeostasis. *ACS nano*, *19*(5), 5460–5474. https://doi.org/10.1021/acsnano.4c13916
16. Karthick, V., Zahir, A. A., Amalraj, S., Rahuman, A. A., Anbarasan, K., & Santhoshkumar, T. (2025). Sustained release of nano-encapsulated glimepiride drug with chitosan nanoparticles: A novel approach to control type 2 diabetes in streptozotocin-induced Wistar albino rats. *International journal of biological macromolecules*, *287*, 138496. https://doi.org/10.1016/j.ijbiomac.2024.138496

17. Chettupalli, A. K., Kar, N. R., Iswariya, V. T., Panigrahy, U. P., Singh, L. P., Roy, H., Urs, D., V, M., Mandadi, S. R., Haque, M. A., Rana, R., & Emran, T. B. (2025). Development and optimization of dapagliflozin oral nano-bilosomes using response surface method: *in vitro* evaluation, *in vivo* evaluation. *Nanotheranostics*, *9*(1), 1–19. https://doi.org/10.7150/ntno.99271
18. Zhang, W., Wang, Y., Zhang, X., Zhang, Y., Yu, W., Tang, H., & Yuan, W. E. (2025). Polyzwitterion-branched polycholic acid nanocarriers based oral delivery insulin for long-term glucose and metabolic regulation in diabetes mellitus. *Journal of nanobiotechnology*, *23*(1), 133. https://doi.org/10.1186/s12951-025-03190-8
19. Xu, M., Xia, M., Yang, L., Song, H., Li, J., Fan, H., & Liu, H. (2025). Preparation of size-controlled soy hull polysaccharide nanomicelles and evaluation of hypoglycaemic activity in type 2 diabetes zebrafish. *International journal of biological macromolecules*, *321*(Pt 4), 146587. https://doi.org/10.1016/j.ijbiomac.2025.146587
20. Chen, Q., Ye, T., Yang, S., Fan, L., Shang, C., Feng, Y., Li, J., Wang, Y., Yu, G., & Dai, J. (2025). Multiple non-covalent bonds reinforced pH/glucose-responsive alginate-stabilized Pickering emulsion for diacylated anthocyanin intestinal delivery. *International journal of biological macromolecules*, *310*(Pt 2), 142721. https://doi.org/10.1016/j.ijbiomac.2025.142721