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ADVANCEMENTS IN NANOTECHNOLOGY FOR PHARMACEUTICAL TASTE MASKING: A REVIEW ON IMPROVING PATIENT COMPLIANCE AND ORAL DRUG FORMULATIONS

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Abstract

Successful pharmacotherapy depends on patient cooperation; however, one of the most enduring barriers to adherence, especially in young or elderly patients, is the taste of oral medications. Since effects can differ based on the formulation, age, and even the route of drug administration, conventional taste-masking techniques have been found to be largely ineffective in practice. The limitations of these conventional approaches are examined in this narrative literature review, which also demonstrates how recent developments in Nanotechnology offer much more reliable alternatives for development that do not impede patient acceptance. Nano carriers, including liposomal, nanoemulsions, and polymeric nanoparticles, are the best taste-masking agents because they don't affect the release, solubility, or bioavailability of medications. The technologies also enable targeted or controlled drug delivery and circumvent age-dependent swallowing problems. This review demonstrates how nanotechnology can challenge oral administration paradigms by combining clinical, formulation, and new research data. In addition, it highlights critical research gaps pertaining to cost-effectiveness, regulatory guidance, and sensory evaluation models that must be filled in order to fully implement an operational framework for integrating these technologies into medical practice.

Keywords: *Cost-effective, Nanotechnology, Nano carriers, Patient compliance, Taste-masking*

INTRODUCTION

UNDERSTANDING PATIENT COMPLIANCE IN PHARMACOTHERAPY

A key component of successful treatment is patient compliance, which is the degree to which patients take their medications as directed. Drugs guarantee an efficient response that result in improved health outcomes and a quicker recovery at a reduced cost when compliance is in place. On the other hand, noncompliance raises the risk of treatment failure, prolonged illness, repeated hospital stays, and higher health care costs. Patients with chronic conditions such as diabetes, hypertension, mental health issues, and other illnesses typically need to take medication for extended periods of time, if not their entire lives. Improper drug consumption may worsen the disease or lead to relapses. According to studies, noncompliance and management of psychiatric care nearly doubles the chances of experiencing relapse in comparison with those who are compliant with treatment plans (1-3). Factors influencing patient compliance are illustrated in Fig. 1.

WHY PATIENTS DON'T ALWAYS COMPLY

Many factors affect the adherence of the patient to treatment, such as:

- **Understanding and Motivation:** The clearer the benefits of the medication are to the patient, the more adherence to therapy is expected to be achieved. Revolution, lack of proper counseling, or fear concerning side effects can lower the adherence (4, 5).

- **Socioeconomic Factors:** Treatment insurance guarantees, age, income, and educational attainment all affect compliance. Elderly patients are likely to encounter more obstacles and patients with fewer resources (6, 7).
- **Treatment Complexity:** Patients become disinterested in continuing treatment when dosing regimens are complicated or when side effects are unpleasant. Better outcomes could be achieved with straightforward routines and assistance from family or a pharmacist (3, 8).

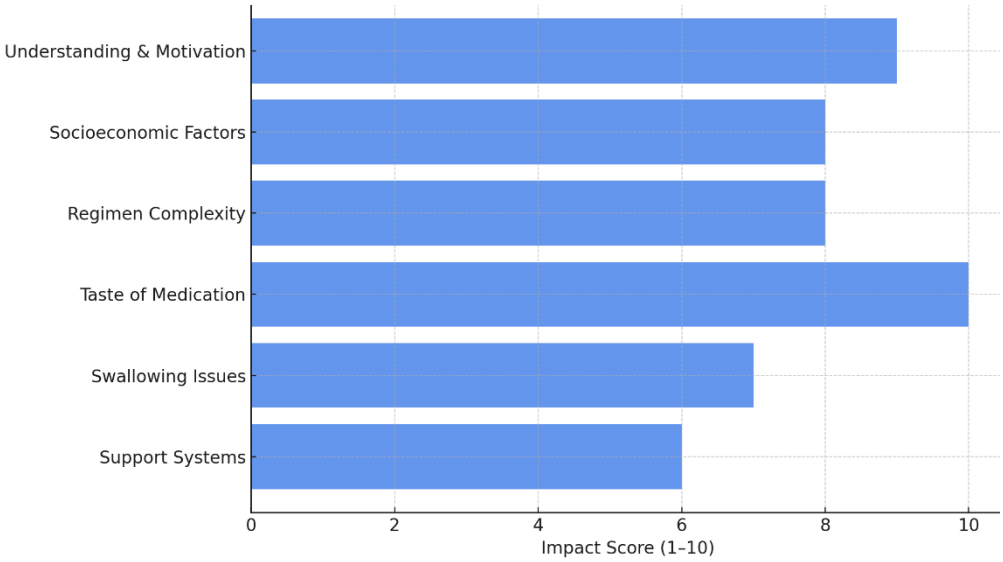

Fig. 1. Factors influencing patient compliance

THE ROLE OF TASTE IN COMPLIANCE

The unpleasant taste of oral medications is arguably one of the most overlooked but significant obstacles to medication adherence, particularly in young patients and the elderly. Refusals, vomiting, or dose skipping are caused by bitter or metallic tastes, which inevitably compromise therapy. For some patients the majority, especially those who are already nearing old age or illness it could endanger their lives (9-16).

Children inherently have greater sensitivity to bitter flavors. So the elderly people experience less salivation and changes in taste perception and failing to swallow decreasing the tolerance for poor-tasting medicines; accumulated, these factors cause adherence to be significantly lower in both. (9-11, 13, 14). Causes of pediatric non-compliance are shown in Fig. 2.

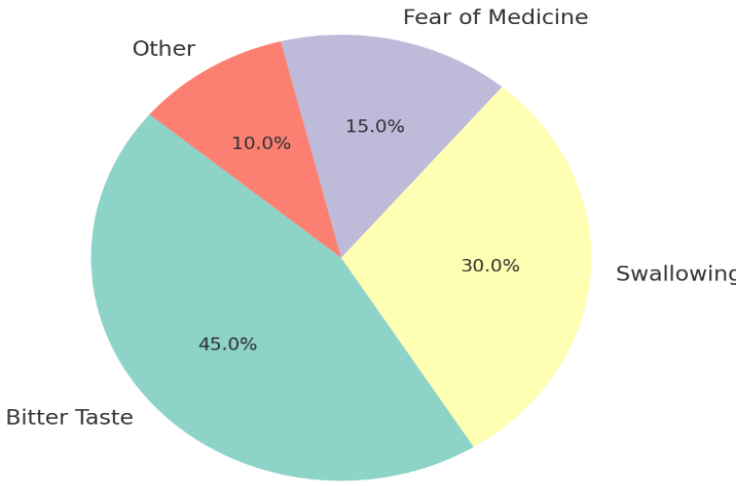

Fig. 2. Causes of pediatric non-compliance

CONVENTIONAL TASTE MASKING TECHNIQUES: STRENGTHS AND SHORTCOMINGS

To improve palatability, pharmaceutical companies have traditionally used a variety of taste-masking techniques. These include:

- **Sweeteners and Flavors:** Sugar, salt, or artificial flavors may help in taste masking of drugs to some extent, but this method may not be sufficient for certain drugs (9-11, 14, 15, 17).
- **Physical Barriers:** Coating tablets or use of capsules can block taste; however, this method may not have patient compliance in terms of swallowing of drug.
- **Chemical Modifications:** Complexation, ion exchange resins, microencapsulation, and other such methods are usually effective but expensive and these methods may alter the activity of the drug (11-15, 17). The limitations of conventional techniques are summarized in Table I.

Table I. Limitations of conventional taste masking techniques

Method	Advantages	Limitations
Sweeteners and Flavors	Easy to implement	Ineffective for strongly bitter APIs
Coating and Encapsulation	Masks taste physically	May not help those with swallowing difficulty
Mixing with Food or Drink	Convenient for caregivers	Alters drug absorption; API-dependent masking success
Inclusion Complexes	Reduces direct exposure of API	Limited solubility and scalability issues
Ion Exchange Resins	Stable, effective for certain drugs	May affect drug release and absorption
Microencapsulation	Offers better taste protection	Formulation-dependent; expensive for large-scale production

THE NEED FOR INNOVATIVE APPROACHES

Evidently, we need more innovative taste-masking technologies that work better and are also safer for the patient. Hence, the objective must be to change the taste of the drug to be more acceptable while maintaining its therapeutic efficacy and safety for a larger number of patients (11, 13, 14).

INTRODUCING NANOTECHNOLOGY IN PHARMACEUTICALS

Nanotechnology is the study of materials at the Nano scale between 1 and 100 nm) for the development of new structures and systems. In the pharmaceutical industry, Nanotechnology has drastically changed drug delivery by improving the absorption, effectiveness, and targeting of pharmaceuticals (18-22). The following are some of Nanotechnology's primary benefits:

- **Targeted Delivery:** Nanoparticles deliver drugs to specific cells and/or tissues, which enhances the efficacy and reduces side effects of the drugs (18, 20, 22-24).
- **Improved Solubility and Bioavailability:** Poorly absorbed drugs are generally in their natural form more effective their absorption can be increased by use of Nanocarriers (19, 22, 25).
- **Controlled Release:** By using Nanocarriers, the drug can be released in a slowly over a specific period of time; therefore, there would be less need for frequent dosing thereby enhancing patient compliance (22, 26, 27).

NANOTECHNOLOGY FOR TASTE MASKING: A NEW FRONTIER

However, despite their promise, Nanocarriers have problems with cytotoxicity, bioaccumulation, and long-term safety. A comprehensive toxicological investigation, including in vivo and chronic exposure studies, is required prior to clinical translation. Recent research suggests that Nanotechnology will become a pharmaceutical trend for adoption as taste masking technique. Through liposomes, Nano emulsions, and polymeric Nanoparticles, the active drug can be encapsulated in Nanocarriers thus reduce the contact of drug with taste buds with the intent of reducing perceptions of bitterness and making it more acceptable for patients to consume it (19, 25, 26).

In contrast to traditional taste-masking methodologies, Nanotechnology-based formulations yield much more reliable results, better drug protection, and greater satisfaction among patients, especially in pediatrics and geriatrics, where there is extreme taste sensitivity and swallowing problems (28). A comparison between traditional and nanotechnology-based taste masking techniques is presented in Fig. 3.

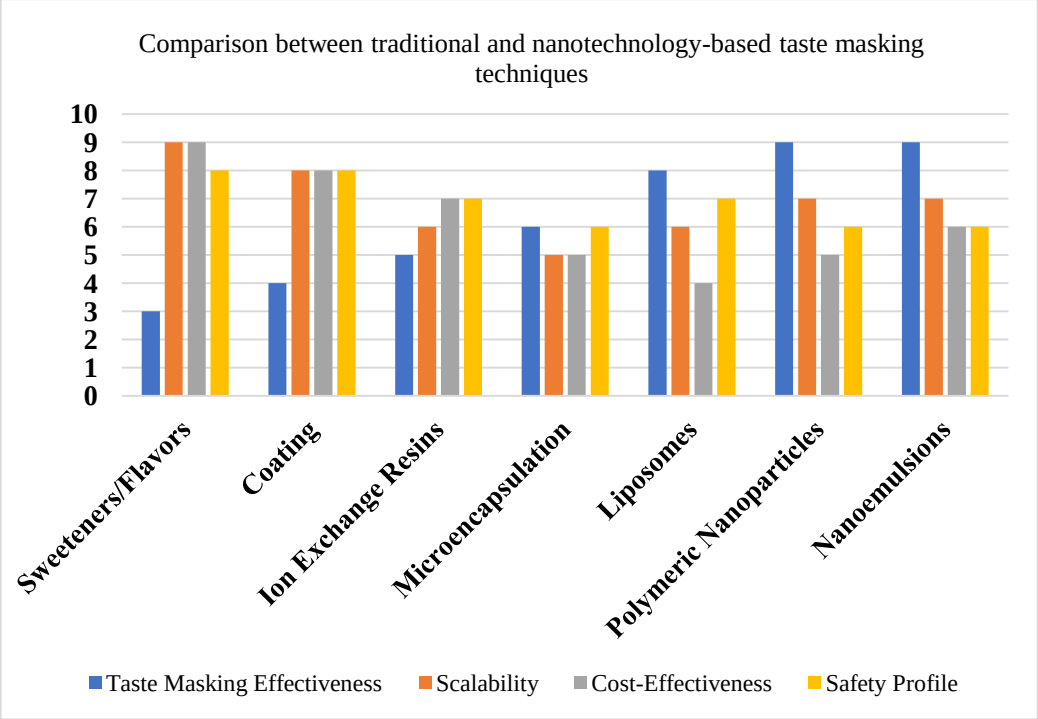

Fig. 1. Comparison between traditional and nanotechnology-based taste masking techniques

METHODOLOGY

DATA COLLECTION

The investigation adopted a narrative review approach to search and review relation to relevant peer-reviewed articles on the intervention of nanotechnology in taste masking and targeting probiotic delivery. A systematic literature search was done through major databases including the following PubMed, Scopus, Web of Science and Google Scholar.

Using a mixed combination of keywords and MeSH terms like, "nanotechnology, nanocarriers, taste-masking, patient compliance, cost-effective, probiotic delivery, intestinal colonization, and gastrointestinal stability," the search was conducted. Finding articles published in English from January 1, 2015, to October 1, 2025, ensured the search was relevant in terms of recent developments.

ARTICLE SELECTION

A total of 1,050 articles were initially identified from database searches. Following duplication removal n=158), 892 articles were subject to title and abstract screening by two independent reviewers for relevance assessment. The discrepancies were resolved by discussion or consultation with a third reviewer. Thus, a total of 156 articles were selected for full-text review with respect to the review's objectives.

INCLUSION CRITERIA AND EXCLUSION CRITERIA

Peer-reviewed articles published from 2015 to 2025 in English in indexed journals. Study designs included systematic review, clinical trial, meta-analysis, and cohort study. Studies based on nanotechnology or nanocarriers for taste-masking or targeted delivery of probiotics for intestinal colonization or gastrointestinal stability. Outcomes focused on patient compliance, cost-effectiveness, or probiotic efficacy.
After full text reviews, 78 articles met these inclusion criteria and were synthesized in the narrative analysis. The quality assessment of the studies included followed the PRISMA guidelines for systematic reviews and the Newcastle-Ottawa Scale for cohort studies to ensure methodological rigor.

Non-English and articles published before 2015 or after October 1, 2025. Studies not related to nanotechnology or nano-carriers e.g. conventional drug delivery systems). Studies not focusing on taste-masking or probiotic delivery or not having gastrointestinal outcomes. Non-peer-reviewed resources, such as editorials, commentaries, or conference abstracts.

RESULTS

Improving patient compliance through effective taste masking is crucial in the pharmaceutical industry, especially for children and the elderly. Noncompliance can lead to treatment failure and increased healthcare costs. Conventional methods like sweeteners and coatings have limitations, particularly with highly bitter drugs. Nanotechnology provides a more effective method of minimizing contact with taste buds while enhancing solubility and bioavailability by encapsulating drugs in Nano carriers. Among the techniques are liposomes for encapsulation, polymeric Nanoparticles for controlled release, and Nano emulsions for improved taste masking and absorption. Nanotechnology-based approaches are summarized in Table II.

Table II. Nanotechnology-based approaches in taste masking

Nanotechnology type	Mechanism	Advantages	Examples
Liposomes	Encapsulation in phospholipid bilayer	Biocompatible, shields taste, improves bioavailability	Prednisolone, antihistamines
Polymeric Nanoparticles	Form tight matrix around API	Controlled release, reduced bitterness, suitable for pediatric use	Steroids, antibiotics
Nano emulsions	Oil-water dispersion of drug	Enhanced taste masking, fast absorption	Antihistamines, antipyretics
Fast-Dissolving Oral Films	Nanocarrier-loaded films	Ideal for patients with swallowing difficulties	Midazolam, caffeine formulations
Hot-Melt Extrusion HME)	Thermoplastic process for taste-masked forms	Scalable, effective in high bitterness APIs	Caffeine citrate, zinc sulfate

DISCUSSION

Furthermore, their assessment and approval are made more difficult by the lack of standardized long-term toxicity models and regulatory guidelines. In order to guarantee patient safety and clinical viability, developing nanotechnology-based taste masking necessitates not only formulation innovation but also thorough toxicological evaluation, safety validation, and scalable, economical production

Pharmaceutical formulation has been transformed by nanotechnology, which has provided creative approaches to patient compliance and taste masking. Drugs are efficiently encapsulated by nanocarriers such as liposomes, nano emulsions, and polymeric nanoparticles, which reduce their interaction with taste buds while improving solubility, bioavailability, and controlled release. This is in contrast to traditional techniques like sweeteners, coatings, or ion-exchange resins, which frequently fail with highly bitter APIs. In pediatric and geriatric populations, where swallowing issues and taste sensitivity frequently restrict adherence, this strategy shows special potential (29-31).

Despite these benefits, the safety and toxicity of nanocarriers continue to be significant obstacles to clinical application. They can cause cytotoxicity, oxidative stress, immune activation, or bioaccumulation in critical organs due to their nanoscale size and surface reactivity. Inappropriate formulation of biocompatible materials, such as lipid-based carriers or polylactic acid PLGA), can cause allergic or inflammatory reactions (32-34).

Additionally, by generating reactive oxygen species ROS) that damage DNA, nanocarriers may cause genotoxicity and possibly mutagenic effects. Apoptosis or necrosis can also be brought on by cellular uptake processes, especially in delicate tissues like the liver, kidneys, or reproductive organs. For example, long-term biocompatibility and environmental persistence are issues with inorganic nanoparticles such as those containing heavy metals), which may exacerbate chronic inflammation or fibrosis after repeated exposure. Another crucial area is toxicity to reproduction and development; research indicates that nanoparticles can penetrate placental barriers or impact fertility by building up in gonads, resulting in hormonal imbalances or abnormalities in the developing embryo. Concerns about the extensive use of pharmaceuticals are heightened by environmental hazards, such as bioaccumulation in ecosystems.

Moreover, evaluation is made more difficult by the absence of standardized models for assessing nanotoxicity; advanced models such as organ-on-a-chip or long-term chronic exposure studies are required because current in vitro and in vivo tests frequently do not accurately predict human responses (31, 34, 35).

Furthermore, their assessment and approval are made more difficult by the lack of standardized long-term toxicity models and regulatory guidelines. In order to guarantee patient safety and clinical viability, developing nanotechnology-based taste masking necessitates not only formulation innovation but also thorough toxicological evaluation, safety validation, and scalable, economical production.

Techniques like surface modification e.g., PEGylation) to lower immunogenicity, the use of biodegradable materials, and thorough preclinical testing are crucial to reducing these risks. However, addressing the variation in nanoparticle behavior among patient populations—including those with comorbidities that could worsen toxicity—is necessary to translate these into clinical setting (29, 32, 36, 37).

CONCLUSION

To increase medication acceptability, Nanotechnology-based systems are being incorporated into pediatric syrups, fast-dissolving oral films, and dosage forms appropriate for the elderly. Traditional approaches have drawbacks, including inability to conceal bitter flavors, guarantee safety, and help with swallowing issues. On the other hand, Nanotechnology provides novel ways to encapsulate active pharmaceutical ingredients, protecting them from taste receptors and improving the effectiveness of drug delivery. Effective taste masking for oral medications is a challenge for the pharmaceutical industry in terms of increasing patient compliance. In addition to improving taste, technologies such as liposomes, Nano-emulsions, and polymeric Nanoparticles also increase bioavailability, permit sustained release, and boost treatment adherence. To create standardized taste evaluation instruments, evaluate long-term safety, and create regulatory frameworks for clinical use, more research is required. By conquering these obstacles, Nanotechnology-based. Establishing standardized taste assessment instruments, evaluating long-term safety, and creating regulatory frameworks for clinical use all require ongoing research. Overcoming these obstacles could make taste masking based on Nanotechnology a common pharmaceutical practice, enhancing therapeutic outcomes for patients of all ages.

FUTURE PERSPECTIVES

Future studies must also examine cost-effectiveness and the feasibility of large-scale manufacturing to ensure practical acceptance. While Nanotechnology holds great promise for taste masking, there are some key areas that require further research before it can be widely used: First, accurate measurement and quality control of novel formulations rely on standardized evaluation tools; Second, research must focus on developing scalable and cost-effective production techniques for widespread use; and Third, because there are currently insufficient guidelines, a thorough analysis of the long-term safety of Nano carriers in pharmaceutical applications is necessary, along with the development of precise regulatory frameworks. Lastly, increased clinical trials are necessary to assess the impact of these formulations on patient compliance and therapeutic outcomes across varying demographics and medical conditions.

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Authors' Contribution:

MN Conceived the idea & designed the structure of the review; ANC and analyzed recent literature ; JS, NF & SP Data compilation, referencing, and critical revision of the draf; STHelped in literature review, language editing.

Declaration of generative AI and AI-assisted technologies in the writing process:

During the preparation of this work the authors) used Chat GPT to enhance the readability of the article. After using this tool/service, the authors) reviewed and edited the content as needed and tooks) full responsibility for the content of the publication.

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