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Original Review Article

Moringa Oleifera Gum A Multifunctional Excipient Transforming Pharmaceutical Drug Delivery: A Review

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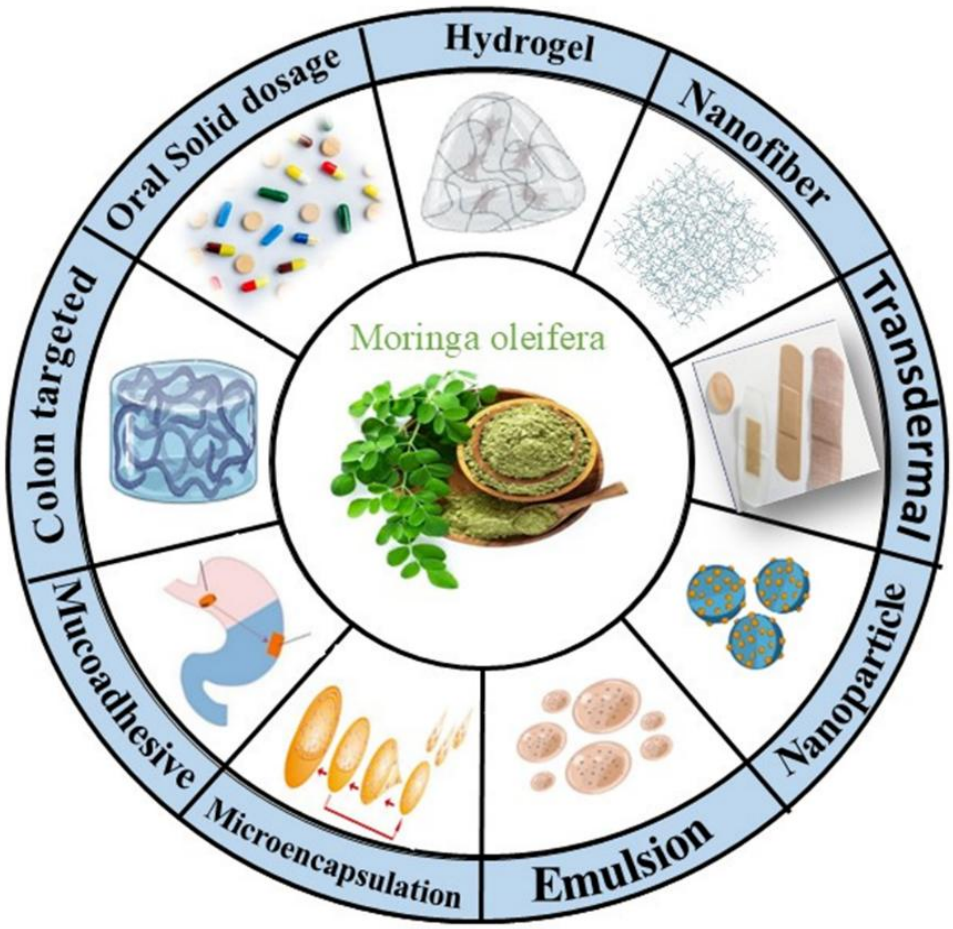
Abstracts: **Introduction**: *Moringa oleifera* (MO) gum has gained significant attention over the past decade as a natural, multifunctional excipient for drug delivery. This review highlights the versatile roles of moringa gum in pharmaceutical formulations, including as a binder, disintegrant, matrix former, suspending agent, and mucoadhesive polymer. Key physicochemical properties (e.g., high polysaccharide content, water-swelling, and film-forming ability) underlie these functions. Near about 12 studies were reviewed in which 5 were in vitro, 6 were in vivo, and 2 were clinical studies. Despite its promising properties, the pharmaceutical application of Moringa Oleifera gum is limited by batch-to-batch variability, limited clinical data, and need for further regulatory validation. ***Methods****:* A comprehensive review of recent studies was conducted focusing on moringa use as a multifunctional excipient for drug delivery. Special emphasis was given to oral drug delivery and colon targeted drug delivery systems (CTDDS) integrated with other bioactive compounds and its multifunctional potential. ***Results****:* Moringa gum-based excipients have been shown to improve tablet integrity and disintegration, sustain drug release in oral and colon-specific systems, and enhance bio adhesion for mucosal delivery. The gum is a biodegradable polysaccharide composed mainly of galactose, arabinose, and xylose, and its natural origin translates to excellent biocompatibility and low toxicity in formulations. ***Discussion***: Recent studies demonstrate that Moringa gum can match or outperform certain synthetic excipients in drug release control and tablet performance. Moreover, chemical modifications (e.g., carboxymethylation, thiolation, grafting) further expand its functionality, yielding improved mucoadhesive strength and controlled-release profiles. With its wide availability and sustainable production, Moringa gum offers an eco-friendly alternative to synthetic polymers.

Conclusion: This review discusses the current state of research (2015–2025) on Moringa gum in drug delivery, covering its extraction, composition, pharmaceutical applications across dosage forms, and recent advances in modified Moringa gum derivatives. Ongoing research and development are expected to facilitate the incorporation of this promising natural excipient into more effective and patient-friendly drug delivery systems.

Keywords: Moringa oleifera, natural excipient, sustained release, tablet binder, pharmaceutical polymer.

Graphical Abstract



Potential Of *Moringa Oleifera* In Pharmaceutical Drug Delivery

INTRODUCTION

In recent years there has been a growing interest in replacing synthetic excipients with natural alternatives in drug formulations due to concerns about safety, environmental impact, and cost[1][2][3]. *Moringa oleifera*, commonly known as the drumstick (sahjan) tree, produces a gum exudate that has emerged as a promising

multifunctional excipient in this context. Moringa gum is attracting attention for its binding, disintegrating, film-forming, and stabilizing properties in pharmaceutical formulations[4]. As a natural polysaccharide, it offers advantages like biocompatibility and biodegradability, and it has been used traditionally for its medicinal benefits[5]. These qualities make Moringa gum a compelling substitute for synthetic polymers in drug delivery systems, aligning with the trend toward more sustainable and patient-friendly formulation practices[2].

The versatility of Moringa gum underlies its potential to transform drug delivery. It can function as a tablet binder to impart mechanical strength, as a disintegrant to facilitate rapid drug release, or as a matrix former to sustain release over time[6]. Additionally, it exhibits natural mucoadhesive and emulsifying abilities, expanding its utility to mucosal drug delivery and liquid formulations[7]. Early studies and contemporary research collectively indicate that excipients derived from *Moringa oleifera* can improve formulation stability, bioavailability, and safety compared to some conventional additives[4]. This review provides a comprehensive overview of Moringa gum's properties, applications in various drug delivery systems, and recent innovations (primarily from the past ten years) that enhance its functionality. Key findings from recent studies are summarized to illustrate how Moringa gum is being leveraged to create more effective and sustainable pharmaceutical products[6]. MO has a highly positive approval perspective as a functional food, dietary supplement, and natural medicine, driven by its exceptional nutritional profile and diverse bioactive compounds, but not yet approved for pharmaceutical use, further studies are proposed to explore the mechanistic approach of the plant to identify and isolate active or synergistic compounds behind its therapeutic potential and used as an excipient[8]. The challenges and future prospects of integrating Moringa gum into mainstream pharmaceutical use are also discussed.

METHODOLOGY

Search Strategy

A comprehensive literature search was conducted to identify relevant studies focusing on the utilization of *moringa oleifera* in novel drug delivery system (NDDS), with particular emphasis on the floating and controlled release drug delivery system (CRDDS) etc. Major electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar, were searched. The following keywords and their combinations were used: *"Moringa oleifera," "natural excipient," "sustained release, tablet binder," "pharmaceutical polymer." And "nanoparticles,"* Boolean operators (AND, OR) were applied to refine the search.

Inclusion Criteria

Studies were included if they met the following conditions:

1. Focuses on the latest work done on *moringa oleifera in the field of pharmacy.*
2. Focused on novel drug delivery systems. (e.g., nanoparticle, hydrogels and nanofiber).
3. Focused on CRDDS.
4. Addressed colon targeted or mucoadhesive drug delivery approaches.
5. Published in peer-reviewed journals in the English language.

Exclusion Criteria

Studies were excluded if they:

1. Were unrelated to novel-based drug delivery.
2. Did not involve any disease diagnosis or therapy.
3. Were non-English publications.
4. Studies without full-text availability.
5. Case reports, letters, editorials, and commentaries

Source And Composition of Moringa Gum

Moringa gum contains phytochemicals such as flavonoids, phenolic acids, vitamins, and tannins, which impart diverse bioactive properties, including anti-diabetic, anti-inflammatory, antimicrobial, and antioxidant activities [9]. Moringa gum is a natural polysaccharide obtained as an exudate from the bark of the *Moringa oleifera* tree. The gum can be collected by making incisions on the trunk or from natural exudation and is typically dried and powdered for use[4]. Chemically, it is a complex heteropolysaccharide rich in sugars such as galactose, arabinose, and xylose, with smaller amounts of rhamnose and uronic acids[10]. For example, one analysis reported Moringa gum to contain approximately 41–42% galactose, 25–27% arabinose, 25–26% xylose, and a few percent rhamnose and uronic acids[11]. This sugar composition is somewhat similar to other plant exudate gums (like gum arabic), which explains many of its functional

properties. The molecular weight of Moringa gum is high (on the order of 106 Da), and it forms viscous colloidal dispersions when mixed with water[4]. The gum is only sparingly soluble in cold water, but it swells considerably upon hydration, yielding a thick mucilage. This swelling behaviour is critical for its roles as a binder, disintegrant, and controlled-release matrix.

Moringa gum typically appears as a light to reddish-brown, amorphous powder that is odorless and tasteless, making it suitable for oral formulations shown in Fig. 1[6]. It contains various functional groups (hydroxyl and carboxylate group on the polysaccharide backbone) that facilitate hydrogen bonding and gel formation in aqueous environments. These same functional groups also make the gum amenable to chemical derivatization[12]. Physicochemical characterizations have shown that Moringa gum exhibits thermal stability and a high glass transition temperature, indicating it can withstand typical processing conditions like drying or compression[7]. The gum's rheological properties are comparable to other pharmaceutical gums; it acts as a viscosity enhancer in solution and can form films upon drying. Importantly, Moringa gum is biocompatible and non-toxic, as evidenced by its long history of use in traditional medicine and food – attributes which carry over to its pharmaceutical use[4]. Overall, the composition and innate properties of Moringa gum provide a foundation for its multifunctional performance as an excipient.

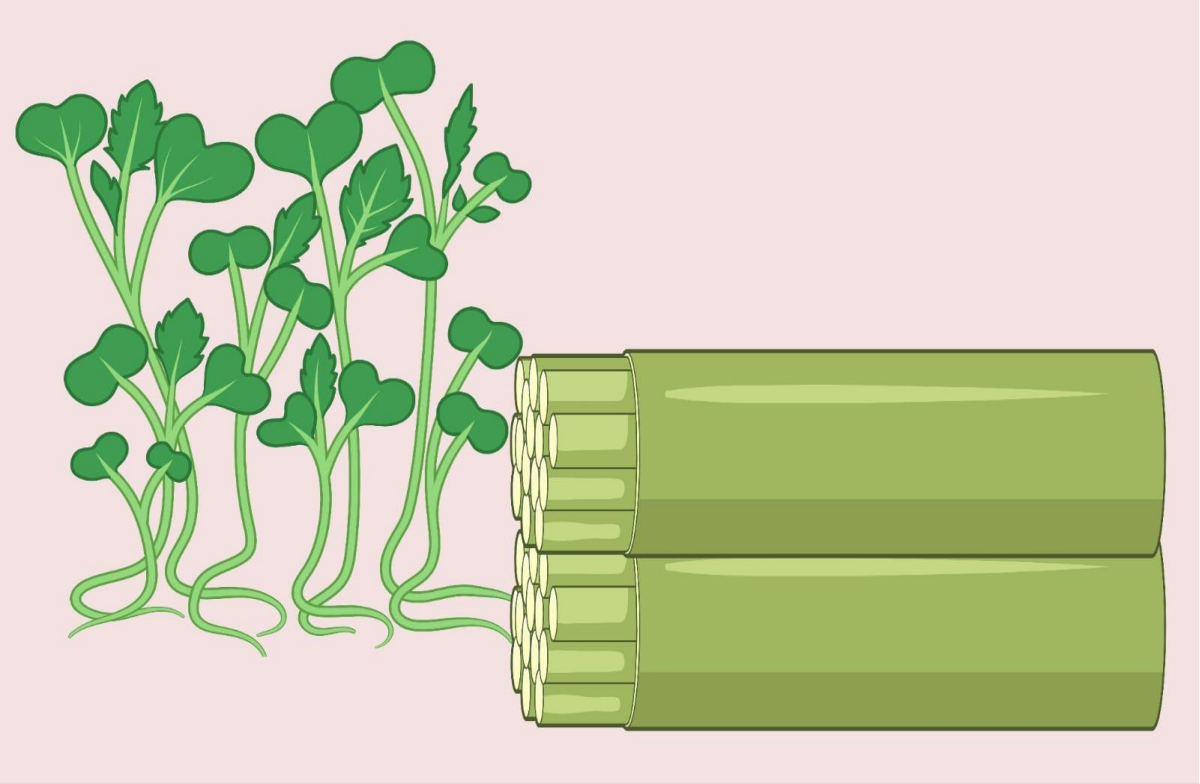


Fig. 1. ***Moringa oleifera***

Pharmaceutical Applications of Moringa Gum Shown In Fig. 2.

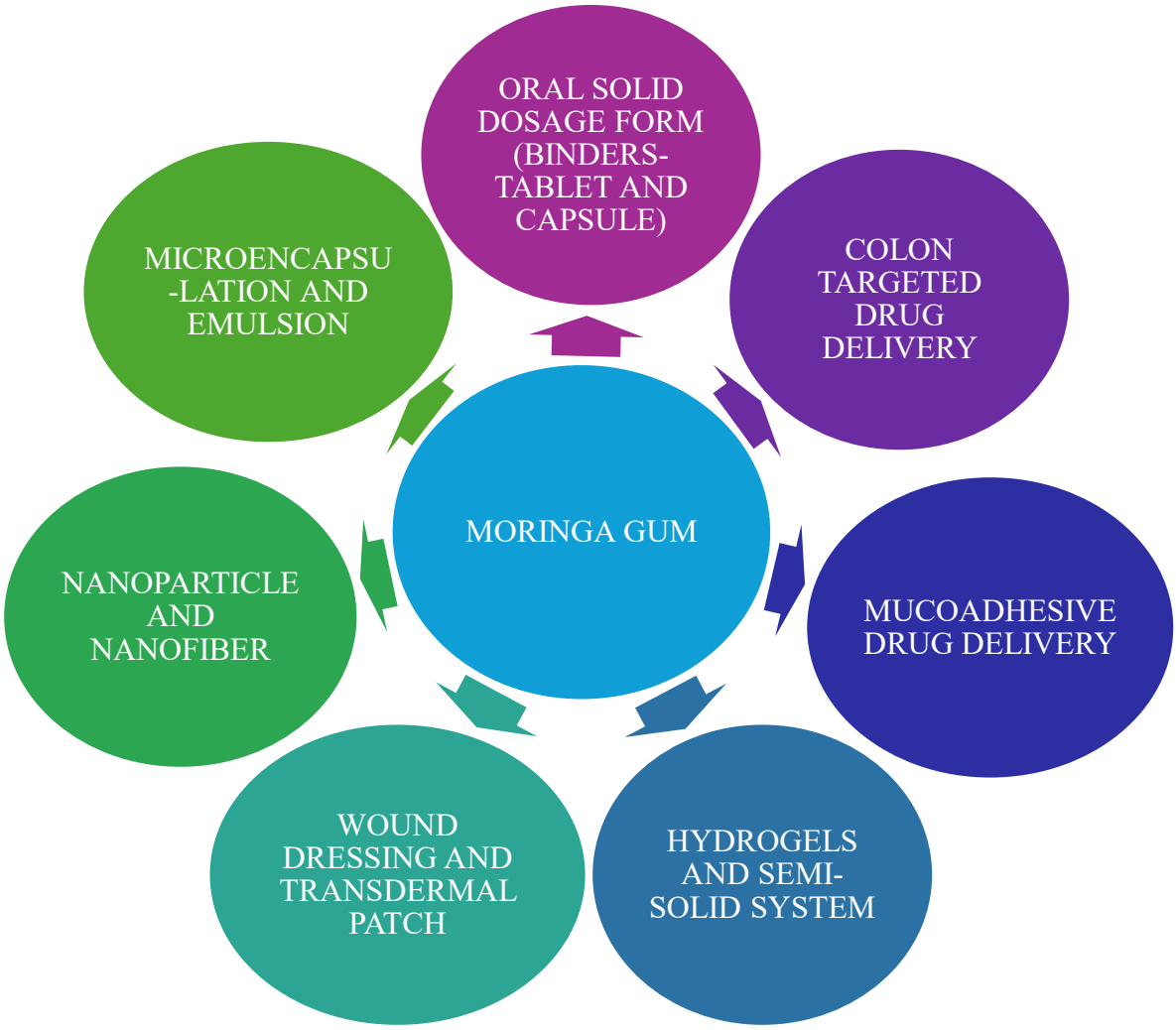


Fig. 2. Illustration Of Use Of *Moringa Oleifera* In Pharmaceutical Formulation

Oral Solid Dosage Forms - Tablets And Capsules

Binder Behaviour

One of the primary uses of Moringa gum in pharmaceutics is in oral solid dosage forms such as tablets. It has been investigated both as a binder (to impart tablet hardness and cohesion) and as a disintegrant (to facilitate tablet break-up in fluids). Studies have shown that Moringa gum can effectively bind powder particles into tablets with satisfactory hardness and low friability, comparable to standard binders like starch or polyvinylpyrrolidone [10]. For instance, tablets of paracetamol prepared using Moringa gum as a binder (at 8–12% w/w) demonstrated increasing hardness and decreasing friability with higher gum concentration, compared with tablets using gelatin as a binder. Notably, increasing the binder level of Moringa gum in those formulation slowed the tablet's drug dissolution rate, suggesting that at higher concentrations it can act as a release retardant [13]. This implies a dual functionality a moderate amount of gum provides binding without impeding release, whereas a higher amount can be leveraged for sustained-release tablet matrices[4].

Disintegrant Efficiency

As a disintegrant, Moringa gum in lower concentrations (around 2–5% w/w) has shown promising results in speeding up tablet disintegration. Its ability to swell and quick water uptake contributes to rapid break-up of tablets in the gastrointestinal fluid[14]. In a comparative

study, metoprolol tablets formulated with Moringa gum (as a disintegrant) disintegrated in approximately 90 seconds, which was faster or comparable to tablets formulated with synthetic super-disintegrants like croscarmellose sodium or crospovidone. The fast disintegration translated into quick drug release, with one formulation releasing ~97% of the drug within 2 minutes when Moringa gum was combined with a small amount of sodium starch glycolate. Such performance underscores the potential of Moringa gum as a natural super disintegrant [15]. Mechanistically, the gum particles rapidly hydrate and expand, causing the tablet to burst apart and liberate the active drug. This property is highly desirable for fast-dissolving and oral dispersible tablet formulations[3][16].

Matrix-Forming Role

Beyond immediate-release uses, moringa gum can serve as a matrix-forming agent in sustained-release tablets. Its swelling and gelling behaviour can prolong the release of drugs by forming a viscous diffusion barrier. Researchers have formulated gastro-retentive floating tablets using Moringa gum as a key polymer, aiming to retain the dosage form in the stomach and slowly release the drug as shown in Fig.3[17]. In one such study, esomeprazole floating tablets containing Moringa gum exhibited a regulated, near-linear drug release profile over 12 hours, delivering about 96% of the drug in that period. This release was more uniform compared to similar formulations made with some other natural polymers[18]. For example, tablets with Moringa gum achieved a final release of 96%, whereas those with neem (Azadirachta) gum released ~89% and xanthan gum ~93% in the same time frame [19]. The comparison indicates that Moringa gum's matrix might maintain integrity and gel structure better, preventing premature drug dumping (it matched the performance of sodium alginate, another common sustained-release polymer, which also released ~96% by 12 hours). The floating capability of those tablets (achieved by incorporating gas-generating agents) was supported by Moringa gum's gel, which kept them buoyant for the full duration, thus enhancing gastric retention[18]. Fig. 3 illustrates the drug release profiles of esomeprazole tablets prepared with different natural polymers, highlighting Moringa gum's effective CRDDS performance[17]

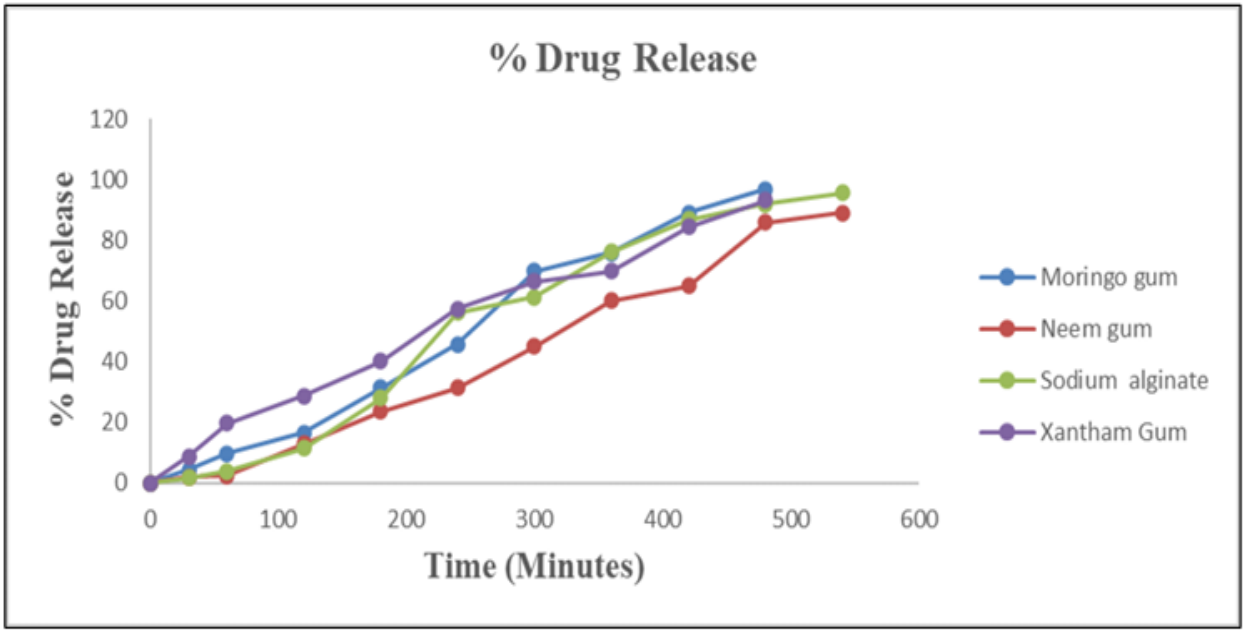


Figure 3*: In vitro drug release profiles of esomeprazole floating tablets formulated with different natural polymers (Moringa gum, sodium alginate, xanthan gum, and neem gum). Moringa gum achieved a nearly complete and uniform drug release (~96% in 12 hours), comparable to alginate and superior to neem and xanthan gum in sustaining drug release (Data adapted from Ghadge et al., 2024).* Reproduced with permission of Ghadge et al.

Comparative Release Performance

In capsule and tablet formulations, Moringa gum can similarly be used as a binder or as a granulating agent to prepare sustained-release granules. Its film-forming ability allows it to coat drug particles or granules, modulating drug release[20]. Additionally, Moringa gum has been co-processed with other excipients to create multifunctional composite excipients for tablets. Such co-processing can improve powder flow and compressibility while retaining the gum's disintegration and binding functions[4]. Overall, in oral solid dosage forms, Moringa gum offers flexibility: at low usage levels it can speed up release (for immediate-release needs), and at higher levels or in combination with other matrix formers, it can slow down release (for sustained-release profiles). This tunable behaviour is a major advantage of this natural excipient[19].

Colon-Targeted Drug Delivery System (CTDDS)

Natural polysaccharides like Moringa gum are particularly attractive for colon-targeted drug delivery because they are generally resistant to digestion in the upper gastrointestinal tract but can be degraded by the colonic microflora. Moringa gum, being composed of complex carbohydrates, passes through the stomach and small intestine largely intact[10]. In the colon, however, resident anaerobic bacteria produce glycosidase enzymes (α-amylase and α-glucosidase) that can cleave polysaccharides such as Moringa gum, leading to breakdown of the gum matrix and triggered drug release. Formulators have exploited this property by using Moringa gum as a protective coating or binder in colon-targeted systems[21].

A representative study involved compression-coated tablets of the anticancer drug capecitabine, where an outer coat composed of Moringa gum mixed with HPMC was applied to a drug core tablet[10]. The goal was for the coat to prevent drug release in the stomach/small intestine and then be enzymatically degraded in the colon to release the drug where it is needed for local action (colon tumors). The results were very promising: the Moringa gum-based coat was able to restrict drug release in simulated upper GI conditions to less than 10% in 5 hours (which would correspond to the transit through stomach and small intestine)[21]. Once the system was exposed to colonic conditions (simulated by adding rat cecal contents rich in bacteria), the coat underwent degradation and a rapid, complete drug release was observed in the colon environment[10]. This demonstrates that Moringa gum can function as a microbially-triggered colon release carrier. The enzymatic action on the gum effectively timed the release to occur primarily in the colon.

An additional advantage noted was that Moringa gum is naturally pH-insensitive (unlike some enteric polymers that only dissolve at high pH); it relies on microbial presence. This ensures that even if the pH in parts of the colon is variable, the mechanism (bacterial degradation) remains reliable. The colon-targeted tablets in the study maintain integrity through acidic and neutral pH, and only broke down when exposed to the colonic enzymes[10]. This approach could be valuable not only for delivering anticancer drugs to colonic tumors but also for treating local inflammatory conditions like ulcerative colitis, where a drug (e.g., 5-aminosalicylic acid or corticosteroids) needs to be released in the colon. Moringa gum's film-forming and matrix-forming capabilities, combined with its biodegradability by colonic flora, make it a strong candidate for these applications[22].

Mucoadhesive Delivery Systems

Moringa gum also shows potential in mucoadhesive drug delivery, where prolonged adhesion to mucosal surfaces (such as the buccal cavity, nasal, or gastric mucosa) can be used to sustain drug absorption at a localized site[7]. Many plant gums are inherently mucoadhesive due to their molecular structure and ability to form gels that adhere to the mucus layer. Moringa gum is no exception – it swells into a sticky, viscous mass that can cling to mucosal tissues, thereby prolonging the residence time of a dosage form[17]. This mucoadhesive property has been explored especially for buccal tablets or films, which adhere to the inner cheek or gum to permit direct absorption of drugs through the oral mucosa.

Native Moringa gum provides moderate mucoadhesion, but researchers have enhanced this property via thiolation. Thiolated polymers (thiomers) form covalent disulfide bonds with cysteine-rich subdomains of mucus, leading to much stronger and longer-lasting attachment. In one study, Moringa gum was chemically modified by attaching thiol groups to it, yielding a thiolated Moringa gum with significantly improved mucoadhesive strength[12]. This thiolated gum (often called a bioadhesive polymer) was tested for adhesion time and force: it showed a marked increase in adhesion to porcine gastric mucosa compared to unmodified Moringa gum. The improvement is attributed to the formation of disulfide bonds between the thiol groups on the

modified gum and the glycoprotein mucin in mucus[11]. Formulations developed with thiolated Moringa gum – for example, buccal tablets – demonstrated not only stronger adhesion but also a slower drug release (since the gum swells and remains in place, releasing drug gradually at the site of absorption).

Another approach has been grafting co-polymerization of Moringa gum with synthetic polymers to improve mucoadhesion and film properties. A notable example is grafting Moringa gum with poly N-vinyl-2-pyrrolidone (PVP) to create a composite that was investigated as a Bucco adhesive film base[23]. The grafted Moringa-PVP polymer combined the flexibility and film-forming smoothness of PVP with the natural adhesiveness of the gum. Buccal films made from this graft copolymer were found to adhere well to buccal mucosa and could potentially deliver drugs like anti-anginal or analgesics through the cheek lining over extended periods[18]. These studies suggest that Moringa gum, especially in modified forms, is a viable mucoadhesive excipient that could be applied to buccal, sublingual, periodontal, nasal, or even vaginal drug delivery systems where localized, prolonged drug presence is desired.

Importantly, using Moringa gum in mucoadhesive systems also taps into its other beneficial properties – for instance, its antioxidant and antimicrobial activity noted in crude form might confer additional therapeutic or preservative effects in a formulation[24]. While these bioactivities are ancillary, they complement mucoadhesive drug delivery by potentially improving the stability of the formulation or the health of the mucosal tissue during therapy.

Novel Drug Delivery Systems And Formulations

The versatility of Moringa gum extends to several novel and advanced drug delivery systems. Researchers have been creative in deriving new materials from Moringa gum or incorporating it into modern formulation types:

- **Hydrogels And Semi-Solid Systems:** Recent studies reported that physical and chemical modifications of the Moringa gum polysaccharide aided in development of hydrogels with biomedical applications such as wound dressings. Because Moringa gum can crosslink (either physically or chemically) to form 3-dimensional networks, it has been used in hydrogel formulations. Hydrogels made from Moringa gum are water-swollen networks that can encapsulate drugs and release them slowly. For example, Singh and Kumar (2021) prepared hydrogels by radiation-induced crosslinking of Moringa gum. In one case, acrylamide monomers were graft-polymerized onto Moringa gum and crosslinked to create a hydrogel matrix[25]. These hydrogels showed enormous swelling (on the order of 1000%+ of their dry weight in water) and were able to load and release drugs in a controlled manner. The drug release kinetics from such Moringa-based hydrogels often follow a diffusion-controlled mechanism (e.g., Peppas–Sahlin kinetics), indicating a combination of diffusion through the swollen matrix and relaxation of the polymer network controlling the release[26]. Such hydrogels have potential applications in oral controlled release, as gastric-retentive gels, or in topical wound care.
- **Wound Dressing And Transdermal Patches:** Wound healing is a remarkable and intricate biological process that the body initiates in response to injury, aiming to restore tissue integrity and function. It progresses through four overlapping and interdependent phases: hemostasis, inflammation, proliferation, and maturation[27]. A specific application of Moringa gum hydrogels is in wound dressings. Singh and Sharma (2021) designed a composite hydrogel dressing by blending Moringa gum with Sterculia gum and polyacrylamide, aiming for a material that can keep a wound moist and gradually release antiseptic or therapeutic agents[25].
  The Moringa-containing hydrogel was evaluated for use as a wound dressing, and it was found to have good fluid absorption (to absorb exudate), acceptable gel strength, and the ability to release loaded drugs over several hours[28]. Additionally, the inherent antimicrobial and antioxidant properties of Moringa gum could be advantageous in wound healing, helping to reduce infection and oxidative stress at the wound site. Although this is a relatively new area of exploration, it showcases the gum's utility beyond oral dosage forms, into transdermal and tissue engineering realms[24].
- **Nanoparticles And Nanofibers:** Moringa gum has been processed into bio nanofibers and nanoparticles for drug delivery applications. Mehetre et al. (2015) reported

the isolation of nanofibers from Moringa gum by acid hydrolysis and sonication. These Moringa gum nanofibers, with diameters on the order of ~100×10-9 m, present a high surface area platform for drug loading[29]. Such nanofibers can be incorporated into films, scaffolds, or microparticles to improve drug dispersion and modulate release rates. Likewise, chemical modifications like carboxymethylation of Moringa gum have yielded derivatives that self-assemble into nanostructures or can be crosslinked into nanoparticles (Ahuja, 2017). Carboxymethyl Moringa gum has enhanced solubility in water and can form polyelectrolyte complexes; it was evaluated as a nanometric drug carrier and found to efficiently encapsulate certain drugs[30]. The development of nanoscale excipients from Moringa gum is particularly interesting for delivering poorly water-soluble drugs, proteins, or genes, where traditional excipients often fall short in required functionality[31].

- **Microencapsulation And Emulsions:** The emulsifying property of Moringa gum has found use in microencapsulation techniques. In the food technology field, Moringa gum has been used as a natural encapsulating agent to spray-dry sensitive liquids[30]. In pharmaceuticals, this translates to the ability to stabilize emulsions or suspension formulations. Moringa gum can act as a surface-active stabilizer for oil-in-water emulsions, similar to gum acacia, thereby being useful in the preparation of emulsion-based dosage forms or in encapsulating lipophilic drugs into a dry powder form via spray drying. While detailed pharmaceutical studies on Moringa gum in emulsions are still limited, its successful application in other industries suggests a strong potential. It is reasonable to expect that Moringa gum could be used to formulate nutrient emulsions, flavour oils in soft gelatin capsules, or as a suspending agent in oral suspensions to keep insoluble drug particles uniformly dispersed[3][6]. In fact, traditional practices have reportedly used Moringa gum as a stabilizer in herbal mixtures, implying its capability to maintain homogeneity in liquids. Although microencapsulation and emulsion systems show promise for drug delivery, limited pharmaceutical studies warrant further investigation to establish mechanistic insights, regulatory acceptance, and clinical translation.

A summary of various pharmaceutical applications of Moringa gum, along with its role and key findings from recent studies, is presented in **Table 1**. This illustrates the breadth of formulation types where Moringa gum has been successfully utilized or evaluated.

Table 1: Applications of Moringa Gum in Pharmaceutical Formulations (2015–2025)

S. No.	Application / Formulation	Role of Moringa Gum	Key Findings	Reference
1	Immediate-release tablets (oral)	Binder, Disintegrant	Low concentrations (2–5% w/w) of Moringa gum produced fast tablet disintegration and drug release. Tablets with ~4% gum disintegrated in ~90 s, showing comparable or superior performance to crospovidone.	Hamman et al., 2025 [3]
2	Sustained-release tablets (oral)	Matrix polymer (gel-forming)	Higher gum levels formed a gel matrix sustaining drug release. Gastroretentive tablets showed ~96% drug release over 12 h, comparable to alginate and xanthan gum matrices.	Ghadge et al., 2024 [17]

3	Liquid formulations (suspensions, emulsions)	Suspending and emulsifying agent	Moringa gum increased viscosity, prevented phase separation, and improved stability of suspensions and emulsions, similar to acacia gum.	Kumari et al., 2022 [4]
4	Hydrogels and wound dressings	Hydrogel matrix (cross-linked network)	Cross-linked Moringa gum hydrogels absorbed wound exudates and provided sustained drug release, creating a moist healing environment.	Singh & Sharma, 2021 [25]
5	Colon-targeted tablets (oral)	Compression-coating polymer	Compression-coated tablets released <10% drug in stomach and small intestine and enabled complete release in the colon due to microbial degradation.	Kotadiya et al., 2019 [10]
6	Buccal / mucoadhesive systems (oral)	Mucoadhesive polymer	Thiolated Moringa gum showed enhanced mucoadhesion, prolonging drug residence time and improving localized drug delivery.	Grewal et al., 2019 [12]
7	Nanofiber / nanoparticle systems	Nanoscale drug carrier	Moringa gum nanofibers and nanoparticles (~100 nm) provided high surface area and CRDDS.	Mehetre et al., 2015 [29]
8	Moringa oleifera gum (emulsifying property)	Emulsifying agent	Moringa oleifera gum showed superior emulsifying properties compared to gum acacia and can be used in pharmaceutical and non-pharmaceutical formulations.	Dibya Sundar Panda [32]

Advantages And Safety Profile

Moringa gum offers several practical advantages as a pharmaceutical excipient. It is naturally abundant in many tropical and subtropical regions (India, Africa, etc.), making it a relatively low-cost and accessible resource[19]. Extraction of the gum is straightforward and does not require harsh chemicals – typically involving collection of exudates, drying, and powdering – which aligns with green chemistry principles[33]. The gum's biodegradability means that formulations using it will break down in the body or in the environment, reducing long-term pollution concerns associated with synthetic polymers.

In terms of safety, *Moringa oleifera* has a long history of use in food and traditional medicine, suggesting a favourable safety profile. Studies on Moringa gum specifically have not reported significant toxicity. On the contrary, the use of Moringa-derived excipients may reduce the risk of adverse effects relative to some synthetic excipients[34]. For example, certain synthetic polymers can cause GI irritation or have toxic residual monomers; natural gum excipients tend to be non-irritant**,** non-toxic**,** and hypoallergenic. Moringa gum is essentially a dietary fiber, and any residual amounts that do not degrade in the body are likely excreted without issues. Recent formulation studies did not note any incompatibilities between Moringa gum and active

pharmaceutical ingredients either[33], indicating it is chemically fairly inert in formulation (aside from its functional interactions like gelation). That said, like any natural product, batch-to-batch variability in composition (due to origin, climate, harvest conditions) can be a consideration, and appropriate quality control (e.g., tests for viscosity, purity, microbial load) is necessary when preparing it for pharmaceutical use[35].

From a regulatory perspective, more data on Moringa gum's toxicity (such as acute and chronic toxicity studies, mutagenicity, etc.) would strengthen its case for inclusion in official pharmacopoeias. So far, the indications of safety are positive, and its use in nutraceuticals and foods (like as a thickener or stabilizer) bolsters the argument that it can be considered Generally Recognized As Safe (GRAS) or atleast biocompatible at the doses used in medicines[36]. Formulators have also noted that Moringa gum is compatible with a range of other excipients (fillers, lubricants, etc.) and drugs, showing no signs of undesired chemical interactions (as cited in Kumari et al., 2022)[4]. This compatibility simplifies its adoption since it can be integrated into existing formulations without significant issues.

Chemical Characterization Techniques Used In Moringa Gum Studies

The crude aqueous extract of MO can be investigated by GCMS, FTIR, NMR, XRD, DSC, TGA, and SEM. GCMS studies are required to know the phytocompounds like hydrolysable, tannins, Saponins, Flavonoids, Glucosinolates and Phenolic acids etc [37][29].

Chemical Modifications And Derivatives Of Moringa Gum

To further enhance the functionality of Moringa gum, researchers have developed various chemical derivatives in the last decade. These modifications aim to overcome certain limitations of the native gum (such as excessive swelling, solubility issues, or insufficient mechanical strength) and to impart new properties (like stronger mucoadhesion or stimuli-responsive behaviour). Some notable modifications include[38]:

- **Carboxymethylation:** Introducing carboxymethyl groups into Moringa gum increases its water solubility and anionic character. Ahuja (2017) evaluated carboxymethyl Moringa gum and found it could form nanoscale carriers and improved the release profile of a model hydrophobic drug[33]. The carboxymethyl derivative tends to dissolve rather than just swell, which can be useful in formulating solutions or mucoadhesive gels that require a smoother texture. It also can form ionic crosslinks with multivalent cations if needed (similar to alginate), allowing for ionically crosslinked beads.
- **Thiolation:** As discussed earlier, thiolated Moringa gumgreatly amplifies mucoadhesive properties. Thiomers of Moringa gum not only stick better to mucosa but also can exhibit some enzymatic inhibition (common with thiomers) which may prolong the residence of co-administered drugs by limiting mucin turnover[12]. Thiolated gum could be beneficial in ocular or nasal formulations as well, where rapid clearance is an issue.
- **Propylation (Alkylation):** Performed a propyl etherification of Moringa gum, yielding a propylated Moringa gum with a higher hydrophobic content. This modified gum showed decreased water uptake and viscosity, making it less prone to immediate swelling. When tested in drug delivery, propylated Moringa gum was able to sustain the release of diclofenac sodium far more effectively than native gum[18]. Additionally, propylated gum was fashioned into ionically crosslinked beads (using calcium ions) that minimized the initial burst release of the drug, achieving about 84% release in 24 hours in simulated gastric conditions. This highlights how hydrophobic modification can convert a fast-eroding natural gum into a more robust, slow-matrix former suitable for once-daily dosing forms.
- **Graft Copolymerization:** There have been multiple efforts to graft synthetic polymer chains onto Moringa gum to create graft copolymers. Apart from the PVP graft mentioned, Singh & Kumar (2018) grafted polyacrylamide and other monomers onto Moringa gum backbone[28]. The resulting graft copolymers can be crosslinked into hydrogels with improved mechanical strength and tailored swelling. Another example is grafting Moringa gum with poly (N-vinyl imidazole) to introduce pH-responsive cationic sites – such a graft polymer was studied for biomedical applications requiring pH sensitivity[4]. Graft copolymers often show synergistic properties: the natural gum provides biodegradability and

biocompatibility, while the synthetic segment imparts strength or responsiveness.

- **Composite Formation:** Rather than covalent modifications, blending Moringa gum with other polymers (natural or synthetic) can also be considered a "derivative" approach. For instance, forming interpenetrating networks of Moringa gum with polyacrylic acid or chitosan could yield pH-sensitive hydrogels. Blending with other natural gums (guar, xanthan) has been suggested to modulate gel strength and drug release characteristics[27]. These composite systems benefit from the complementary properties of each component.

Provide a comprehensive review of various modified forms of Moringa gum and their potential in pharmaceutical and biomedical fields. The general consensus is that chemical modifications expand the applicability of Moringa gum: for example, making it more mucoadhesive, more hydrophobic, or stimuli-responsive as needed[4]. Importantly, these modifications are usually designed to be relatively simple and to use reagents that are not excessively toxic (so that the final product remains biocompatible). After modification, thorough characterization (UV, FTIR, DSC, rheology, molecular docking etc.) is performed to confirm the structural changes and to ensure the material's safety for drug delivery purposes.

One must note that while modified gums show improved performance in laboratory tests, their regulatory approval may require additional safety evaluation, since the chemical changes could potentially introduce new impurities or alter metabolic pathways. Nonetheless, modified Moringa gum derivatives represent a promising route to tailor natural excipient properties for specific formulation needs, bridging the gap between natural polymers and the precision of synthetic polymers.

CONCLUSION

We have seen that Moringa gum-based excipients enable innovative solutions: fast-melt tablets that dissolve rapidly in the mouth, 12-hour sustained release tablets that improve patient compliance, colon-specific delivery systems that release drugs at the desired site of action, and bioadhesive formulations that can localize therapy to mucosal tissues. Moreover, the ability to chemically modify Moringa gum expands its applicability even further – whether it is by thiolation to enhance mucoadhesion or grafting to create responsive hydrogels, these advancements are transforming a traditional natural product into a cutting-edge biomaterial for drug delivery. Comprehensive toxicological studies and regulatory documentation will be needed to facilitate wider acceptance of Moringa gum in commercial drug products. Additionally, most current studies are at the laboratory or pilot scale; therefore, scale-up feasibility, long-term stability of gum-based formulations, and compatibility with high-speed manufacturing processes are areas ripe for further research.

In conclusion, Moringa gum exemplifies how a plant-derived excipient can play a multifaceted role in modern pharmaceutics. Its incorporation can lead to more sustainable and patient-centric drug delivery systems, echoing the broader industry trend of embracing natural polymers. Continued research and development, especially focusing on clinical evaluation of Moringa gum-containing formulations, will pave the way for its translation from research labs to marketed pharmaceutical products. Given it demonstrated potential, it is plausible that the coming years will witness Moringa gum being a key component in novel dosage forms, thereby truly transforming and enriching the field of pharmaceutical drug delivery.

Future Prospective

As the pharmaceutical industry increasingly shifts towards natural and sustainable excipients, moringa gum presents significant potential for future research and development. Some promising directions include:

1. **Long-term drug delivery systems:** Studies on the use of blended matrices in nanotechnology-based dosing systems such as nanoparticles, liposomes, and hydrogels to increase solubility, stability and target delivery.
2. **Combining with synthetic polymers:** Study of synergistic compounds combining moringa gum and synthetic content to optimize mechanical resistance, bioadhesion and controlled release.
3. **Improved bioavailability:** Studying its role in improving oral bioavailability of soluble drugs in the development of composition.
4. **Healing local injuries and applications:** Use properties of service stations, creams, or biofilm (nanofiber), natural antibiotics and anti-inflammatory agents.
5. **Toxicological and clinical studies:** Perform in vivo and clinical evaluations to establish

security profiles and therapeutic benefits for regulatory approval.

6. **Stability and commercial scale:** Development of economically effective and environmentally friendly extraction and cleaning processes to make mixed resins viable for large-scale pharmaceutical use.
7. **Personalized Medical:** Integration of gums into 3D printing techniques for patient dosage production and drug release profiles and drug release profile.

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Declaration Of Competing Interest
The author says they are no known personal interests and relationships that may affect work reported in this paper.

Abbreviations – *Moringa oleifera* (MO), poly N-vinyl-2-pyrrolidone (PVP), colon targeted drug delivery systems (CTDDS), Novel drug delivery system (NDDS), controlled release drug delivery system (CRDDS).

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