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REVIEW ARTICLE

Fenugreek Gum: Potential as an Eco-Friendly Alternative to Synthetic Polymers

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ABSTRACT

Fenugreek (*Trigonella foenum-graecum* L.) seed gum has recently gained significant attention as a multifunctional natural polymer owing to its unique physicochemical and biological attributes. Rich in galactomannans, this gum exhibits excellent swelling capacity, viscosity, and film-forming properties, making it a promising candidate for diverse industrial and biomedical applications. Beyond its traditional use as a dietary fiber and stabilizer, emerging research highlights its role as a sustainable excipient in controlled drug delivery, disintegrant in novel dosage forms, and bioadhesive agent in transdermal and mucoadhesive systems. In addition, fenugreek seed gum (FSG) demonstrates antioxidant, antimicrobial, and prebiotic activities, expanding its utility in functional foods, nutraceuticals, and cosmetic formulations. Its biodegradability, biocompatibility, and low toxicity further support its potential as an eco-friendly alternative to synthetic polymers. This article presents an overview of the novel applications of FSG, emphasizing its pharmaceutical, biomedical, and industrial prospects, while also outlining future research directions to optimize its functionality and commercial translation.

Keywords: Controlled release, fenugreek gum, gelling capacity, polysaccharides

INTRODUCTION

In Ayurvedic medicine, *Trigonella foenum-graecum* (Family: Leguminosae), commonly known as methika, is used to treat a variety of conditions, including wounds, abscesses, arthritis, diabetes, bronchitis, and digestive issues. It is believed that fenugreek originated in the Mediterranean region.[1] *T. foenum-graecum* is an annual leguminous plant that grows up to 60 cm in height. It is native to western Asia and southern Europe and has been used for centuries as a culinary and medicinal herb. Currently, the plant is cultivated in Canada, northern Africa, the Mediterranean, western Asia, and northern India.[2] India is the largest producer of fenugreek worldwide. Additional reported benefits of fenugreek include antiulcer, antibacterial, antihelminthic, antioxidant, antifertility, antibaldness, and antinociceptive activities.[2]

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STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF FENUGREEK GUM (FG)

FG solutions display characteristics typical of random coil polymers. Rheological testing shows pseudoplastic behavior at high shear rates. Comparative studies reveal that the mechanical spectra of fenugreek, guar, and locust bean gums with identical molecular weights are similar, although FG exhibits slightly smaller moduli values. FG, a non-gelling galactomannan, demonstrates resilience to freeze–thaw cycles with minimal synergistic interactions with other gums. Despite its multiple medicinal benefits, fenugreek is primarily a source of polysaccharides. In the pharmaceutical sector, polymers are utilized to regulate drug release from oral dosage forms. Natural polysaccharides are preferred over synthetic hydrophilic polymers due to their biocompatibility, non-toxicity, and biodegradability.[3-5]

CHEMICAL COMPOSITION AND APPLICATIONS

FG contains fenugreek seed polysaccharide (FSP), a hydrophilic polymer widely used as an emulsifying, thickening, gelling, and suspending agent. Owing to its diverse chemical structures and physical features, it finds applications in biological sciences, tissue engineering, controlled drug delivery, imaging, and diagnostics. The primary galactomannan sources include fenugreek (*T. foenum-graecum*), tara (*Caesalpinia spinosa*), locust bean (*Ceratonia siliqua*), and guar (*Cyamopsis tetragonoloba*).[6] FSP emulsions produce homogeneous and fine oil droplets (70% <1 µm), giving them superior performance compared to other hydrocolloid gums. For emulsion stability, a combination of FSP and guar gum (GG) is recommended, where FSP aids stability and GG enhances viscosity. Overall, polysaccharides are widely utilized as thickening, gelling, emulsifying, hydrating, and suspending agents.[7]

NOVEL APPLICATIONS OF FG

Fenugreek seed gum (FSG) has attracted significant attention due to its antioxidant, antifungal, and eco-friendly properties, with applications across food, pharmaceutical, cosmetic, and packaging industries.

Food and Packaging Applications

T. foenum-graecum has been used for edible film formation with functional modifications for sustainable packaging.[8] Antimicrobial packaging using FSG/clay nanocomposites (Memiş *et al*., 2017). Aerogels derived from oxidized FSG show strong water absorption, suitable for eco-friendly materials.[9]

Water Treatment and Environmental Uses

Bioflocculants from FSG are effective in arsenic removal from.[10] Microwave- and thermally-modified FG graft copolymers show strong flocculant activity in wastewater treatment.[11] FG-borax hydrogels improve soil water conservation in agriculture.[12]

Antibacterial properties and magnetic removal of Fe_3O_4

The study successfully developed Fe_3O_4 nanocomposites coated with FSG and silver nanoparticles, demonstrating enhanced antibacterial efficiency. The natural polymer coating improved nanoparticle stability, controlled silver release, and enabled magnetic recovery without environmental risk. Compared to individual components, the Fe_3O_4/FSG/Ag system showed superior activity against both Gram-positive and Gram-negative bacteria. These results highlight its promising application in eco-friendly water purification and antimicrobial treatments.[13] Fenugreek seed galactomannan was successfully isolated, characterized, and evaluated for its functional properties. Galactomannan exhibited superior emulsifying activity, oil-holding capacity, foaming ability, and swelling index, though with lower water-holding capacity. FSG has been found to have potential applications in food, pharmaceutical, and film-forming industries.[14]

FG-grafted used in the removal of Congo red dye

This study developed a cost-effective and eco-friendly hydrogel adsorbent by modifying FG with quaternary ammonium groups and organic monomers. The composite exhibited high swelling ability, strong adsorption efficiency, and excellent stability. Its performance followed the Langmuir isotherm and pseudo-second-order kinetics, with adsorption being spontaneous and exothermic. Moreover, the hydrogel maintained high reusability across multiple cycles. Overall, this novel material offers a practical and sustainable solution for the effective removal of Congo red dye from wastewater.[15]

FG-grafted used in the removal of heavy metals

In this study, zirconium MOF-based fenugreek composite (FG/Zr-AIPA) beads were successfully developed for efficient removal of Cr(VI), Pb(II), and Fe(III) from water. Structural and adsorption studies confirmed their high capacity, monolayer chemisorption behavior, and spontaneous endothermic interactions. The beads also demonstrated good reusability, highlighting their promise as eco-friendly adsorbents. Overall, polysaccharide–MOF composites such as FG/Zr-AIPA provide a sustainable and effective approach for wastewater treatment applications.[16] All galactomannans demonstrated strong water and oil holding capacities, along with distinct thermal transitions in DSC analysis. Rheological studies confirmed shear-thinning behavior and viscoelastic fluid characteristics, with viscosity decreasing under increasing shear rate and higher G’ and G” values at higher frequencies. These findings highlight FG as a promising natural biopolymer with wide applicability in food, pharmaceutical, and cosmetic industries.[17]

Pharmaceutical and Biomedical Applications

Carboxymethyl FG gels loaded with nanovesicles for onychomycosis treatment.[18] Hydrogel composites with cellulose for wound dressing.[19] Ocular drug delivery potential using FSG and mucilage blends.[20] FG-assisted nanoencapsulation enhances the stability of natural antioxidants such as sesame phenolics.[21,22]

Nutraceutical and Health Benefits

It has been found that *T. foenum-graecum* acts as a dietary supplement for obesity management and lipid regulation[23] and demonstrates prebiotic potential in animal feeds.[24] *T. foenum-graecum* reduces oxidative stress when combined with other natural gums.[25]

Nanotechnology and Material Science

Fe_3O_4/FSG/Ag nanocomposites provide antibacterial and water purification benefits.[25] Sulfated derivatives of FG enhance biological activity.[26] FG-based galactomannan matrices improve therapeutic use of asafoetida gum. Rheological studies further confirm FSG’s suitability in food, pharmaceutical, and cosmetic formulations.[27] Overall, FG holds promise as an eco-friendly alternative to synthetic polymers.[28] FG, derived from *T. foenum-graecum*, is a multifunctional, eco-friendly, and biocompatible natural polysaccharide. Its structural characteristics, rheological properties, and diverse applications in pharmaceuticals, food, packaging, water treatment, agriculture, and nanotechnology highlight its immense potential as a sustainable alternative to synthetic polymers. The extracted gum contained 84.12% carbohydrates and a galactose-to-mannose ratio of 1:5, with 55% galactomannan in raw seeds. Its strong gelling ability at a 75% concentration highlights its suitability as a cost-effective and sustainable alternative to conventional galactomannan sources for food and industrial applications.[29]

UTILIZED AS A BINDER OR SUSPENDING AGENT

It was shown that the mucilage of fenugreek seeds has been employed as an effective suspending agent and has been proven to work better than gum made from tragacanth, gum acacia, and bentonite. Even at low concentrations, fenugreek (*T. foenum- graecum* L.) seed mucilage has the potential to be a novel suspending agent. The purpose of this study is to determine whether the mucilage from fenugreek seeds is suitable for use as a suspending agent. Given its accessibility and affordability, the investigation can be expanded to assess its viability for additional medicinal uses.[30] The fenugreek-paracetamol suspension was prepared and assessed and were found suitable used as the preferred stabilizer and that high viscosity is preferred, particularly in the food, pharmaceutical, and cosmetic industries.[31] As with other materials containing mucilage, fenugreek seeds expand and become slippery when they come into contact with liquids.[32] The husk’s capacity to produce mucilage and its binding characteristics in solid dosage forms were investigated.[33] Pharmaceutical studies have investigated FG’s potential uses as an emulsifier, disintegrant, binder, and solubility enhancer.[34-36]
Two phases went into creating the nanoemulsions. Initially, ultrasounds were used to create a main

O/W emulsion that was less viscous. Olive oil constituted the oily phase in the emulsions, and the only emulsifier agent utilized was isolated protein. FG was added as a stabilizer to the primary formulations later on, which led to the higher viscosity secondary emulsions. In comparison to their coarse secondary emulsions made by high shear mixing, they demonstrated increased viscoelastic characteristics and consistency, which led to a significant increase in stability. Even the formulations with the lowest weight percentage of olive oil, 2.5% wt, showed better stability over the course of a 6-month storage period. The macro- and nano/submicron emulsion formulations can be used as stabilizers or suspending agents to improve the physical qualities and stability of the mixture.[37,38]

CONTROLLED RELEASE FORMULATIONS

These natural polymers' hydrophilic and gelling qualities are primarily responsible for regulating medication release over an extended period of time. Hydrophilic polymers are generally preferred when creating controlled-release formulations for poorly soluble drugs in water. In modified release matrices, FG (*T. Foenum-graceum*), a member of the leguminous family, was employed as a prolonged release polymer. In the presence of FG, the gelatinization and retrogradation behavior of cornstarch have been investigated. The investigation showed that the inclusion of FG prevented the composite system's structural hardening.[39] Using FG as a reference, the hydrophobic and drug release-delaying properties of the octenyl succinate anhydride derivative of FG (OSFG) were produced. The study examined the effects of three variables, namely reagent/substrate concentration, reaction temperature, and duration, on the degree of substitution of OSFG. The reaction was conducted in anhydrous circumstances at several temperatures (40–98°C) using $NaHCO_3$ as a mild basic catalyst. In order to achieve a regulated release, it was determined that the created formulations, including OSFG, had a release retarding effect and could be utilized either alone or in conjunction with other polymers.[40] For a sustained therapeutic response over an extended length of time, a sustained-release formulation is typically favored over a standard dosage form. Reduced frequency of administration, stable plasma drug level, absence of dose dumping effect, and decreased adverse effects are this formulation's main benefits.[41,42]

MUCOADHESIVE FORMULATION

It was proposed that metformin HCL might be delivered under control using fenugreek mucilage as a suitable carrier. The ionic-gelation approach was used to create calcium pectinate-fenugreek seed mucilage (FSM) mucoadhesive microsphere beads that contained metformin HCl. The medium's pH had an effect on these beads' swelling and mucoadhesivity. Over an extended duration following oral administration, the optimized beads demonstrated a stronger mucoadhesive and noteworthy hypoglycemic effect on alloxan-induced diabetic rats.[43]

IN NASAL DRUG DELIVERY

T. foenum-graecum, a naturally occurring mucoadhesive substance, has been used in a new nasal medication delivery system for benzodiazepines. Concluded that using a polymer appropriate for this kind of distribution could be both practical and affordable.[44]

USED AS DISINTEGRATING AGENT

According to studies, the mucilage that has been isolated is a useful medicinal polymer, more especially, a disintegrating agent.[35] Research has shown that FG exhibits promising additive anti-inflammatory action when combined with diclofenac sodium. It also functions well as a super dissolving agent.[45]

IN TABLET FORMULATION

We looked into how lactose affected the release of propranolol hydrochloride from matrices containing fenugreek mucilage. Propranolol

Name of drug	Types of polymer	Methods	Types of formulation	References
Glimepiride	Carboxymethyl fenugreek galactomannan, gellan gum, and calcium silicate	Ionotropic gelation	Novel composite beads controlled the delivery for two diabetes	[53]
Glycyrrhetinic acid	Stearic acid-modified fenugreek gum	Nanomicelles	Liver-targeted drug delivery system	[54]
Metformin HCl	Ionotropic gelation with zinc acetate as a cross-linker	Diethanolamine-modified high-methoxyl pectin-alginate	Controlled intragastric delivery	[55]
Glimepiride	Carboxymethyl fenugreek galactomannan–gellan gum–calcium silicate	composite beads	Sustained drug release	[56]
Acarbose	Galactomannans—fenugreek gum, Boswellia gum, and locust bean gum		Sustained drug release	[57]
Epalrestat	fenugreek, gum karaya, and banana powder	Direct compression method	Mouth dissolving tablets	[58]
Venlafaxine hydrochloride	Hydroxy propyl methyl cellulose, Carbopol, and Xanthan Gum	Direct compression method	Bilayer tablet	[59]

hydrochloride release rate decreased in matrices with increased mucilage concentration, similar to what was seen with hypromellose matrices. Using fenugreek mucilage, the release rate of propranolol hydrochloride is effectively regulated. However, this is because lactose causes the tortuosity of the channels to decrease and their pore sizes to expand, which allows water to seep into the tablet. Using fenugreek husk dispersion and starch paste as a benchmark, the binding characteristics of husk were optimized with respect to diclofenac sodium and propanolol. For the pill formulation, they found that fenugreek husk dispersion worked better than starch paste. According to the findings, it might make a useful granulating agent in the future for the formulation of tablets. Research revealed that fenugreek husk had good binding properties.[46] Developed and successfully tested a fast-dissolving pill of sildenafil citrate utilizing the mucilage of fenugreek seeds.[47] FSM combined with a propranolol hydrochloride antihypertensive medication matrix composition. For comparison, a typical controlled-release polymer called Methocel K4M was utilized.[48] The fenugreek mucilage's gelling capability was assessed.[49] Reducing the size of the seeds, floating them in chloroform for a while, and then decanting allows the husk to be separated from the seeds. The oily part is eliminated by repeated extraction using chloroform, and it is subsequently air-dried.[50]

By integrating the floating and swelling mechanisms, new alginate-FG gel membrane-coated hydroxypropyl methylcellulose (HPMC) based matrix tablets were created for intragastric quetiapine fumarate (QF) distribution. The tablets underwent a diffusion-controlled interfacial complexation process wherein they were covered with Ca+2 ions and crosslinked using an alginate-FG gel membrane. The optimized matrices coated with biopolymeric demonstrated enhanced buoyancy, favored swelling properties, and a reduced rate of drug release. The recently developed alginate-FG gel membrane-coated HPMC matrices have been shown to be effective for long-term intragastric delivery of QF with improved therapeutic outcomes.[51]

IN NANO PARTICLES FORMULATION

Improved zone of inhibition and controlled drug release profile with the lowest concentration are made possible by the created natural polymer-based cefixime nanoparticles, which also increase patient compliance.[52] Some researchers has been prepared nanoparticles of drug with fenugreek seed gum and reported that this gum could be used for the development of futuristic dosage development, some novel applications of fenugreek seed gum shown in Table 1.

Novel Applications of FG

Novel Applications of fenugreek seed gum are shown in tabulated form in Table 1.

CONCLUSION

Historically, excipients have been included in medicine formulations as inert materials whose primary function has been to facilitate the manufacturing process. However, during the past few decades, their inclusion in dosage forms has increased in order to perform certain functions meant to enhance drug delivery. FSP serves multiple purposes in biopharmaceutical applications, including disintegrating tablets and providing a controlled-release excipient. The polysaccharide is typically used in conjunction with another substance, has significant synergistic effects, and has a wide range of applications, including buccal, oral, and controlled drug administration, among others that have been mentioned. There is still a great deal of research to be done to fully understand the potential that this polysaccharide may have. Based on the existing literature, it appears to be especially intriguing when it comes to the synergy formed with other polysaccharides, such as carrageenan and xanthan gum, among others.[60,61]

Perception of the Future and its Uses

FG has been recommended by a number of researchers as an affordable polysaccharide for the creation of many medicinal formulations, including emulsifiers, suspensions, cosmetics, tablets, and controlled release forms. It can be directly extracted from plant sources and is readily available. Hence, it can be found unadulterated. FG or polysaccharides have the potential to be the best polysaccharides for medication administration in the future, potentially replacing synthetic polymers.

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