



Gum Tragacanth: A Novel Biopolymer Platform for Advanced Applications

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ABSTRACT

Gum tragacanth, a natural biopolymer sourced from the Astragalus plant, has often been overlooked but is now emerging as a promising sustainable alternative to synthetic materials. This review explores the rich potential of gum tragacanth, focusing on its distinctive molecular structure, functional properties and diverse applications. Gum tragacanth is increasingly valued in industries like pharmaceuticals, cosmetics, and food for its ability to create thick gels, stabilize emulsions, and maintain high viscosity. Its eco-friendly characteristics, such as biodegradability and environmental compatibility, attract attention in today's sustainability driven landscape. This review highlights the versatility of gum tragacanth and its potential to provide innovative solutions that address both

INTRODUCTION

The global community is increasingly confronting the urgent challenges of environmental degradation and dwindling resources¹. In response, there has been a significant shift toward sustainable practices, fueling renewed interest in biopolymer research². These polymers, derived from renewable sources like plants, microorganisms, and marine life,

present a compelling alternative to their synthetic counterparts^{3,4}. Unlike traditional petroleum-based materials, biopolymers often boast superior biodegradability, biocompatibility and renewability, making them highly attractive for various applications⁵. As the world strives to reduce its carbon footprint and lessen its ecological impact, biopolymers are gaining considerable attention^{6,7}. Their potential to replace conventional petrochemical-based materials



in diverse sectors such as packaging, agriculture, biomedicine, and automotive industries is driving both innovation and investment. The intrinsic link between biopolymers and sustainable development has created a collaborative ecosystem that brings together academia, industry and policymakers, all working towards a future where economic growth and environmental stewardship go hand in hand. This convergence of scientific advancement, industrial application, and policy support has positioned biopolymers as a cornerstone in the global transition toward a circular economy and a low-carbon future⁸.

Amid the growing interest in biopolymers as sustainable alternatives, gum tragacanth stands out as a natural polymer with tremendous, yet largely untapped, potential. Gum tragacanth is extracted mainly from plants belonging to the genus *Astragalus* and for centuries, they have been used for food industry and medicinal purposes⁹. While it has been traditionally valued as a thickening, emulsifying, and stabilizing agent, determining its molecular structure, functional properties, and potential for modern applications is still developing. The gap in knowledge has led to gum tragacanth being overshadowed by more extensively studied biopolymers, which limits its broader use in contemporary industries.

Despite the historical use and well-known functional properties of gum tragacanth, it has yet to be fully explored for its multifunctional characteristics in the scientific literature. Although some studies have investigated specific aspects of this biopolymer, a comprehensive understanding of its molecular structure, physicochemical properties, and the interactions among these elements that shape its functionalities is still incomplete. This gap in knowledge hinders the development of innovative applications and prevents us from fully realizing the potential of gum tragacanth.

Methodology

In this study the literatures has been taken from the journals, conference proceedings, and book chapters on Gum tragacanth biopolymer and its applications from the span of 10 years from 2014 to 2024 were considered. The literatures were selected only in English language. The search for literature was conducted over the internet using online databases, including Google Scholar, Scopus, Web

of Science, and Science Direct. The search was done using various combinations of key words relevant to the subject matter, such as gum tragacanth, natural biopolymers, *Astragalus* plant biopolymer, sustainable polymers, functional properties, industrial applications. Based on title and abstract content, only literature that address gum tragacanth, natural biopolymers, and industrial applications were selected and reviewed. Furthermore, bibliography in key selected documents were also examined with the aim of identifying other relevant papers.

Production, Import and Export Statistics

Iran is the largest global producer and exporter of gum tragacanth, accounting for approximately 70% of the total production¹⁰. The annual production volume in Iran is estimated to be between 1500 to 2000 metric tons followed by Turkey and Pakistan. The country's favorable climatic conditions and extensive *Astragalus* plantations contribute to its dominant production capacity. In Pakistan, the production is primarily concentrated in the northern and western regions of the country. Iran exports roughly 300 to 500 metric tons annually, serving major markets in Europe, North America and Asia¹¹. Where United States, is the major importer with an amount approximately 200 to 300 metric tons annually.

India is not a major producer of gum tragacanth compared to leading countries like Iran and Turkey. However, there is a small-scale production of gum tragacanth in regions where *Astragalus* species are cultivated, particularly in the northwestern states. The annual production volume in India is relatively modest, estimated at around 50 to 100 metric tons.

Maximize Market Research¹² forecasts that the Global Tragacanth Market will experience moderate growth and achieve a substantial market value by the conclusion of the projected period. It is anticipated that the Global Tragacanth Market size will approach US\$ 4.76 billion by 2029, demonstrating a 4.32% compound annual growth rate during the forecast period.

Molecular Architecture and Functional Properties

Gum tragacanth is a complex polysaccharide made up primarily of two key components: arabinogalactan and tragacanthin. Arabinogalactan, the dominant component, features

a backbone of β -(1 \rightarrow 3)-linked galactose units, with branching chains of β -(1 \rightarrow 6)-linked galactose and arabinose units¹³. Though tragacanthin is a smaller component, it has a more intricate structure that includes glycosidic bonds between galactose, arabinose, and rhamnose¹⁴. This complex molecular arrangement gives gum tragacanth its high solubility in water and its ability to form thick, viscous solutions. The polysaccharide chains are characterized by a high molecular weight and a tendency to intertwine, which significantly contributes to its unique rheological properties.

The rheological properties of gum tragacanth are closely tied to its molecular structure. In aqueous solutions, this gum forms a gel-like consistency due to its ability to interact with water molecules and other polysaccharides¹⁵. The way its molecules intertwine and bond with each other creates a network that gives the solution both viscosity and stability. This gel formation is also reversible, making gum tragacanth an ideal choice for applications that require controlled thickness and viscosity, such as in pharmaceutical suspensions and food products.

The Gum thickening ability of tragacanth gum is largely due to its high molecular weight and the formation of a three-dimensional network structure when dissolved in water. This network significantly boosts the viscosity of aqueous systems, making it especially valuable in food products where a consistent texture is important. Gum tragacanth has impressive emulsifying properties, as it can stabilize emulsions by forming a protective layer around oil droplets¹⁶. This feature is particularly beneficial in the cosmetic industry, where stable emulsions are essential for creating creams and lotions. The gum's gel-forming capability is linked to its unique polysaccharide structure, which promotes cross-linking and the formation of gel networks. This property is utilized in the pharmaceutical field for controlled drug release systems and in the food industry for producing gel-based products¹⁷. Beyond that, gum tragacanth acts as a stabilizer in various formulations, helping to prevent phase separation and ensuring long-term product stability.

The molecular structure of the gum is important for its remarkable properties. Its detailed polysaccharide composition, including

arabinogalactan and tragacanthin, gives it special qualities such as thickening, gel formation, and emulsification¹⁸. These attributes make it a valuable ingredient in many fields, from pharmaceuticals to food and cosmetics. Through understanding how its molecular makeup influences these functions, we can better utilize gum tragacanth in different products and recognize its importance in today's industries.

Gum Tragacanth as a Green Material

Gum tragacanth is sourced from the bark of Astragalus trees found in countries like Iran, Turkey, and Pakistan. The gum is collected by carefully making cuts in the bark to let it ooze out¹⁹. This process is designed to be gentle on the trees, that allows to continue growing without significant harm or deforestation. Since gum tragacanth is a renewable resource, it stands out as a sustainable alternative to synthetic polymers and materials, making it a great choice for eco-friendly applications²⁰.

One of the most significant environmental benefits of gum tragacanth is its biodegradability. Being a natural polysaccharide, it breaks down into harmless components when exposed to environmental conditions²⁰. This is a stark contrast to many synthetic materials, which can linger in the environment for a long time, adding to pollution and waste. Because gum tragacanth naturally decomposes, it is an excellent choice for products where disposal at the end of life is a concern, like packaging materials and agricultural products²¹.

Gum tragacanth stands out for its lower environmental impact compared to synthetic materials. Since it comes from natural sources and requires little processing, it leaves a smaller carbon footprint. Its water-absorbing qualities make it effective in stabilizing soil and preventing erosion, adding to its eco-friendly benefits^{22,23}. Industries can reduce their reliance on petrochemical-based products and minimize environmental degradation with the replacement of synthetic materials with gum tragacanth.

Gum tragacanth's thickening and gelling abilities make it a strong choice for creating biodegradable packaging materials. Blending it with other natural polymers enables the creation of films and coatings that are both effective and environment friendly. In agriculture, gum tragacanth

works well as a soil conditioner and stabilizer²⁴. Its moisture-retaining properties help improve soil structure, promoting sustainable farming practices by reducing the need for synthetic soil additives and preventing erosion²⁵. This natural gum is also widely used in pharmaceuticals and cosmetics, where it enhances product performance while meeting the rising demand for eco-friendly and natural ingredients. Its natural water-binding properties and gel-forming capabilities make it useful in environmental remediation, such as cleaning up oil spills. This demonstrates its potential not only in addressing environmental challenges but also in promoting sustainability.

The gum is increasingly being seen as a valuable eco-friendly alternative to traditional petrochemical materials in green chemistry²⁶. Its hydrophilic nature, biodegradability and ability to form gels and films make it a promising candidate for various applications. For example, it could be used as a base for catalysts, creating a renewable and sustainable environment for chemical reactions. Its properties also allow it to form hydrogels and emulsions, which can be used to develop environmentally friendly solvents and extraction agents²⁷. The use of gum tragacanth instead of harmful organic solvents, we can significantly cut down on the environmental impact of chemical processes. Gum tragacanth's porous structure and chemical features make it a strong candidate for applications like filtering out heavy metals and organic pollutants from water and wastewater.

To fully unlock the potential of gum tragacanth and push towards a greener future, we need to integrate it into a circular economy. This shift involves moving away from the traditional model of taking, making, and disposing of products to a more cyclical system²⁸. Emphasizing recycling and reusing can greatly enhance the economic and environmental benefits of gum tragacanth. Recovering valuable by-products from its production, such as residual biomass, process water and energy allows us to find new and beneficial uses for these resources. This not only cuts down on waste but also lessens our environmental impact. Developing biorefinery processes to break down gum tragacanth's complex structure can produce a variety of useful chemicals, biofuels and materials, making the most out of our resources and expanding

our product options. The natural biodegradability and film-forming ability of gum tragacanth can make it stand out as a promising alternative to synthetic polymers²⁹. Designing products with their end-of-life in mind such as using biodegradable packaging can significantly boost gum tragacanth's contribution to a circular economy. For achieving this, collaboration among researchers, industry leaders and policymakers is essential. Together they must focus on fostering innovation, establishing necessary infrastructure and developing supportive policies.

The basic elements of gum tragacanth, its biodegradability and biocompatibility contributes to its green profile³⁰. Its natural polysaccharide structure allows it to break down through microbial activity under the right conditions, which helps reduce its long-term environmental impact³¹. Gaining insight into gum tragacanth's environmental impact involves examining how swiftly and effectively it degrades. Similarly, its suitability for medical and pharmaceutical use hinges on its biocompatibility. This requires comprehensive toxicological studies and safety evaluations to confirm that it is safe for both human and animal use.

Novel Applications: Beyond the Horizon Biomedical Engineering

Gum tragacanth's exceptional combination of biocompatibility, biodegradability, and viscoelastic properties makes it an incredibly versatile biomaterial, especially in the realm of biomedical engineering. Its capacity to form hydrogels with adjustable mechanical properties and porosity makes it an ideal candidate for developing tissue engineering scaffolds¹⁷. Researchers can create scaffolds that closely replicate the native extracellular matrix by carefully adjusting variables such as polymer concentration, crosslinking density, and the incorporation of bioactive molecules. These carefully designed scaffolds offer an optimal environment for cell adhesion, growth, and differentiation, making them highly promising for the regeneration of various tissues, such as bone, cartilage, and skin. The potential of this approach in advancing tissue engineering underscores the versatility and importance of gum tragacanth in biomedical applications.

Tragacanth's mucoadhesive properties and controlled release capabilities make it an attractive option for drug delivery systems. Encapsulation of

therapeutic agents within tragacanth-based matrices can protect drugs from degradation, enhance their bioavailability and achieve sustained release profiles³². The gum's ability to form hydrogels allows for the creation of injectable formulations, enabling minimally invasive drug delivery. Incorporating targeting ligands or stimuli-responsive elements allows for precise tuning of drug release, enhancing therapeutic effectiveness and reducing side effects. The hemostatic properties of tragacanth, along with its potential to promote wound healing, make it highly suitable for wound care applications³³. The gum can act as a physical barrier, promoting blood clotting and helping to control bleeding while preventing infection. Tragacanth can stimulate tissue regeneration by providing a moist environment and delivering growth factors³⁴. These properties make it a promising candidate for the development of advanced wound dressings and hemostatic agents.

Nanotechnology

The integration of gum tragacanth with nanotechnology opens up new avenues for creating innovative materials and systems with enhanced functionalities. The fusion of tragacanth with inorganic nanoparticles, like metallic or ceramic ones, can lead to the development of nanocomposites that offer better mechanical strength, improved barrier protection and enhanced antimicrobial properties. These materials have potential applications in various fields, including packaging, biomedical devices and environmental remediation.

Tragacanth stands out for its ability to create nanoparticles and micelles, making it a valuable tool for drug delivery systems. Encapsulating medications within tragacanth-based nanoparticles not only boosts drug solubility and bioavailability but also enhances targeted delivery³⁵. Adjustments to the size and composition of these nanoparticles enable controlled drug release, paving the way for more effective treatments and fewer side effects. This approach could revolutionize how drugs are delivered, ensuring they work more effectively where needed while minimizing unintended impacts.

Gum tragacanth's potential extends into the realm of sensor technology where it can be used to detect a variety of substances including environmental pollutants, biomolecules and pathogens³⁶. Incorporating functional groups

or nanoparticles into tragacanth's matrix can notably enhance the sensitivity and selectivity of these sensors³⁷. This innovation opens doors to groundbreaking applications in environmental monitoring, disease diagnosis, and food safety. The unique characteristics of gum tragacanth combined with advancements in nanotechnology can create the way for exciting new biomedical and technological applications.

Energy Storage and Conversion

Gum tragacanth with its remarkable physicochemical properties holds great promise for various applications in the rapidly evolving energy sector. Its potential as an additive in battery technology is particularly promising, where it could enhance ionic conductivity and improve battery performance overall³⁸. Its ability to form strong, flexible films also makes it ideal for use as a separator in batteries, an essential component that prevents short circuits while facilitating ion transport. The gum's viscoelastic properties can be exploited to develop advanced battery binders that enhance electrode stability and cycle life^{39,40}.

Fuel cells, another cornerstone of clean energy technology can benefit from tragacanth's characteristics. Its hydrophilic nature and ability to form ion-conducting membranes make it an attractive candidate for polymer electrolyte membrane (PEM) fuel cells. These membranes are important for enabling proton exchange between the anode and cathode, which directly impacts the efficiency of the fuel cell⁴¹. Improving the structure and attributes of tragacanth-based PEMs could help scientists to achieve higher proton conductivity, improved mechanical stability and enhanced fuel cell performance.

In the quest for better solar energy solutions tragacanth offers an intriguing possibility. While it may not have a direct application in photovoltaic cells, it has potential as a component in materials used to protect solar cells or as a base for dye-sensitized solar cells. Its film forming ability along with its clear and biodegradable nature, makes tragacanth a promising eco-friendly alternative to the synthetic materials typically used in these technologies, this can lead to more sustainable innovations in solar energy.

Water Treatment and Purification

Gum tragacanth is highly effective in purifying water due to its ability to absorb heavy metals, organic pollutants, and other contaminants. Its natural properties, like being hydrophilic and having a porous structure, make it a strong candidate for cleaning up polluted water sources^{42,43}. With enhancement in its pollutant-trapping ability through subtle chemical modifications or the addition of functional groups can significantly improve tragacanth's performance. The gum helps improve water quality by causing colloidal particles to clump together making it easier to remove suspended solids⁴⁴. Adjusting factors like pH levels, the amount of tragacanth used and mixing conditions can optimize this process leading to cleaner and safer water.

Tragacanth has the potential to enhance membrane technology used in water purification and desalination⁴⁵. Its natural film forming ability and potential to create porous structures makes it an ideal material for developing sophisticated membranes. The modification in membrane's characteristics through crosslinking or combining it with other polymers the researchers can fine-tune its selectivity and permeability, which can allow it for the efficient filtration of contaminants while allowing the passage of water molecules.

Trends in gum tragacanth research and applications

The growing demand for natural, renewable materials has brought gum tragacanth to the forefront of scientific research. Researchers focus on unraveling the intricate structure of this biopolymer, using advanced techniques to gain a deeper understanding of its molecular makeup. This deeper understanding allows for innovative modification approaches, such as chemical derivatization and enzymatic treatments, which are tailored for specific uses. The exploration in synergistic interactions between tragacanth and other biopolymers or nanomaterials is leading to new advancements in materials science⁴⁶ especially in the development of multifunctional composites with improved performance.

Gum tragacanth's remarkable characteristics such as its biocompatibility,

biodegradability and unique rheological properties are catching the eye of researchers across various fields beyond its conventional uses⁴⁷. In biomedical field, it is proven to be a promising material for drug delivery systems, tissue engineering scaffolds and wound dressings. Its ability to form hydrogels with customizable features is perfect for controlled drug release formulations⁴⁸ and as a supporting matrix for cell growth⁴⁹. Meanwhile in the food industry, there is a growing shift towards using tragacanth as a natural thickener, stabilizer and emulsifier, which offers a greener alternative to synthetic ingredients. Beyond these areas, its potential in cosmetics, personal care and environmental remediation is also being explored, highlighting its versatility and promise as a sustainable and functional biopolymer.

Overcoming Challenges and Future Perspectives

Gum tragacanth shows great promise but faces some significant hurdles before it can be widely used. One basic issue is the variation in gum quality and composition that can change based on factors like the plant variety, geographical origin and harvesting conditions. This inconsistency can affect product performance and reproducibility, making it harder to use in industrial applications. The gum's complex structure often requires specialized processing, which drives up production costs and complicates large-scale manufacturing. To overcome these issues, there needs to be a focus on improving quality control, standardizing how the gum is cultivated and developing better extraction and purification techniques.

Expanding the uses of gum tragacanth requires innovative approaches. Chemical modifications such as esterification, oxidation and crosslinking can tailor the gum's properties to specific needs. Increasing solubility or altering viscosity can enhance its suitability for various formulations. Physical modifications like grinding or irradiation can also influence the gum's behavior. There is need to assess these modifications carefully to ensure they achieve the desired properties without compromising biocompatibility or safety. Synergizing tragacanth with other materials opens up promising possibilities for creating innovative, high-performance products. As suppose blending it with synthetic polymers can enhance its processability, mechanical strength, and barrier properties, broadening its potential

applications across various industries. In addition, integrating nanomaterials can introduce unique functionalities, such as antimicrobial properties or controlled drug release.

Unlocking the commercial potential of gum tragacanth involves a strategic approach. Conducting in-depth market research helps identify which industries and customers are most interested, guiding product development and

commercialization. Crafting production methods that are both cost-effective and sustainable ensures long-term economic viability. Building strong relationships with industry partners, academic institutions, and government agencies supports knowledge sharing and regulatory navigation. Addressing these factors and embracing emerging technologies can transform gum tragacanth into a valuable resource with widespread impact across different sectors.

Table 1: Properties and Applications of Gum Tragacanth

Property	Description	Applications	References
High viscosity	Ability to form thick solution	Pharmaceuticals, Food products	15;18
Gel formation	Forms gel like consistency in aqueous solutions	Drug delivery, Cosmetic formulations	16;17
Emulsification	Stabilizes emulsions by forming protective layers	Cosmetics, Food industry; Nanoparticles	17
Biodegradability	Breaks down into nontoxic components	Packaging, Agricultural products, Soil conditioners	49;21
Biocompatibility	Safe for use in human and animal applications	Pharmaceuticals, Biomedical engineering	17;48
Mucoadhesive	Adheres to mucosal surfaces, enhancing retention	Drug delivery system, Mucosal adhesives	33
Hydrophilic	Affinity for water, aiding in moisture retention	Water treatment, Hydrogels, Moisturizing products	42;22
Film- forming	Forms coatings or films that are flexible and transparent	Packaging materials, Protective coatings	29;48

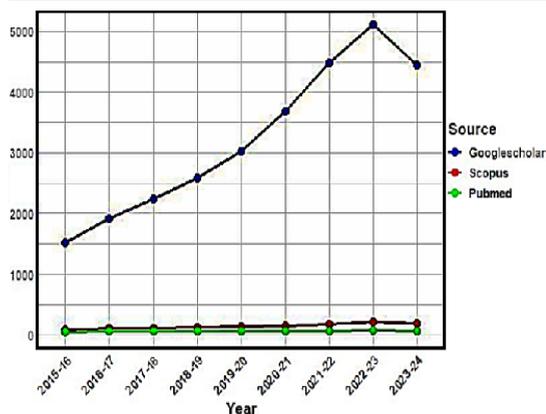


Fig. 1. Publications related to Gum Tragacanth from year 2015 to July 2024

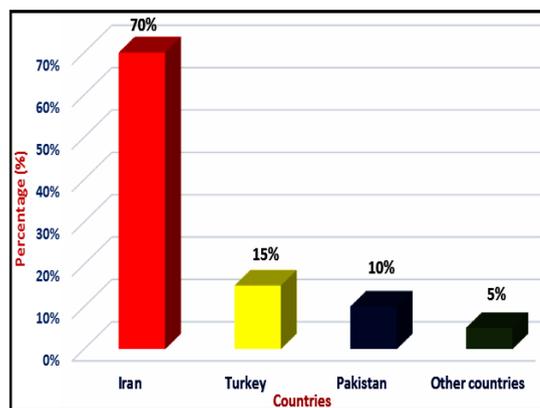


Fig. 2. Gum Tragacanth producing countries

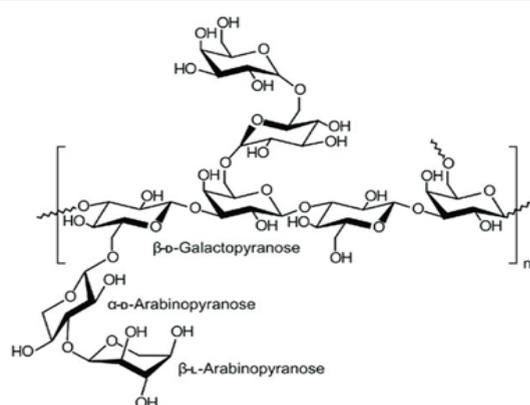


Fig. 3. Molecular structure of gum tragacanth⁵⁰

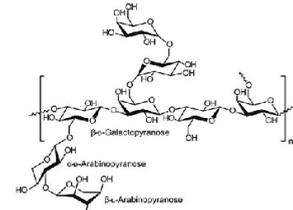
Properties	Details
Structure	
Molecular Formula	C ₁₀ H ₃₀
Molecular Weight	150.35 g/mol
Source	<i>Astragalus gummifer</i>
Physical Characteristics	Dull white or yellowish powder, Odourless, Mucilaginous in taste, Soluble in Alkaline Solution

Fig. 4. Physiochemical properties of gum tragacanth¹⁷



Fig. 5. Environment related advantages of Gum Tragacanth

CONCLUSION

Gum tragacanth stands out as a versatile biopolymer with broad potential across various fields. Its complex polysaccharide structure and numerous functional groups give it remarkable properties like emulsification, gelation and film formation. This review showcases advancements in understanding how tragacanth's structure influences its properties and its uses in areas like pharmaceuticals, cosmetics, and emerging fields such as biomedicine and nanotechnology. With its biodegradability, biocompatibility and sustainability, tragacanth is a promising base for innovation. Its capacity to create hydrogels, film forming and nanoparticles opens up numerous opportunities for developing new materials and products with specific attributes. Future research should focus on standardizing cultivation methods,

improving extraction techniques and refining characterization processes to ensure consistent quality. Investigating new modification approaches and combining tragacanth with other materials can reveal exciting new applications. Evaluating the environmental and economic impacts of tragacanth-based products through life cycle assessments is also important for assessing their overall value.

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Conflict of interest

The author declare that we have no conflict of interest.

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