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Review

Gum Ghatti: A Comprehensive Review on Production, Processing, Remarkable Properties, and Diverse Applications

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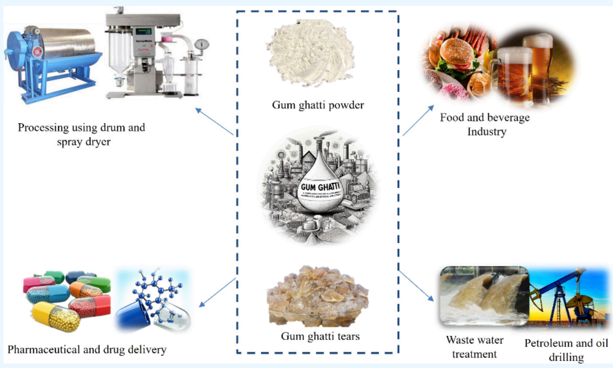
Cite This: *ACS Omega* 2024, 9, 9974–9990

ABSTRACT: Gum ghatti, popularly known as Indian gum and obtained from *Anogeissus latifolia*, is a complex high-molecular-weight, water-soluble, and swellable nonstarch polysaccharide comprised of magnesium and calcium salts of ghattic acids and multiple monosugars. Unlike other nontimber forest produce, gums ghatti is a low-volume but high-value product. It has several applications and is widely used as food, in pharmaceuticals, and for wastewater treatment and hydrogel formation, and it has attracted a great deal of attention in the fields of energy, environmental science, and nanotechnology. Industrial applications of gum ghatti are primarily due to its excellent emulsification, stabilization, thickening, heat tolerance, pH stability, carrier, and biodegradable properties. However, utilization of gum ghatti is poorly explored and implemented due to a lack of knowledge of its production, processing, and properties. Nevertheless, there has been interest among investigators in recent times for exploring its production, processing, molecular skeleton, and functional properties. This present review focuses on production scenarios, processing aspects, structural and functional properties, and potential applications in the food, pharmaceuticals, nonfood, and other indigenous and industrial usages.



1. INTRODUCTION

Gum ghatti is a complex nonstarch polysaccharide exudate of *Anogeissus latifolia*, which is a blend of magnesium and calcium salts that are produced from ghattic or uronic acids and most commonly found in the dry deciduous forests of India.[1] The scientific classification of *Anogeissus latifolia* is illustrated in Table 1. The presence of this tree in the mountains, which are recognized as "Ghats", of India is the reason behind the nomenclature of this exudate gum as gum ghatti or Indian gum.[2] It is also known as *Gummi Indici* and *Gummi Indicum* worldwide. Other common names used in the scientific literature are bakli, dhau, dhawa, or dhaora in Hindi and takhian-nu and raam in Thai and Vietnamese, respectively.[3] *Anogeissus latifolia* is also known as axelwood (because it is used in cart axels) in the USA and Australia.[4]

Table 1. *Anogeissus latifolia* Cassification

kingdom	Plantae
subkingdom	Tracheobionta (vascular plant)
super division	Spermatophyta (seed plant)
division	Magnoliophyta (flowering plants)
class	Magnoliopsida (dicotyledons)
subclass	Rosidae
order	Myrtales
family	Combretaceae (white mangrove family)
genus	*Anogeissus*
species	*Anogeissus latifolia*

Anogeissus latifolia is able to grow in stress and limited water conditions, even in dry areas.[1,5] The formation of natural gums in the tree occurs through a cyclic process known as gummosis in which cellulose portions of the plant tissue are fragmented and decayed.[6] The gum exudation or oozing process starts when the tree is under stress due to any injuries or wounds generated either naturally or artificially in the tree bark. The oozing process of tree gum can be a slow process and may occur over a period of days, based on tree age and size.[7] The exudate gum forms small size nodules in the range of 5 to 50 g by weight in a spiro-tubular form and rounded tear shape. The shape of the nodules is influenced by the opening size or shape of the tree bark, the pressure of gums in the tree, sunlight, heat,

Received: October 18, 2023
Revised: January 12, 2024
Accepted: January 18, 2024
Published: February 26, 2024

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974–9990

and wind conditions.[8] Exudates of gum ghatti have a glassy appearance, and the nodule color ranges from dark red to translucent white depending on the amounts of tannin present in the gums.[9] Use of quality exudate gum in the food, pharmaceutical, and cosmetic industries requires drying and contaminant removal. It is “Generally Recognized as Safe” (GRAS) by USA regulations, which are based on the toxicity, mutagenicity, and teratogenicity of natural products.[10] It is widely accepted as a food additive in Japan, Latin America, and other areas, where it is employed as a substitute hydrocolloid as an emulsifier, thickener, and binder.[11] It has superior emulsification properties and is a more cost-effective emulsifier than gum arabic, particularly as a stable emulsifier in food products. Indeed, it plays a very effective role in the preparation of stabilized formulations as compared to gum arabic and other commercial natural gums.[11−13] Surprisingly, the true potential of gum ghatti as an an emulsifier, thickener, and binder has remained largely obscure. Nevertheless, recent investigations have reported various encouraging applications of gum ghatti. In view of the above-mentioned context, the present Review is focused on comprehensive review of the production, processing, properties, and applications of gum ghatti.

2. PRODUCTION

2.1. Gum Ghatti Tree (*Anogeissus latifolia*). The gum ghatti tree with an erect trunk rises in the unclouded parts of peninsula ranges, the Shivaliks, and outer Himalayas at an altitude between 200 and 1250 m, having rainfall of 100 ± 200 mm in the temperature range of 5−40 °C. It grows best in well-drained and clay loam soil, though it is capable of prospering in antagonistic climatic and land conditions like dry rocky slopes, where it inclines to be stunted.[4,16] It is a moderately large tree and may grow up to height of 25 m, attaining its maturity in about 70−80 years.[17] The stem is deeply fluted toward the base,[16] and the bark of the tree is about 4 ± 5 mm thick with a greenish white color and smooth surface. The gum ghatti tree has a slightly rounded crown, and its branches may sag bearing long oblong leaves.[18] Their leaves are thick and to some extent have a shining surface, resembling guava leaves. New leaves appear during the months from February to March after the old leaves have been shed between October and December. Inflorescence is apparent during May and remains up to the furthest limit of June. The blossoms are off-white in color, and berries appear in the period of July. The growth of the tree is moderate, with seven annual rings per inch cross section of its stem.[10] It is probably the best hardwood on the Indian sub-landmass, with a weight density of about 28−32 kg/ft.[3] Though seasoning of gum ghatti tree wood is quite difficult if left unsupervised in the sun, where it tends to split, keeping the logs in shade at least 6 months reduces splitting.[10]

2.2. Mechanism of Exudation and Tapping, Collection, and Harvesting Practices. Generally, gum from the ghatti tree is exuded from all of the bark irrespective of the position, for example, a branch or tree trunk. Exudation of gums occurs upon injury or exposure to harsh climatic conditions and is initiated for the safeguard of nutrients or when required by the tree for existence.[5] Exudation of gum occurs naturally due to pressure created within the bark by extreme natural conditions without wounding, such as common methods used with other exudate gums.[10] However, to increase the yield of gum, cut injuries can be carefully introduced in the tree bark.[19] If the incisions are crudely and heavily introduced (e.g., with heavy blows by axes), there may be permanent damages, affecting the life span of the gum ghatti tree.

An improved tapping method in which gummosis is increased significantly relies on the application of ethephon (1600 mg) to enhance the gum ghatti yield (466 times), as reported by Bhatt.[20] Ethephon is an ethylene-releasing synthetic chemical and mimics the effect of water stress, leading to schizolysigenous formation of gum cavities in the axial parenchyma of sapwood. Associated with formation of cavities, many vessels of the secondary xylem become clogged with the gummy material.[20,21] Other commercial tapping methods to obtain yield sof gum ghatti utilize various methods like blazing, peeling, or making deep cuts on base of bole or stem.[21] Collection/picking of the soft gel-like gum is done manually from tree bark at particular sites regularly to provide a smooth flow of fresh gums continually at the same sites. In order to increase the yield, basic practice is to pick the old gum and clear a path for new gum to streamflow.[5] The best time period for gum collection is during the absence of monsoon rains, and the maximum amount of gum is harvested throughout the late spring, for example, between the months of March and mid-June. During this time, as the climate gets hotter, gum yield increases.[19,22] Major gum harvest is in the month of April, when average yields approach approximately 1−2 kg/tree.[18]

Traditionally, solidified gums have been handpicked by tribal people residing in the forest every day by collecting single nodules of gum from trees. They generally use axes or sharp edged tools to separate the gum from the bark.[20] This is the main reason for the impurities associated with freshly collected gums. Further contamination is due to the conventional methods used to store the gum.[5] World harvest of gum ghatti is relatively miniscule and probably does not exceed 12 000 tons.[19,22] India represents 30% of the overall gum ghatti production worldwide, and 64% of it is produced in Maharashtra.[19,23] Apart from the Western Ghats of Maharashtra, other regions where gum ghatti is harvested include dry plateaus of Vindhyachal, Satpura, Madhya Pradesh, Jharkhand, Chhattisgarh, Bihar, Odisha, Gujarat, and Andhra Pradesh.[21,24] The population density of gum-yielding species of *Anogeissus latifolia*, *Boswellia serrata*, and *Sterculia urens* may be as high as 11 and 18 individual trees/hectare in Madhya Pradesh and Chhattisgarh, respectively. This has allowed the gum-producing forest area to be marked for assortment and divided into various small, medium, and large units. These units are sold in advance through tenders and auction by federations, authorized by the state government.[25] The prices of different grades of gum ghatti for the year 2015−2016 were around Rs. 600−800/kg for grade 1, Rs. 200−300/kg for grade 2, and Rs. 100−150/kg for grade 3.[23] In certain parts of India, gum ghatti is utilized as a prosperity item as an image of status and wealth,[26] and as a result the prices may fluctuate considerably.

3. PROCESSING, STORAGE, AND HANDLING

Freshly exuded gum ghatti has a high moisture content (more than 30%, wet basis (wb)) and is very soft in nature. There are more chances of contamination and microbiological spoilage at this stage due to the high moisture content. Thus, to reduce its moisture content for safe storage (10−13%, wb) and further processing, collected exudates are left for sun-drying in the open for few days or mechanically dried in a few hours.[27] Dried

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974−9990

hardened gum nodules acquire a rounded tear-like shape after drying and are suitable for further processing.[28] Contaminations with derivatives like bark, sand, dust, etc. may be between 1% and 3%, while ash content may be in the range between 3% and 5% depending on the grade of the material.[29]

Gum ghatti can be categorized into three grades based on the color, viz. white, yellow, and red. Grade 1 is off-white to buff colored, grade 2 represents light amber to brown, and grade 3 is dark brown.[27] The color and hence the grades are dependent on the contamination level present in gum ghatti. Appropriate knowledge of gum ghatti tree plantation and unit operations like cleaning, winnowing, etc. yield the best quality of ghatti gum. Gum ghatti processing varies as per the need of gum processing and manufacturing industries. The general outline for cleaning and grading of gum ghatti is shown in Figure 1.

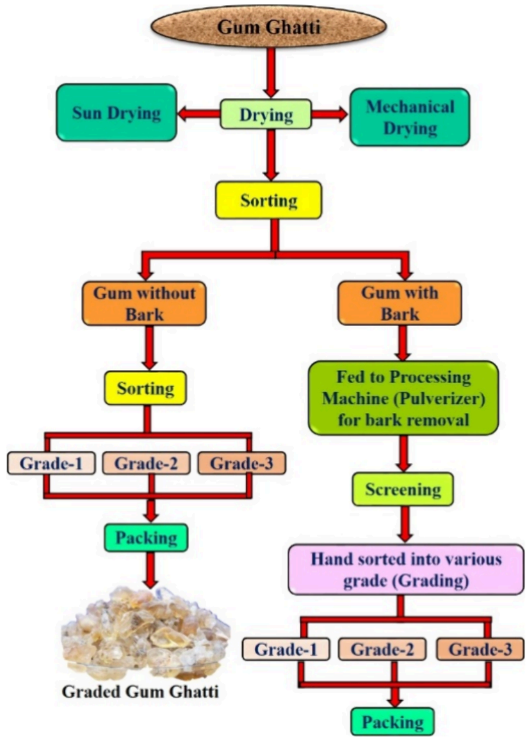


Figure 1. Outline flow of the cleaning and grading of gum ghatti.

3.1. Method of Manufacture/Processing. Collected and stored (moisture content, 10% wb) gum ghatti can be further processed to add more value in quality for direct use as well as in its processed form in food and pharmaceutical products for higher monetary returns. Gums with varying levels of impurities and color need primary processing such as cleaning, sorting, and grading.[5] Gums with large bark pieces may be cleaned by hand in primary processing centers. Lighter bark contaminants adhered to gum ghatti samples may be removed with a pulverizer machine. Pulverized gum ghatti is separated on the basis of particle sizes using different mesh size screens, and residual barks are eliminated. Gum ghatti free from bark can be further sorted by hand to remove particles that are not suitable for storage and marketing and can then be graded into grades 1−3, according to impurity levels and colors.[28] Ghatti gum tears can also be further processed by pulverizing tears into a fine powder. Meshes of different sizes can be used for the separation of the gum ghatti powder based one particle sizes as per the requirement of the users and consumers. During pulverizing process, particle breakdown may occur that results in optimal separation of adhered impurities from the gum, providing high quality purified clear gum ghatti powder.[30] Such preparations are partially dissolved in water, filtered, and sterilized. The final product is either prepared directly as the gummy, lumpy form after sterilization or as a powder by drum drying or spray-drying processing.[31] Of note, gum ghatti powder produced by such spray-drying techniques (e.g., commercially available Gatifolia SD preparation) is completely soluble in water and of consistent color.[10] Further, the viscosity of aqueous solution of spray-dried gum ghatti falls between gum arabic and gum karaya, and the gum has a high degree of solubility and emulsification properties. As such, these preparations are extensively used as emulsifiers in several emulsion formulations that are not stabilized by gum arabic and other gums.[26] A generalized outline for processing gum ghatti powder is shown in Figure 2.

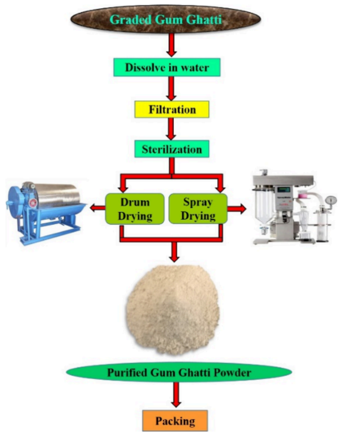


Figure 2. General outline for the manufacturing process of gum ghatti powder.

3.2. Storage and Management. The journey of gum ghatti from tree to end user can take anywhere between 3 and 12 months.[5] Hence, proper storage and packaging are required to maintain its quality parameters. Primary processed gum ghatti, which is graded in to different grades, can be conveniently packed in up to 50 kg burlap sacks for bulk storage and transportation. Bulk storage of gum ghatti in warehouses is usually recommended in cool and dry conditions in order to avoid agglomerate and lump formation and enhance shelf life.[17] When the gum ghatti is kept in enormous volumes, a faint sweetness of taste and a very faint odor are perceived.[28] The supply chain of raw and processed gum is shown in Figure 3.

3.3. Quality Control. As indicated, primary processed gum ghatti can be sorted on the basis of color and foreign matter content and graded into three grades, which are employed for diverse applications.[17] According to the grade, the color of the gum ghatti varies from lighter to dark (nearly black). Moreover, levels of impurities, total ash, and acid-insoluble ash vary from low to high, while viscosity varies from high to low according to grades (grade 1 to grade 3, respectively). Bureau of Indian Standards specifications (IS 7239:1974) for food-grade gum ghatti are listed in Table 2.[33]

3.4. Composition and Structure. For the most part, gum ghatti is composed of polysaccharides (78−89%), moisture

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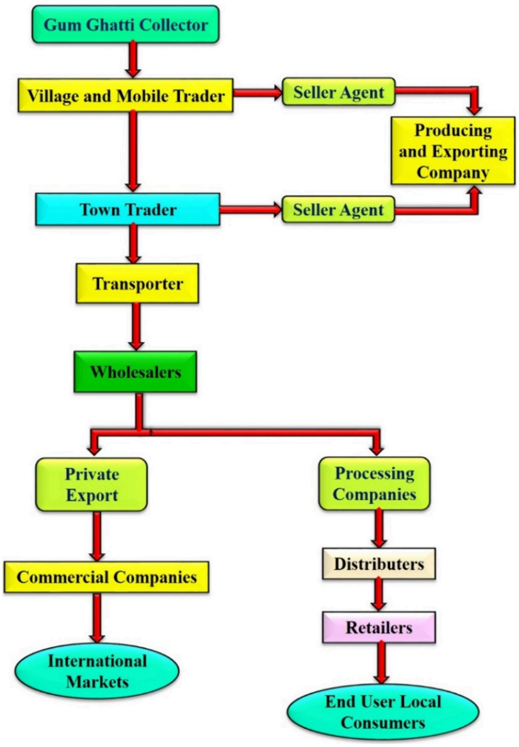

Figure 3. Supply chain of raw and processed gum.

Table 2. Quality Parameters for Food-Grade Gum Ghatti

grade	impurities (%)	total ash (%)	acid-insoluble ash (%)	viscosity, cps (5% solution)	moisture content (%, wb)
grade 1	0.9–1.6	1.4–1.9	0.02–0.2	30–400	12–15
grade 2	1.4–3.6	2.2–3.9	0.2–1.0	30–350	12–15
grade 3	11.0–15.0	6.0–10.0	3.7–5.8	30–300	12–15

(8–13%), proteins (3.40- 4.34%), and ash (2.16–4.0%), which occurs in nature as mixed calcium and magnesium salts of uronic acid and/or ghattic acids. The majority (ca. 90%) of total sugars in gum ghatti consist of arabinose and galactose.[14,34,35] The proportions of sugars in gum ghatti generally are a 48:29:10:5:10 molar ratio for L-arabinose, D-galactose, D-mannose, D-xylose, and D-glucuronic acid, with <1% of rhamnose.[36] As per work done by Aspinall et al.[37] and Jefferies et al.,[38] gum ghatti's structure contains alternating 4-O-substituted and 2-O-substituted μ-D-mannopyranose units and chains of 1 → 6 linked β-D-galactopyranose units with side chains of L-arabinose units; however, the complete structural information has not been deciphered completely due to limitations of analytical tools. Recently, Kang and co-workers,[39] attempted to elucidate the complete structure of gum ghatti using fractionation. Out of the four fractions, F50, F65, F80, and FS, three (F50, F65, and F80) corresponded to precipitates of gum ghatti solutions (15% w/v) in ethanolic solvents of varying concentrations (50%, 65%, and 80% v/v). Fractions F80 (precipitate of 80% ethanol gum ghatti solution) and FS (supernatant of F80) were selected to explain the main structure and surface activity of gum ghatti, respectively, by using methylation analysis and 1D and 2D NMR spectroscopy. The results concluded that the main structure of gum ghatti is a highly branched polysaccharide and the majority of the terminal units are α-L-Ara*f* (arabinose in furanose form) with small amounts of T-Glc*p*A (galactopyranuronic acid in pyranose form), T-Ara*p* (arabinose in pyranose form), T-Rha*p* (rhamnose in pyranose form), and T-Gal*p* (galactose in pyranose form). The structure of gum ghatti is shown in Figure 4.[34,40,41] The soluble (FS) fraction was found to have a

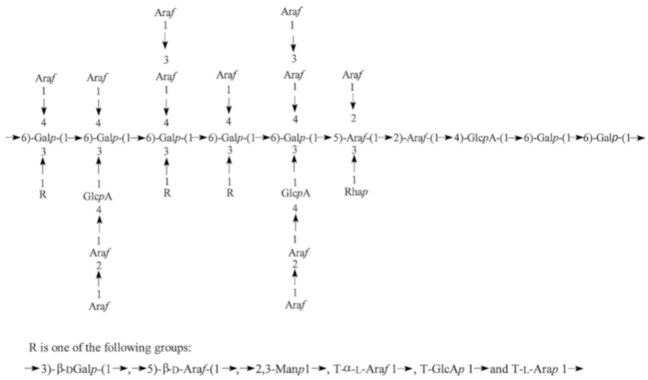

Figure 4. Proposed structure of the F80 fraction from gum ghatti.

globular structure with a highly branched polysaccharide containing composed of rhamnose, arabinose, galactose, and glucose in the ratio of 2.3:72.9:16.4:8.6, with a small amount of acetyl substitution, 4.6% proteins, and 2% uronic acid (Figure 5).[40]

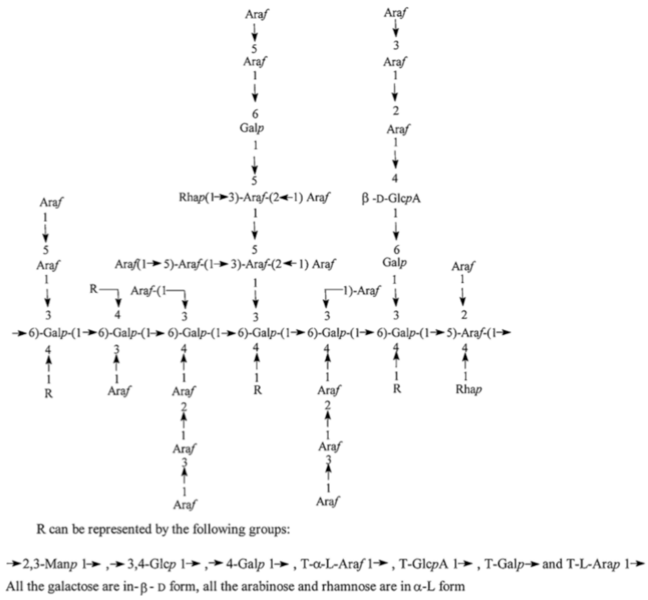

Figure 5. Proposed structure of the gum ghatti fraction FS.

In comparison to F80, fraction FS is much more branched and has longer side chains; consequently, FS is more soluble than F80 and shows better physical properties like excellent surface activity.[34] The glycoprotein nature of gum ghatti was examined by Kang et al.,[42] who showed that proteins or polypeptides are attached directly to the core of the polysaccharide, as shown in Figure 6.

4. PROPERTIES

The physical properties of gum ghatti largely depend on the chemical behavior of its complex polysaccharide moiety in aqueous media. Gum ghatti contains calcium and magnesium salts, which contribute to the 80% water-soluble portion, in

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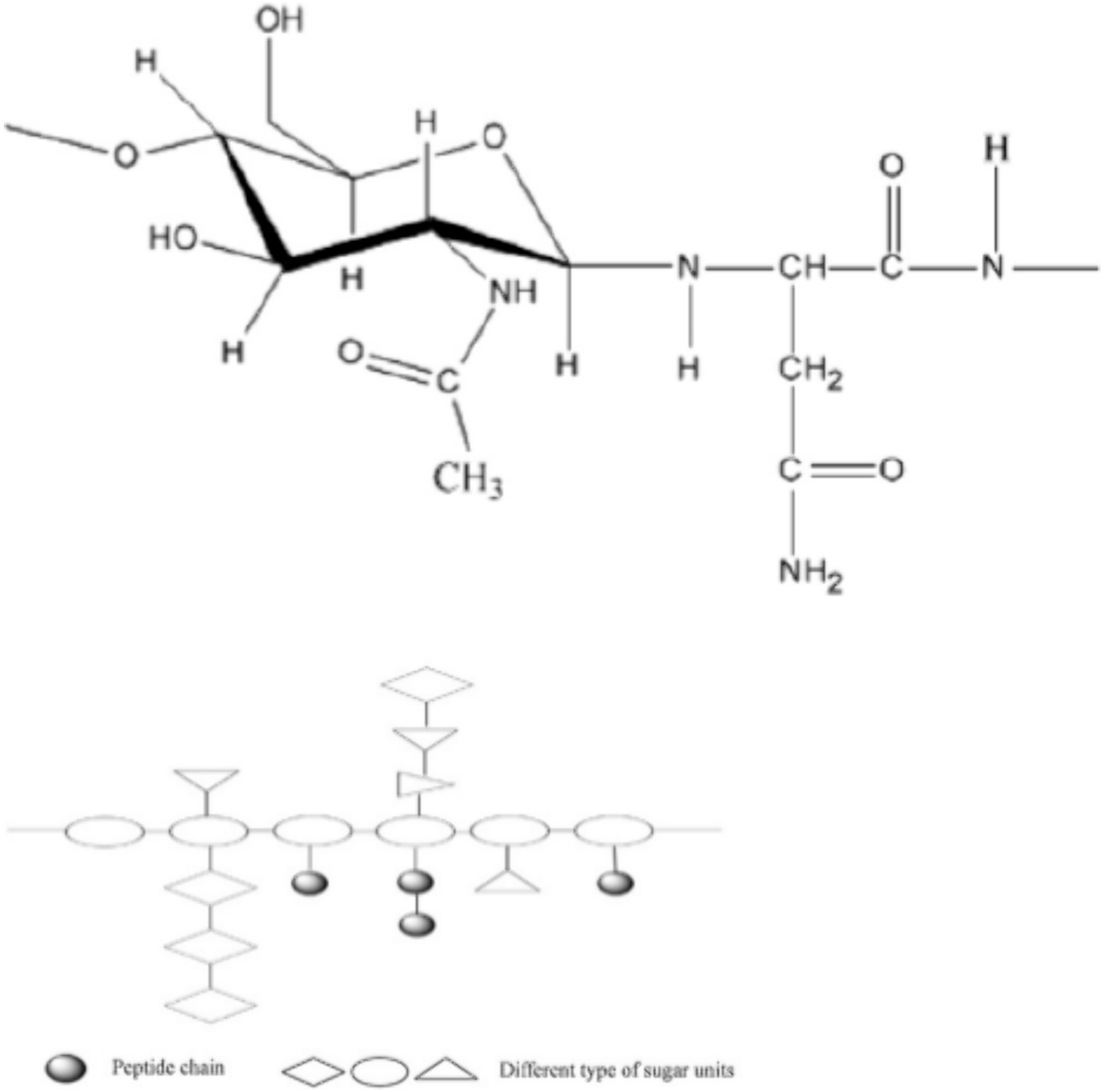

Figure 6. Linkage pattern of amino acid and sugar units in gum ghatti.

addition to the insoluble water-swellable fraction, which forms the gel component. The formation of the gel is due to the intermolecular linkage, not because of calcium ions.[41] As such, gum ghatti is partially soluble in hot water, and the water-swellable gel component can be dissolved in water by the process of maceration.[43] In fact, gum ghatti is insoluble in organic solvents but can be dissolved in polar solvents such as water.[44] The rate of dissolution and viscosity of gum ghatti are heavily influenced by particle size, pH, and temperature, and both solubility and viscosity increase with decreasing particle size and pH of the solution and increase with the temperature of the solution. The rate of hydration is influenced by the presence of salt and binding material, and a reduced rate of hydration is observed in the presence of dissolved salts and other water-binding agents, such as sucrose.[9] Accordingly, the physicochemical properties, for example, water holding capacity (WHC), viscosity, hydration, and solubility, are related to the molecular structure (e.g., the class and number of monosaccharides present and the type, number, and extent of connected glycosidic linkages). The presence of protein segments, alongside the monosaccharide moity of gums, may likewise influence their water solubility.[45]

Some key physicochemical and functional properties like bulk density, true density, angle of repose, solubility, electrohydrocyclization (EHC), operability level coefficient (OLC), coefficient of friction, and compressibility index vary with the different grades of gum ghatti. In the food industry, processing, and pharmaceuticals, these need to be considered to facilitate common unit operations like grinding or pulverisation, sieve separation, filtration, sedimentation, centrifugation, drum-drying, spray-drying, freeze-drying, mixing, and conveying in order to get high-quality, purified, and processed gum ghatti for diverse applications.[48] Thus, parameters like bulk density, true density, angle of repose, coefficient of friction, and compressibility index are needed for optimal processing in equipment such as tablet-making machines, storage hopper designs, and conveying systems. On the other hand, parameters like solubility, EHC, and OLC are needed for various process like, drum-, spray-, and freeze-drying.[47] In addition to basic chemical structure (including carbohydrate backbone and side chains), processing parameters are equally important for determining the final characteristics of a natural gum for its eventual performance in any industrial application.[48] Lastly, gum ghatti has a similar

https://doi.org/10.1021/acsomega.3c08198
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monosaccharide profile compared to gum arabic, and other properties like viscosity and emulsification behavior lie somewhat in between gum arabic and gum karaya.[49,50]

4.1. Rheology. Rheology deals with the flow and deformation of aqueous and solid material, respectively. Rheological properties of gums are helpful in the determination of flow behavior, consistency, mouth feel, ease of conveying, and processing operation in industrial applications.[51] The flow behavior of gums is either Newtonian (flow behavior index, $n = 1$) or non-Newtonian, viz., pseudoplastic ($n < 1$) and dilatant or shear thickening ($n > 1$). Determination of these properties hence is very helpful in quality control, sensory evaluation, handling applications, and illustrating the size and shape of macromolecules.[52,53] The rheological behavior of gum ghatti can be calculated by eq 1.

$$\eta_a = K\dot{\gamma}^{n-1} \tag{1}$$

η_a is the apparent viscosity, K is the flow coefficient (Pa·s^n), $\dot{\gamma}$ is the velocity gradient (s^{-1}), and n is the flow behavior index (dimensionless).[54]

A gum ghatti solution with a concentration of 5% w/v shows shear-thinning (decrease in viscosity as stress increases) at lower velocity gradients and reveals Newtonian flow at higher velocity gradients.[26] Based on time-dependent shear-thickening behavior, Rao[53] suggested that gum ghatti with a concentration greater than 10% exhibits shear thickening ($n > 1$) and shows negative hysteresis because of the rise in the size of the structural components, which results in higher resistance to flow during shear. The storage modulus (G') gives the capacity to store energy elastically, and the loss modulus (G'') is used as a measure for the capacity to release stress in form of heat in the field of rheology. Deviation in G' and G'' is associated with complex viscosity (η*) used for the characterization of plant gums. The rheological behavior of gums can be measured by other parameters such as variable shear rate, shear stress sweep, and constant shear rate known as frequency sweep. For the rheological behavior of gums, frequency sweep is a major parameter because it gives detailed information about the structure and arrangement of a gel based on G' and G'' values. Generally, gums with $G' \gg G''$ behave like semisolids and form a gel.[55] On the other hand, gums with higher frequency dependence behave like a molecular mess structure. Mathematically, gums having lower value of tan $\delta = G''/G'$ at higher frequency and a higher value of tan δ at lower frequency behave like solids and liquids, respectively.[56] It was observed that the ratio of G'' and G' is greater than 1 for gum ghatti, which reveals that it does not act as a characteristic viscoelastic gel. This means G'' prevailed over the G' at all frequency and temperature sweeps under the range of frequencies (0.01−100 Hz), temperatures (20−25 °C), and concentrations (5%, 7%, 10%, 15%, 20%, and 25%, w/w). Based on these characteristics ,gum ghatti can be utilized as an emulsifier in different food and pharmaceutical products.[14]

4.1.1. Solution Properties: Viscosity and pH. The properties of a gum solution largely depends on its solubility, which plays an important role in emulsification, foaming, stabilization, and thickening for food and pharmaceutical application. As indicated, solubility depends on the structure of the gum, the presence of a protein fraction, the molecular weight, and the type of solvent used.[57] Solution properties like the intrinsic viscosity (η) of a gum represent the final viscosity (hydrodynamic volume of individual molecules) of dispersion for the polysaccharide. It is determined by multiple light scattering method, molecular sieve chromatography, and using mathematical model such as Kraemer and Huggins curves and the Floxy−Fox equation (eq 2).

$$T_g = T_{g,\infty} - \frac{K}{M_n} \tag{2}$$

T_g is the maximum glass transition temperature, K is the empirical parameter, and M_n is the number average molecular weight.

In previous studies, the intrinsic viscosity (η) of gum ghatti in concentration ranges of 0.1−1%, w/w in 0.1 M NaCl was detected to be 92 mL/g.[14] As compared to gum arabic, the intrinsic viscosity of gum ghatti showed higher η, indicating that gum ghatti molecules are of asymmetric nature.[58] According to Karamella and co-workers,[59] the intrinsic viscosity of gum arabic is in the range of 1−73 mL/g for different samples from Sudan. The viscosity of the solution increases with a decreases in temperature and increase in concentration. In increase in concentration causes overlapping of chains and formation of more physical contact, altering the flow behavior of gum ghatti at certain concentrations; beyond that concentration, overlapping chains of gum ghatti start extending, resulting in alterations in viscosity.[53] The extent of chain overlap is calculated by the coil overlap parameter, $c[\eta]$, which relates to volume engaged by molecules of gums in the aqueous solution. The viscosity of the gel fraction of gum ghatti is 10−30× greater than that of the soluble fraction.[60]

Gum ghatti solution is also affected by the pH of the aqueous medium, and the pH of gum dispersion affects the viscosity of the solution. As the pH of the gum dispersion increases, the viscosity decreases since higher pH causes an increase in intermolecular interactions between functional groups of the polysaccharide chain.[61] Hydrated aqueous solutions of ghatti gum (5%) show maximum viscosity in a basic pH of 7.8 at normal room temperature and pressure. Further, the emulsification action of gum ghatti is due to the presence of the arabinogalactan−protein complex, which binds to the sugar molecule of gum. As the impurity level of gum ghatti increases, the emulsification action decreases. In the emulsification process, the oil−water interface and hydrophilic polysaccharide chains form a protective shield due to the surface activity of the protein complex.[62] As the temperature of the emulsion is increased to 60 °C, its stability also increases, which means it is safe upon mild heating.[58]

4.2. Functional Characteristics. *4.2.1. Density.* Density plays a crucial role in the determination of functional properties of tree gums and their powder. It depends on the shape, size, compaction level, and arrangement of the particles. The bulk and true density relate to the particle compaction status of the material.[63] Bulk density refers to the measure of bulk material in which interparticle forces, size, shape, and distribution play significant roles in determining the density,[64] whereas determining the true density of a particle arrangement is dependent on the exclusion of volume of the voids and pores.[65] The bulk density of powder may be estimated with a measuring cylinder and calculated as the weight of the powder divided by the volume attained by the powder.[66] The bulk densities of various natural gums lie between 0.95 and 1.20 g/mL (950 and 1200 kg/m^3), and for gum ghatti the bulk density is 1.13 g/mL (1130 kg/m^3). True densities are generally determined using the liquid displacement method,[67] and true density of natural gums have generally been recorded between

https://doi.org/10.1021/acsomega.3c08198
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1 and 1.66 g/cm^3. For gum ghatti, the true density was calculated to be 1.66 g/cm^3 (1660 kg/m^3), which is similar to piyar gum, guar gum, and gum tragacanth.[68]

4.2.2. Compressibility Index. The compressibility index is one of the powerful indices used for particulate interaction in powder flow properties.[69] It gives an idea about the tendency of powders to flow and is expressed as a ratio of tap density to bulk density. The Hausner ratio is related measure and is also determined in a similar fashion (eqs 3 and 4).[66] Bulk density, moisture content, size, shape, and cohesiveness of the gum material affect its compressibility index.[70] As a rule of thumb, a compressibility index value between 11 and 15 indicates good powder flowability, a value between 16 and 20 indicates fair flow ability, a value more than 31 shows poor flowability.[69] Gum ghatti has a compressibility index of 31.92 and comes under the category of poor flowability as compared to acacia gum (11.2) and xantham gum (6.4).[68]

$$\text{Hausner's Ratio} = \text{Tap density}/\text{Bulk density} \tag{3}$$

$$C = \frac{\rho_T - \rho_B}{\rho_T} \tag{4}$$

C is Carr's compressibility index, ρ_T is the tapped density, and ρ_B is the bulk density

4.2.3. Water Holding Capacity and Oil Holding Capacity. The water holding capacity (WHC) of exudate gums has wide industrial relevance, as it determines the rate of vaporization and freezing, retention of moisture, and texture.[71] WHC determined the safe storage conditions and preparation of food and pharmaceutical items.[72] Generally, WHCs of different natural gums vary widely and can be anywhere between 35 and 1025 g of water/100 g of gum. Gum ghatti holds water at 304.33 g of water/100 g of gum, whereas, other exudate gums like acacia (35 g of water/100 g of gum) and psyllium (1025 g of water/100 g of gum) have lowest and highest WHCs, respectively.[68] The poor WHC of acacia gum is due to the presence of a slightly acidic salt (D-glucoronic acid) of a complex polysaccharide that comprises ions of calcium, magnesium, and potassium and forms highly viscous solutions at 50% concentrations, whereas other gums such as gum ghatti, which are difficult to dissolve in aqueous media at concentrations higher than 5%, hold relatively more water.[73] WHC is reliant on the quantity and nature of water-binding moieties, such as the ratio of protein and polysaccharide fractions in the exudate gum. The water holding capacity (WHC) may be calculated as shown in the eq 5.[74]

$$\text{WHC} = (\text{SSW} - \text{SW})/\text{SW} \tag{5}$$

Where WHC is the water holding capacity, SSW is the swollen sample weight (g), and SW is the sample weight (g)

The oil holding capacity (OHC) of exudate gums indicates the amount of oil or fat absorbed per unit weight of exudate gum and is crucial for enhancing the texture, juiciness, lubricity, and liquefying sensation of the products.[51] OHCs of different exudate gums range from 115 to 215 g of oil/100 g of gum. For gum ghatti, the OHC has been calculated to be 160 g of oil/100 g of gum. In comparison, xanthan gum and tamarind gum hold oil at the lowest (115 g of oil/100 g of gum) and highest (215 g of oil/100 g of gum) values among the exudate gums.[68] Interactions of nonpolar parts of the side chains with hydrophobic fat and oil determine the capacity to hold oil. Indeed, reducing the amounts of hydrophobic impurities increases the OHC of purified gums.[51] The oil holding capacity (OHC) may be calculated using equation eq 6.[75]

$$\text{OHC} = (\text{HOSW} - \text{SW})/\text{SW} \tag{6}$$

OHC is the oil holding capacity, HSW is the held oil sample weight, and SW is the sample weight.

4.2.4. Solubility. The solubility of exudate gums in any aqueous medium is the most important factor to evaluate their utility, as it enhances the appearance and texture of the final products. Solubility is mainly affected by the protein fraction and monosaccharide composition in the backbone and side chains of the molecular skeleton. The solubility of linear structures of gum is low as compared to branch structures of exudate gum.[76] Generally, the solubility of exudates gums range between 60% to 84%, and the solubility decreases as the impurities, organic matter, and insoluble matter increase.[45] Gum ghatti has 72% solubility, which is intermediate among exudate gums, while karaya gum has among the lowest solubility (60%) among them.[68]

4.2.5. Angle of Repose. The angle of repose is a critical feature, indicating the flow characteristics of powder granules of exudate gums. It is evaluated by the resistance offered by gum powder to the flow under gravity and is reliant on the various surface properties of the particles.[77] Angles of repose of different exudate gums range between 380° and 40°, and gum ghatti and piyar gum have lowest angle of repose at 380°, whereas guar gum has the highest at 40°.[68] As per the report published by Onunkwo,[77] the angle of repose has an inverse relation with granular binding, indicating that decreases in the angle of repose result in an increase in the granule binding force. This may be because of the decrease in cohesive forces between larger granules formed at higher binding levels.[78] The angle of repose is expressed by eq 7.[66]

$$\tan q = h/r \tag{7}$$

θ is the angle of repose (°), h is the height (cm), and r is the radius of the plate (cm).

4.2.6. Static Coefficient of Friction. the coefficient of friction can significantly vary from material to material and for the same material from surface to surface.[79] Podczeck et al.[80] had concluded that friction properties can be predicted by properties of the surface that are in contact with material and may not be dependent on the chemical structure of compound *per se*. Thus, friction properties could depend on the hydrophilicity of the material, and hydrogen bonding, particle size, and presence of water all contribute to friction properties between particles and surfaces. The static coefficient of friction (μs) can be calculated using eq 8.[46]

$$\mu_s = \tan a \tag{8}$$

μ_s is the static coefficient of friction and α is the angle of tilt.

Static coefficients of friction of various gums were recorded by Sarkar et al.[68] on five surfaces, viz. glass, plywood, aluminum, steel, sunmica, and laminated sunmica. Gum ghatti showed the highest coefficient of friction on glass (0.62), whereas psyllium gum had the lowest (0.52) coefficient of friction against glass. On the other hand, on aluminum surfaces, gum acacia (0.58) showed the highest coefficient of friction, while gum ghatti (0.52) exhibited the lowest. For gum ghatti, the coefficients of friction against other surfaces like laminated sunmica, plywood, and sunmica, were determined to be 0.57, 0.56, and 0.55, respectively.

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974−9990

5. APPLICATION IN FOOD INDUSTRY

In the food industry, gum ghatti is widely utilized as a novel food additive in a variety of foods and value-added products. It changes the behavior of water in food products and act as an emulsifier, stabilizer, and thickening agent.[81] Various properties of gum ghatti such as acid resistance, salt resistance, and ability to bind with oil are better than those of other gums. As compare to gum arabic, gum ghatti has a high potential against acid resistance, salt resistance, and the ability to bind with oil at lower concentration.[58] While the viscosity profile and sugar composition are similar, the protein content for gum ghatti is approximately 1.5× higher than that of gum arabic. Emulsions of 5% gum ghatti show a similar viscosity and emulsification property as those using 15% gum arabic and have higher storage stabilities (i.e., maintain their suspension of oil without causing separation after storage) than gum arabic. Hence, gum ghatti may be more suitable for emulsion preparation with a high oil phase level. Further, it can be used to enhance the stabilization of emulsified particles even when processed under high pressure and an increased number of homogenizer passes.[13] Moreover, gum ghatti may be preferable for food industries, manufacturers, and end users because of the natural characteristics and cost effectiveness. Some of the most common food applications of gum ghatti and their characters are discussed below in Table 3. Figure 7 provides the information on various applications of gum ghatti in food and pharmaceutical industries.

Table 3. Food Applications and Their Characters in Food and Beverages Industries

food application	characters	refs
emulsifier for carbonated drinks	stabilizes water and oil emulsions	5, 10
beverages (powder)	encapsulation of flavor	82
wine	colloidal stabilization and tannin suspension	83
flavors (powdered)	encapsulation of oil entrapments	22
fruit jellies	independent gelling of sugar	5, 33
sweets	source of fiber	84
coated sweets	coating film forming and glazing	85
gum drops	prevent sugar crystallization	26, 32
caramels	improves chew ability	5, 31
bakery products		25, 16
powdered medicines	encapsulation and oil entrapment	83, 15

5.1. Beverages. The beverage industry uses gum ghatti for controlling the viscosity, thickness, and optical clarity of their products. Optical clarity is one of the most important visual properties of beverages and is critical for attracting consumers and end users. During enrichment or supplementation of a beverage by fat-soluble colorants such as β-carotenoids, turmeric pigments, or other means, increased turbidity cause the formation of a separate layer at the top of the beverage, which needs to be diminished. Therefore, 30−65 wt % gum ghatti is very effective against fat-soluble active ingredients for the enrichment (vitamin A, D, E, K, and derivatives), fortification, and/or coloration of food and beverages, which attenuates the separation phenomena and visible turbidity problems.[86] Gum ghatti may be added to prevent the adhesion of carotenoid pigments to manufacturing equipment or containers such as PET bottles during the production of liquid foods. Studies indicate that for beverage production

Figure 7. Major functions of gum ghatti in food and pharmaceutical applications.

different amounts of gum ghatti can be employed to inhibit adhesion. Other natural products, such as gum arabic and modified starch, may not achieve such adhesion inhibition for carotenoid pigments to containers.[87] Accumulation and sedimentation of turmeric pigment used to color and enrich hydrous solutions is effectively prevented by the addition of gum ghatti in the concentration range of 1−10%.[88,89] In the field of brewed cappuccinos, espressos, and flavored beverages as well as café and coffee houses, purified or modified gum ghatti is utilized to enhance the flavor, creaminess, and sweetness characteristics and acts as thickening agent as well as edible carrier for emulsified fat in nonfoaming creamer.[90] In the case of table syrup emulsions, gum ghatti may be used to get stable emulsions, which improves resistance to separation of oil and aqueous medium. It also modifies the refractive index of the syrup until it becomes clear. Such stable emulsions are widely used in the food industry for salad dressings, sauces, candy cream, and syrup.[24]

5.2. Dairy Products. In the dairy industry, gum ghatti is used for the heat treatment of milk and stabilization of ice cream and frozen products. During the high-temperature short-time (HTST) process and retort sterilization of milk at temperatures exceeding 120 °C, gum ghatti may be employed to retain the activity of the basic protein fraction in the milk.[91] Gum ghatti is used for the stabilization of frozen products, especially for ice cream stabilization, because of its high water binding properties. Since the stabilizer concentration affects the flavor of the products, gum ghatti is particularly suitable as only up to 1% concentration of gum ghatti serves as an efficient stabilizer for ice creams.[92] A plain ice cream mix with 10% fat, 11% nonfat solids, 15% sugar, and different levels of gum ghatti (0.25, 0.50, 0.75, and 1.0%) as a stabilizer and emulsifier was prepared using buffalo milk, cream, skim milk powder, and sugar. The concentration of the stabilizer was found to affect the viscosity of the ice cream mix, which in turn influenced the mouth feel (i.e., texture) of the finished product. Optimal usage of gum ghatti as a stabilizer based on these characteristics has been proposed for gum guar (0.96%), gum acacia (0.91%), and gum ghatti (0.95%).[93] Aerated frozen confectionery products comprising of 0.2−3% by weight of gum ghatti stabilizer have also been manufactured.[94]

5.3. Bakery Products. Baking is a unit operation related to the production of flour-based items, which uses dry heat in some kind of oven (hot air or microwave) to alter the eating quality of foods. During this unit operation, heat and mass

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974−9990

Table 4. Traditional Practices of *Anogeissus latifolia* Plant Parts

plant part used	indigenous and remedial uses	references
gum	edible (with cup of water or milk for lactation)	108
	dysentery	25
	tonic (postnatal) to women after child birth	16
stem bark	scorpion string	16, 109, 110
	fever	111
	stomach disorder	16, 112
	anemic condition and urinary discharges	25
	cough, lever disease, skin disease, and snake bite	5, 16, 127
	piles (concentrated liquor is prepared by boiling the bark in water and patients are advised to wash the anus with this, or bark is burnt and anus is exposed to oncoming fumes)	5, 16
	jaundice (very popular among the traditional healer), etc.	5
leaf juices	purulent discharges from the ear	113, 123
leaves	leather industry (for the manufacture of shrunken grain, constitute the natural texture of leather) because of the high content of tannin	5, 19, 128
	tassar silk (leaves fed on by *Antheraea paphia* moth to produce silk)	29
	fodder for cattle and buffalo (leaves are digestible nutrients up to 45%, contain 7.45−11.5% crude protein)	129
fruits	diarrhea	5
	astringent to bowels and cures kapha	123
wood	house construction, posts, agricultural implements, elastic nature of this wood adds to its utility, well-seasoned wood used for quality furniture and cart axel (reason behind the name " axel-wood tree")	5, 129
	good quality charcoal and firewood (energy value of 17600−20500 kJ/kg)	129
roots	liver related troubles	5
flowers	pollen source of bees	129

transfers occur simultaneously, which enhances the shelf life of the food products by destroying microorganisms and reducing the amount of available water.[95] Bakery items includes breads, biscuits, pastries, cream cake, sponge cake, quick bread, and pasta formulations.[96,97] The addition of gum in bakery products enhances dough quality by increasing the oil and water holding capacities and the emulsion activity of the flours. It increases shelf life and sensory quality and reduces fracture of the baked product, which is not achieved by flour alone.[98]

Emulsions of 5% gum ghatti show a similar viscosity and emulsification properties as those using 15% gum arabic due to presence of a higher percentage (1.4%) of proteinaceous component in gum ghatti.[13,58] Further, the addition of 0.1−0.2% gum ghatti may enrich the loaf volume, softness, texture properties, and water absorption, as shown by a farinograph.[99]

5.4. Edible Films and Coating. Edible films and coatings have been globally recommended for replacing synthetic and plastic polymers because of their nontoxic and biodegradable nature.[100] They are relevant for retaining moisture and essential components and help in the respiration process for controlled exchange of oxygen, carbon dioxide, and ethylene gases, improving surface sterility and retaining solute transmission in food preservation.[101] Films prepared from edible resources such as gums, seaweeds, starch, chitosan, pectin, and pullulan are the most effective alternatives because of their environmentally sustainable nature and potential ability to reduce pollution worldwide. Films derived from various natural gums can be used to improve the organoleptic, nutritional, and microbiological properties of food.[102] Edible films derived from polysaccharides act as effective oxygen barriers and have been extensively used in the food industry. Due to their hydrophilic properties, gums have the ability to act as moisture barriers in different food items.[103] Consequently, they are mixed with different materials (honey wax, solid fats, palm oil, and stearic acid) to improve the water evaporation permeability (WVP).[104] The feasibility of creating an edible film using gum ghatti was investigated by Zhang et al.,[85] who found that it can be utilized as a novel film making material with increased usefulness and adaptability of edible films. Edible films prepared with gum ghatti may have 0.75−1.0% w/v gums and may employ either of the two plasticizers, glycerol or sorbital. Glycerol-based gum ghatti edible films were shown to have a more swollen network, whereas sorbital-based gum ghatti had a lower moisture content and water vapor permeability. The color of gum ghatti films seems to be green and yellow, and as the concentration of plasticizer increased, the whiteness index was found to decrease. Glycerol-based gum ghatti films behaved as type III isotherms, where an increase in the water activity of the film increased its moisture content and an increase in the temperature of the film decreased its moisture content, indicating that they may be useful as a novel fresh food preservation technique.[105] The edible films based on gum ghatti may act as a barrier for moisture, ultraviolet light, deteriorating gases, and temperature from the environment to enhance the shelf life of the food products. Therefore, they can be integrated with antimicrobials, probiotics, antioxidants, and aromatic compounds to improve their diverse application in nutrient rich food for the food industry.

6. PHARMACEUTICAL INDUSTRY

Medicinal uses of gum ghatti have been reported since ancient times in Ayurvedic and Unani therapies, and its unique properties also make it more valuable for use in different food items. Table 4 summarizes the traditional medicinal uses of gum ghatti. In the modern pharmaceutical industry, it is frequently utilized as an emulsifier and may be a better emulsifying agent than gum arabic.[13] Examination of different natural gums and their derivatives for various medicine formulations indicated that gum ghatti could be utilized as a potential vehicle for pharmaceutics as a tablet binding agent. Indeed, due to its highly viscous nature in an aqueous solution,

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974−9990

gum ghatti may be a superior stabilizer in the formulation of thick drug emulsions and suspensions.[122]

It has been reported that in three-layered matrix tablets used to treat high blood pressure and chest pain, gum ghatti releases diltiazem hydrochloride at a constant rate (zero-order kinetics).[114] The three-layered matrix consisted of gum ghatti along with guar gum and xanthum gum used as a matrix in the core as well the barrier layer acting as a release retardant. Any variations in levels of individual xanthan or guar gum and the blends of two gums in matrices did not produce zero-order drug release, and release followed first-order kinetics (eq 9). However, incorporation of gum ghatti in either the core or barrier layer modified the release toward zero-order kinetics ($r^2 \geq 0.9462$) (eq 10).

Zero order kinetics/Constant rate kinetics

First-order kinetics:

$$Q_t = Q_o + K_o t \tag{9}$$

$$Q_t = Q_o e^{K_{ot}} \tag{10}$$

Q_t is the cumulative amount of drug released at time t, Q_o is the initial amount of drug, K_o is the release kinetic constant, and t is the time at which the drug is released.

Another release matrix composed of gum ghatti and gum karaya as a matrix polymer for tablets containing diclofenac sodium was studied by Reddy and co-workers.[115] Diclofenac sodium is a potent anti-inflammatory, analgesic, and antipyretic used typically for the relief of pain and inflammation. The plasma half-life of diclofenac is about 1−2 h, and its bioavailability is about 50%. Since it has a shorter half- life, the drug must be administered every 6 h. The increased frequency of administration and its harmful gastric side effects makes it a model drug of choice for the sustained-release dosage form.[115] In this contrast formulation of diclofenac sodium, karaya gum (16−32%), and gum ghatti (4−12%), the time taken for 50% drug release increased from 3.98 to 9.56 h,[116] indicating that drug release rate tends to decrease with increases in the concentration of the polymer (karaya gum or ghatti gum) because the viscosity of the gel layer around the tablet increases with increases in the gum concentration.[117]

In addition to emplying gum ghatti for pharmaceutical preparations, recent studies have also proposed the therapeutic actions of gum ghatti on its own. Thus, treatment with gum ghatti from *Anogeissus latifolia* at 750 mg/kg body weight was found to produce a significant decrease in the serum cholesterol and triglyceride levels and elevate the amounts of high-density lipoproteins (HDLs) in rodent models.[84] Antibacterial actions of *Anogeissus latifolia* bark were evaluated against Gram-positive (*Staphylococcus aureus*) and Gram-negative microorganisms (*Escherichia coli*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*). Moderate action was seen against all organisms. The use of an ethanolic concentrate of *Anogeissus latifolia* bark elicits skin wound healing properties in rodents by accelerating recovery.[118] Govindrajan et al.[119] examined the antiulcer potential of gum ghatti and aspirin against cold-resistant stress- and ethanol-induced ulcers and reported that the ethanolic extract significantly restrained ulcer development. The bark of gum ghatti is especially helpful in treating chronic diarrhea.[16] Further, L-arabinose from gum ghatti may be used for the preparation of nucleosides for oncological applications. Because of the high L-arabinose content, gum ghatti is a particularly suitable source of commercial L-arabinose.[6]

7. NON-FOOD APPLICATIONS

In addition to the food and pharmaceutical applications, gum ghatti has immense nonfood applications as well (Table 5).

Table 5. Food and Non-Food Category and Use Level

	% dose/level	function	refs
food			
beverages and beverage bases, nonalcoholic	0.2	emulsifier and emulsifier salt	33
all other food categories	0.1	emulsifier and emulsifier salt	33, 107
non-food			
printing		film forming	16, 106
hair fixers		binding agent	16
cigarette industry		adhesive for sticking paper	
petroleum industry		drilling mud conditioner	26
paper industry		coating and moisture barrier	122

7.1. Waste Water Treatment.

Waste water contaminants such as dyes, heavy metals, toxic chemicals, phosphates, nitrates, radioactive components, and biodegradable and pharmaceutical waste need to be eliminated from wastewater before its disposal in water bodies.[120] There are various techniques for the removal of pollutants from wastewater, including membrane separation, chemical oxidation, electro-coagulation, adsorption, coagulation, and flocculation.[121,122] Many of them have certain limitations, like low removal efficiency, high cost of treatment, and production of carcinogenic byproducts.[123] Gum polysaccharide-based polymer adsorbents have been effectively used for the expulsion of impurities from wastewater due to their accessibility, biocompatibility, low cost, and eco-friendly nature.[124] Generally chemical dyes are more soluble and stable in water, and their nondegradable nature is a serious ecological concern in municipal sludge treatments plants, affecting the survival of photosynthetic microbes.[124] Mittal and Mishra[125] successfully utilized a Fe_3O_4 and gum ghatti nanocomposite for the removal of methylene blue, a dye used widely in the paper and textile industries and as a hair colorant. Similarly, gum ghatti and acrylamide were used to obtain a copolymer for promoting the elimination of poisonous and microbial-resistant Congo red dye from wastewater.[126] Studies have also reported the utilization of other adsorbent gum ghatti- and 4-acryloylmorpholine-based nanocomposites for the adsorption of cationic dyes, such as rhodamine 6G and methylene blue, as well as metal particles (Cu(II), Cr(VI), and Hg(II)).[126] Lastly, Pal et al.[127] have studied the destabilization of aqueous suspensions of carbon nanoparticles via a synthesized hydrolyzed graft copolymer of gum ghatti and indicated its potential utility.

7.2. Hydrogels.

Hydrogels consist of an assembly of cross-linked polymer grids with the ability to swell and hold huge volumes of water without dissolving.[128] Hydrogels are employed in different research fields, including biomedical,[129] agriculture,[130] water purification,[131] sanitation,[131] biosensing,[132] and biotechnology fields.[133] Superabsorbent hydrogels have likewise been investigated principally for drug delivery

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974−9990

purposes. Natural gums, such as gum ghatti, are suitable raw materials for hydrogels. A hydrogel synthesized from gum ghatti and acrylamide utilizing a microwave-assisted embedding strategy was tested for its efficiency as an adsorbent. The drafted hydrogel with a swelling capacity of 211% successfully removed suspended particles in clay solution at neutral pH and 40 °C.[134] Biodegradable flocculants of an *Anogeissus latifolia*-derived gum ghatti-based hydrogel with acrylamide synthesized using graft copolymerization with potassium persulfate—ascorbic corrosive redox pair as an initiator and *N*,*N*′-methylene-bisacrylamide as a cross-linker, similarly showed highest flocculation effectiveness at concentrations of 15 mg/L polymer portion in an acidic medium at 50 °C. Biodegradation investigations of the copolymers were studied with a soil burial technique in which gum ghatti was able to significantly accelerate soil burial breakdown.[135]

A programmable gum ghatti-based hydrogel grid has also been assessed for release kinetics of anticancer therapeutics. Gum ghatti-based hydrogels with a customized cross-link density and mesh size beneficially regulate the drug release rate.[136] Further, hydrogels composed of gum ghatti, acrylamide, and acrylonitrile comonomers with a swelling capacity of 921% at neutral pH and 60 °C were found to absorb saline water from different saline water—petroleum fraction emulsions, and the maximum absorption was observed in the petroleum ether emulsion. The original hydrogel matrix, gum ghatti-cl-poly(AM), had an adsorption capacity of 769.23 mg/g; however, once TiO2 NPs were added, that amount rose to 1305.5 mg/g.[137] Similarly, microwave-assisted hydrogel synthesis with *N*,*N*′-methylene-bisacrylamide and ammonium persulfate were found to act as electrically conductive hydrogels.[138] Such a conducting polymer within the hydrogel may open new possible avenues in the field of fuel cells, super capacitors, dye-sensitive solar cells, and rechargeable lithium batteries. Further, interpenetrating polymer network hydrogels may elicit novel applications in the biomedical field, pharmaceuticals, environmental technology, and the tissue engineering sector.[139,140] Hydrogels composed of copolymers of gum ghatti and acrylic acid-aniline with cross-linker *N*,*N*′-methylene-bisacrylamide and ammonium persulfate have shown potential for regulating drug-releasing characteristics in a pH-dependent manner. This may allow regulation of drug delivery, stimulating fast release of the drug at early stages and decelerated release at later stages.[141] A smart hydrogel of etherified gum ghatti was recently developed by Ray et al.[142] and successfully tested for controlled delivery of ropinirole hydrochloride, which is used to treat Parkinson's disease.

7.3. Nanotechnology. Nanoparticles, made from either natural or artificial sources, are of extreme use in almost all aspects of everyday life. They improve our lives by intensifying the performance and effectiveness of multiple items utilized in a daily life. Nanoparticle synthesis from natural sources is considered as green synthesis in the field of nanotechnology.[143,144] In recent years, nanoparticles derived from non-wood forest produce have gained tremendous momentum in the fields of biosensors, agrochemical nanosensors, drug carriers, and cosmetics and in paint, food, and biomedical sectors. The applications of these nanoplatforms range from antibacterial functions to removal of heavy metals, organic pollutants, and radioactive substance from the wastewater.[145]

Gum ghatti has potential applications in various fields of nanotechnology for drug delivery, biosensing, diagnosis, and theranostics uses (Figure 8). For instance, Shelly et al.[146]

Figure 8. Potential use of gum ghatti in the field of nanotechnology.

prepared polyelectrolyte 121.6 nm sized nanoparticles with gum ghatti (0.12% w/v) and chitosan (0.22% w/v), with ofloxacin (0.1% w/v) as the model drug. It was found that these polyelectrolyte nanoparticles had 94% entrapment, with antibacterial activity exhibiting Higuchi's square-root release kinetics. Based on the results of in vitro drug release tests, the Gg-*g*-AM(Au) nanocomposite with gold-embedded gum ghatti-grafted polyacrylamide showed a higher release of curcumin due to an enlarged porous network.[147] Magnetic nanocomposites utilizing gum ghatti cross-linked with poly(acrylic acid coacrylamide) supported with magnetic iron oxide have been used for the expulsion of toxic dye rhodamine B from wastewater effluent from biotech and cosmetic industries. Green synthesis of palladium nanoparticles with mean particle size of 4.8 nm was developed using arabinogalactan polymer and gum ghatti by Kora and Rastogi.[148] They found that these nanoparticles elicited improved antioxidant activities and exhibited excellent catalytic activity in dye degradation, indicating their usefulness as nanocatalysts in environmental remediation. Metallic nanoparticles, especially gold nanoparticles, are being synthesized using gum ghatti as a reducing agent, with potential applications as a capping agent for stability as well as surface functionalization for drug delivery purpose. It has been observed that as the gum concentration increases, the hydrodynamic size of the gold nanoparticle decreases considerably.[149]

7.4. Miscellaneous Application. *7.4.1. Leather and Silk Industries.* The leaves of gum ghatti are used adequately in the leather industry for the manufacture of shrunken grain, which is frequently used in watch straps and other bands.[19] Gum ghatti leaves have tannins and in combination with goran tannin (obtained from Goran bark) or karada tannin can be used for the manufacture of suitable quality leather.[128] The leaves of *Anogesious latifolia* may be used as feed for the *Antheraea paphia* moth that creates tassar silk (Tussah), a type of wild silk of commercial importance.[29]

7.4.2. Petroleum. Gum ghatti has applications as an emulsifier for both petroleum and nonpetroleum waxes for the paper industries and acts as coating layer and moisture

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974−9990

barrier to enhance paper quality and shelf life.[26] It is also used as stabilizer in auto polishes. It replaces guar gum in the hydraulic fracturing fluid in the oil and gas industry. Suitable for low-permeability unconventional sources such as shale gas. The larger molecular weight of gum ghatti polymer improves proppant carrying capacity and fracture propagation because it is a good thickening agent and becomes good alternative during fluctuating demand and pricing of guar.[152]

7.4.3. Mining. Gum ghatti is helpful for acidizing oil drilling wells to enhance their productivity.[122] The gum is saturated with water-insoluble nonaqueous fluid that is inactive to gum as well as acid. In addition to increasing oil productivity, it can also prevent fluid loss in the drilling mud at higher temperatures.[26]

7.4.4. Binder and Moisture Barrier. Ghatti gum has potential to act as binder and moisture barrier in long-fiber lightweight papers. In particular, it is popular under domestic settings due to its adhesive nature and is used in hair gel formulation.[150] It is also used as a moisture barrier in powder explosive industries to protect explosives from water harm during the submergence of explosive cartridge.[29]

7.4.5. Printing and Metal Analysis. Gum ghatti is also used for calico printing.[16] It may also stabilize Prussian blue color in spectrophotometric determinations and polarographic determination of Cu, Pb, and Fe.[26] Gum ghatti-based thickeners are used to reduce the amount of coloring substance on textile patterns during printing because use artificial thickeners have harmful effects on the employee as well as the environment.[153]

7.4.6. Molecular Biology. Acidic polysaccharides from gum ghatti, carrageenan, dextran sulfate, gum arabic, and gum karaya have inhibitory actions against DNA restriction enzymes (e.g., *Hin*dIII and *Eco*RI). However, their applications have been largely underutilized.[151]

7.4.7. Indigenous Uses. The bark of the gum ghatti is viable for curing anemia, urinary discharges, and piles.[126] Jain and DeFilipps[109] suggested that stem bark is helpful in diarrhea, painful urination, cold cough, colic, liver disease, snakebite, and dermal infection. It is also used for the treatment of fever in the some part of India.[125] Tribal dwellings in the forest apply paste of stem bark on scorpion stings.[124] Jagtap et al.[108] also reported the wide use of gum ghatti along with water and milk during early morning to improve lactation by the Pawara tribes of Satpura hills in India.

8. LIMITATIONS AND CHALLENGES OF IMPLEMENTING GUM GHATTI IN DIVERSE APPLICATIONS

Despite the numerous advantages and applications of gum ghatti, a key limitation lies in its inferior mechanical strength and physical features when compared to nonbiodegradable synthetic polymers[154] and its very poor behavior in native form.[155] Therefore, there is a need to modify gum ghatti to enhance its mechanical strength and physical features. The most important drawback of gum ghatti is that it is extremely biodegradable. To counteract this, the biodegradability of these products has been addressed through structural modifications involving the integration of organic synthetic molecules into natural polysaccharides.[156] Gum ghatti's relatively high hydration rate limits its use in bakery, confectionery, and medicinal formulations. In certain circumstances, quick or excessive hydration could damage the product's shelf life, texture, or performance.[157] An additional limitation is the presence of an insoluble fraction, which can reach up to 20% in various grades and sources of gum ghatti. This fraction tends to create gel-like formations in water solutions, requiring specialized process such as high-pressure homogenization to achieve a uniform colloidal solution in water.[158]

9. CHALLENGES AND FUTURE PROSPECTS

One of the big challenges for gum ghatti in food, beverage, and bakery that it does not completely dissolve in water and forms dispersions, resulting in difficulties achieving uniform dispersion and consistency in some formulations;[159] accordingly specialized processing is necessary, capable of modifying the solubility and dispersion of gum ghatti. More specific investigations needed to be done regarding the gelling property, surface activity, and emulsification property of soluble and gelling fractions of different grades of gum ghatti for their more precise application in food industries, which has still received little attention. Formulating gluten-free bread and cakes with gum ghatti, which mimics gluten's structural features and its viscoelastic properties, can be researched by selecting, optimizing, and altering the gum's properties and structure.[160,161] Edible films and various coating formulations synthesized from different components of gum ghatti have huge potential in encapsulating beneficial living microorganisms like prebiotics and probiotics. Understanding the complex interaction between water thermodynamics and thermal properties of edible films based on gum ghatti for food packaging and coating is difficult.[162] Extensive study is needed to determine how moisture content and internal environmental equilibrium relative humidity affect the edible packaging film's physicochemical, mechanical, and microstructure properties at different temperatures. Using gum ghatti and other biopolymers as reducing and capping agents for the in situ synthesis of silver nanoparticles and integrating them into bio-nano-composites suitable for food packaging applications is complex.[163] The future prospect is using the promising antibacterial activity of these nanoparticles within polymer blends to develop advanced food packaging materials for improved food safety and shelf life.

In the area of water purification, desalination, and wastewater treatment, gum ghatti-based hydrogels and desiccants need improved mechanical strength, recyclability, physical integrity, and pollutant specificity. Gum ghatti-based hydrogels used in different water purification systems exhibit restricted adsorption of cationic or anionic pollutants,[164] and it is necessary to modify hydrogels with the capability to adsorb both cationic and anionic pollutants at the same time. This can be engineered through incorporating functional groups into the polymer structure, partially altering natural gums before hydrogel formation, or combining anionic natural gums with cationic monomers and vice versa to make hydrogels. Hydrogels based on gum ghatti used in solar evaporators prevent salt crystallization during seawater desalination.[165] Porous capillary channels, internal gaps, and molecular meshes allow seawater to enter continually and prevent evaporator interface salt buildup.[166] Small hydrogel-based evaporators have limited usage in larger desalination operations. The advancement and refinement of hydrogel-based evaporators to enable the large-scale production of water for industrial purposes are crucial areas of development. Considering the case of desiccants, in high relative humidity, hydrogel-based desiccants collect water vapor well. However, low relative humidity situations greatly reduce their water collection capability.[167] Due to the hydrogels' weak hygroscopicity,

https://doi.org/10.1021/acsomega.3c08198
ACS Omega 2024, 9, 9974−9990

some water vapors trapped in low-humidity environments dissipate easily. Material structure alterations, surface treatments, hybrid compositions, and specialized functionalities may be used in future studies to increase performance. Gums ghatti-based adsorbents effectively remove dyes, showing good performance compared to other materials like carbon nanotubes, activated carbons, and silica, but are limited to a fixed type of effluent.[168] More research focusing on adsorbents that selectively remove colors from mixed effluents is essential.

In the field of pharmaceutical and biomedical research, carboxymethylation of gum ghatti is promising for creating drug delivery carriers from lab to commercial scale. Their susceptibility to microbial contamination challenges long-term stability.[169] This prompts the need to study the impact of storage on microbial growth. Improving carboxymethylated gums ghatti through grafting, cross-linking, and esterification may enhance their physicochemical properties. There is a need for in-depth investigations on potential uses of gum ghatti as a smart/controlled drug delivery system that explore the potential of gum ghatti as a carrier vehicle for oral protein and peptide delivery to protect these compounds from gastrointestinal breakdown, improve absorption, and overcome gut barriers to increase their therapeutic efficacy.[170]

10. CONCLUSIONS

Gum ghatti is an amazing polysaccharide-based natural gum that is greatly acknowledged in the national and international market for its excellent emulsification property. It forms a viscous solution in aqueous media, and due to being viscous in nature it has wide applications in food, drug, leather, textile, petroleum, oil, paint, printing, cosmetic, paper, and explosive industries. The utilities of gum ghatti have been expanded in recent years to various modern technologies, such as edible film, antimicrobial packaging, biomedical, smart sensor, nanotechnology, therapeutic, environmental remediation, etc. Further, its low cost and ready availability make it more popular in gums and the stabilizer industry. Hence, it is clear that gum ghatti has tremendous applications, which have largely remained unharnessed. Further, the conventional and widely used tapping techniques employed for gum ghatti are ruthless and damaging to the trees, causing their death. In fact, standardized regimens must be formulated, evaluated, and implemented in order to improve all aspects of gum ghatti production, such as tapping, collection, processing, grading, classification, value addition, and marketing. Moreover, research and development are lacking in the areas of bioactive component encapsulation, creative food structure development, prebiotics, probiotics, increased edible barrier-layer films, nutraceuticals, intelligent sensors, oil drilling wells, genetic improvement, and selection of species of gum ghatti. This review aims to summarize all the potential application of gum ghatti and its tree in order to attract scientists to improve these aspects of production, processing, and application of gum ghatti.

■ ASSOCIATED CONTENT

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors extend their appreciation to the Deputyship for Research & Innovation, Ministry of Education in Saudi Arabia for funding this research work through project number ISP23-101.

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ACS Omega 2024, 9, 9974−9990

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