Review on Uses and Modification of Gum Arabic

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ABSTRACT

Gum Arabic (GA), a natural, edible hydrocolloid obtained predominantly from *Acacia senegal* and *Acacia seyal*, is a highly branched heteropolysaccharide composed mainly of arabinose, galactose, rhamnose, glucuronic acid, and small proportions of protein. Its unique molecular architecture comprising arabinogalactan (AG), arabinogalactan protein (AGP), and glycoprotein (GP) fractions confers exceptional solubility, emulsification, film-forming capacity, and stability, which underpin its long-standing relevance in food, pharmaceutical, cosmetics, and industrial applications. Renewed scientific interest in GA is driven by its biodegradability, safety, and functional versatility, as well as its growing importance as a sustainable biomaterial. Recent advances have focused on modifying GA to enhance its physicochemical and functional properties. Chemical, physical, and enzymatic approaches including oxidation, cross-linking, esterification, graft-copolymerization, and nanoparticle functionalization have produced derivatives with improved rheological behavior, stability, and targeted performance. Modified GA has demonstrated significant potential in Nano chemistry as a stabilizer and reducing agent for metal nanoparticles, in drug delivery through pH-responsive hydrogels and polysaccharide drug conjugates, and in environmental technologies such as wastewater remediation and semiconductor development. In construction materials, GA acts as a natural binder that improves compressive strength, durability, and water resistance of stabilized earth blocks, offering a sustainable alternative to conventional stabilizers. Beyond industrial applications, GA provides notable health benefits. As a fermentable dietary fiber, it functions as a prebiotic, enhancing mineral absorption and supporting gut microbiota. Its antioxidant, anti-inflammatory, antimicrobial, and detoxification properties contribute to renal, cardiovascular, and gastrointestinal protection. Modified GA derivatives, including aldehyde-functionalized and cross-linked forms, have also shown promise for controlled drug release, tissue engineering, and biomedical therapeutics. This review synthesizes current knowledge on the composition, structural characteristics, physicochemical properties, and applications of GA, with emphasis on recent modification strategies that broaden its utility across scientific and industrial domains. The growing development of GA-based materials highlights its potential as a renewable, biocompatible platform for next-generation technological innovations.

Keywords: Gum Arabic, Modification, Crosslinking, Chemical, functionalization, Stabilizer.

INTRODUCTION

Gum Arabic (GA), also known as Acacia gum, is an edible biopolymer that is extracted from the exudates of mature Acacia senegal and Acacia seyal trees, as well as Acacia karoo, Acacia polyacantha, and Acacia sieberana trees, to name a few. These trees are primarily found in Sudan's Sahel area of Africa. Rich in soluble fibers and a non-viscous liquid, exudate typically emerges from stems and branches in response to stressors such damage, poor soil fertility, and drought (Williams and Phillips, 2000).

In terms of chemistry, GA is a complex blend of macromolecules with varying sizes and compositions, primarily proteins and carbohydrates. Today, a wide range of industrial industries, including textiles, ceramics, lithography, cosmetics and pharmaceuticals, encapsulation, and food, use GA, whose qualities and features have

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been extensively studied and developed. According to Verbeken et al. (2003), it is utilized in the food sector as an emulsifier, thickening, and/or stabilizer in products including soft drink syrup, gummy candy, and creams.

According to Baldwin (1999), Seigler (2002), and Savalry et al. (2009), GA is a vegetable-derived polysaccharide with a high molecular weight. They also noted that GA primarily functions as thickeners and gelling agents and exhibits certain functional qualities like emulsification (Ray et al., 1995), stabilization, and microencapsulation (Kim et al., 1996). GA possesses strong hydrophilic and anionic qualities and is employed in food emulsions (Reichert et al., 2010). It is a very diverse substance with both hydrophilic and hydrophobic properties. GA is a class of macromolecules with a low proportion of protein, primarily hydroxyproline, and a high proportion of carbohydrates, of which D-galactose and L-arabinose are the main monosaccharides that give it its hydrophilic affinity (Al-Asaaf et al., 2006). A backbone of 1,3-linked â-D-galactopyranosyl units with significant branching at the C6 position makes up the carbohydrate structure. Galactose and arabinose make up the branches, which end in glucuronic acid and rhamnose (Al-Asaaf, 2009). The structure can be separated into three major molecular fractions, known as arabinogalactan (AG), arabinogalactan protein (AGP), and glycoprotein (GP), according to Al-Asaaf (2006). These fractions differ mostly in size and protein content. According to Randall et al. (1988), the main ingredient in gum arabic that gives the gum its capacity to stabilize emulsions is AGP. They suggested that the hydrophilic carbohydrate component of the AGP protruded into the aqueous phase, inhibiting droplet aggregation through electrosteric repulsions, while the amphiphilic protein component attached the molecules to the oil droplet surface. Based on its peptide sequences and carbohydrate blocks, a fresh understanding of the AGP fraction's structure would help to clarify how it functions in an emulsion (Mahendran et al., 2008).

The proteins that make up GA can have their functional and physical characteristics changed by cross-linking. Cross-linking in proteins can be induced by a variety of techniques, including enzymatic and chemical treatment (Whiteside et al., 2006).

Chemical cross-linking agents include glyoxal, formaldehyde, and glutaraldehyde (Grosso et al., 2004). Nevertheless, the toxicity of these chemical cross-linkers restricts their application in food systems (Kiada et al., 1990). Inducing cross-linking using enzyme treatments is expensive and time-consuming. As a result, cross-linking must be induced physically using ultraviolet (UV) irradiation. The main benefit of UV irradiation is that it avoids environmental problems by not employing radioactive sources like gamma-radiation (Smith and Pillai, 2004). Furthermore, UV irradiation is inexpensive, non-thermal, and safe for the environment because no chemicals or additives are used.

This study intends to itemize the various methods of modifying gum Arabic and its application in various aspects of our daily life. This study will provide information on the various methods adopted for the modification of GA and its application in medicine, food and non-food use.

The main purpose of this study are to:

(a) to know Gum Arabic and understand its composition.

(b) characterize the Gum Arabic biopolymer.

(c) evaluate the modification methods of Gum Arabic and its corresponding application.

LITERATURE REVIEW

Gum Arabic (GA), also known as Acacia gum, is an edible biopolymer that is extracted from the exudates of mature Acacia trees, which are mostly found in the Sahel region of Africa (Glyn and Peter, 2020). Exudate is a non-viscous liquid that typically emerges from stems and branches in response to stressors such damage, poor soil fertility, and drought (Glyn and Peter, 2020).

In terms of chemistry, GA is a complex blend of macromolecules with varying sizes and compositions, primarily proteins and carbohydrates. These days, a wide range of industrial applications, including textiles, ceramics,

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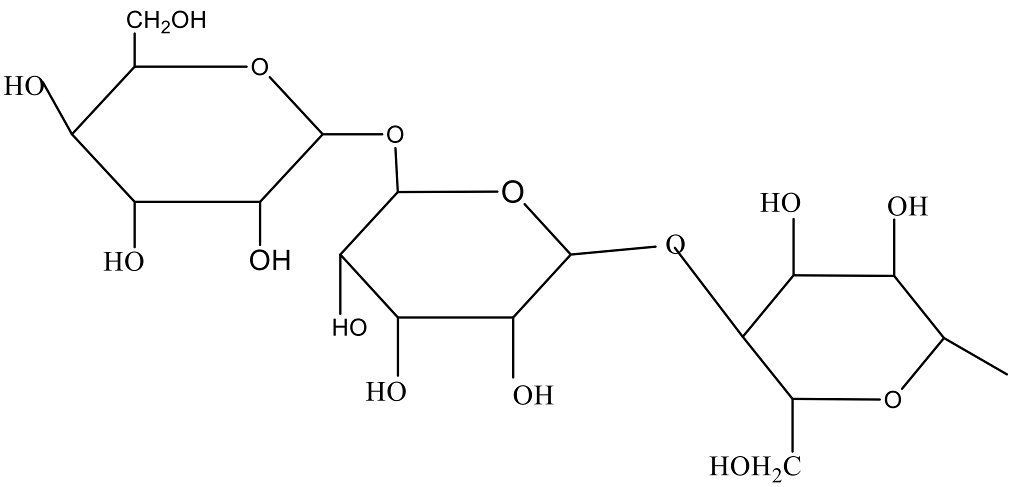
lithography, cosmetics and pharmaceuticals, encapsulation, and food, leverage GA's qualities and features, which have been extensively studied and developed. It is utilized in the food industry as an emulsifying agent, thickening, and/or stabilizer in creams, gummy candy, and soft drink syrup (Long et al. 2017). GA is a high molecular weight polysaccharide derived from vegetables (Masuelli, 2013).

Additionally, according to Long *et al.*, (2017), GA exhibits some functional qualities as emulsification, stability, and microencapsulation in addition to acting as thickeners and gelling agents (Kim *et al.* 1996). This polysaccharide is utilized in the mining, food, pharmaceutical, and biotechnology adhesive sectors, according to Nasir et al. (1997). In concentrated solutions with low viscosity, it can stabilize oil-in-water emulsions (Philips, 1998).

According to Ziada *et al.* (2008), GA is mostly a complex polymer with branched chains that is either neutral or slightly acidic. It is a very diverse substance with both hydrophilic and hydrophobic qualities. It is a collection of macromolecules with a low percentage of protein, primarily made up of hydroxyproline, and a high percentage of carbohydrates, with D-galactose and L-arabinose serving as the main monosaccharides that give it its hydrophilic nature (Al-Asaaf *et al.*, 2006). A backbone of 1,3-linked α-D-galactopyranosyl units with significant branching at the C6 position makes up the carbohydrate structure. The following illustrates the repeating units found in the Gum Arabic molecule (Arash *et al.*, 2021).



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Source: Arash *et al.*, (2021).

Galactose and arabinose make up the branches, which end in glucuronic acid and rhamnose (Al-Asaaf, 2009). The three main molecular fractions of the structure—Arabinogalactan (AG), Arabinogalactan Protein (AGP), and Glycoprotein (GP)—can be separated based on their size and protein fractions, according to Al-Asaaf (2006). According to Imeson (1997), the main ingredient in gum Arabic that gives the gum its capacity to stabilize emulsions is AGP. The proteins that make up GA can have their functional and physical characteristics changed by cross-linking. Cross-linking in proteins can be induced in a variety of ways. Among these are enzymatic and chemical treatments (Whiteside *et al.*, 2006). Chemical cross-linking agents include glyoxal, formaldehyde, and glutaraldehyde (Grosso *et al.*, 2004).

Origin of Gum Arabic

The gum Arabic tree has been around for 4,000 years. Because of its sticky properties, Egyptian artisans used it to thicken cosmetics, mummify, and as a binder for papyri pigments.

Gum Arabic is a natural gum that was first made from the hardened sap of two species of Acacia trees, Senegal gum and Vachellia seyal (Royal Botanic Gardens, 2022). It is also referred to as gum Sudani, acacia gum, Arabic gum, gum acacia, acacia, Senegal gum, Indian gum, and by other names (Mortensen et al., 2017). Legally, the word "gum Arabic" does not designate a specific plant source. Throughout the Sahel, from Senegal to Somalia, the gum is commercially extracted from wild trees, primarily in Sudan (80%). In the Middle East, the term "gum

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Arabic" (al-samgh al-'arabi) was in usage at least since the ninth century. Gum Arabic kept its name since it was initially brought to Europe through Arabic ports (Van, 2020).

The "gum belt," which includes several parts of Sudan, is home to gum Arabic, a naturally occurring vegetal resin. Two distinct acacia species that grow in the South Sahara's "gum belt," or Sahel zone, which covers various parts of Sudan, are the source of this resin. The African gum belt lies south of the Sahara Desert and north of the Equator. Between latitudes 4o and 18o, this area is desert and stretches constantly from east to west from Somalia through Ethiopia, Sudan, Chad, Niger, Nigeria, Burkina Faso, Mali, Mauritania, and Senegal. Other regions of Africa, such as Tanzania, Zimbabwe, Malawi, and South Africa, are also home to it. The Arabian Peninsula and India are home to Acacia Senegal in Asia (Glicksman, 1979).

The trunks of the Acacia Senegal (used in the food, beverage, and pharmaceutical industries) and Acacia Seyal (used in biotechnological applications) are specially tapped to provide this resin. The Acacia Senegal tree's pod, seeds, blooms, and leaves are displayed in Plate II below (Dauqan and Abdullah, 2013). When the resinous liquid that emerges from the tappings to repair the bark's wounds comes into touch with air, it thickens and forms a hard, glassy gum. This "gummosis" phase typically lasts three to eight weeks (Plate II) (Cecil, 2005).

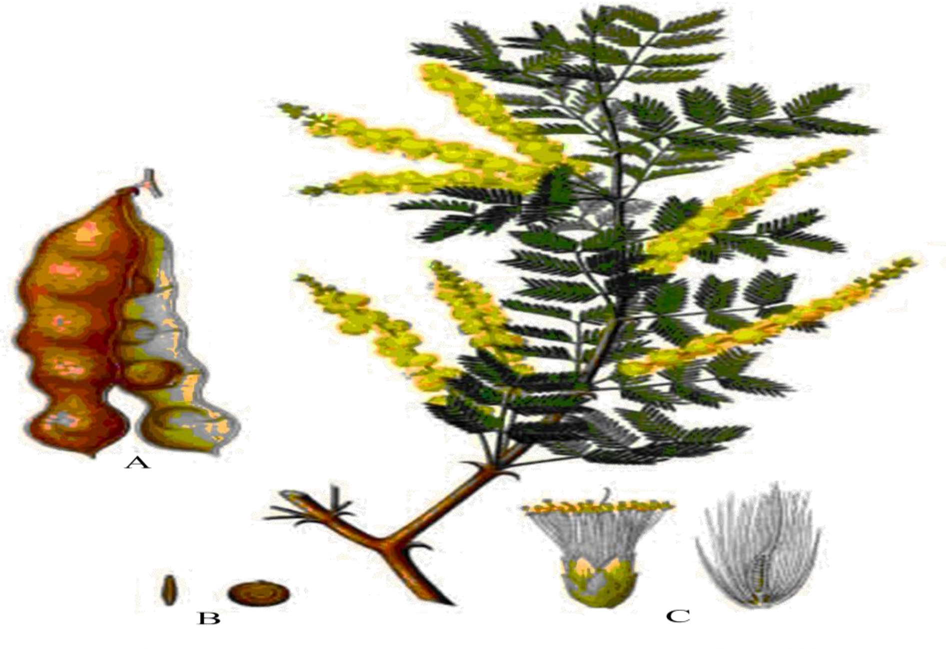

Plate II: Pod(A), Seeds(B), Leaves and Flowers(C) of *Acacia senegal*

Source: Cecil, (2005).

Plate III: Gummosis

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Geographical Distribution of Gum Arabic

These plants are found throughout the Indian Peninsula and the west of Africa. Mauritania, Senegal, Mali, Burkina Faso, Niger, Nigeria, Chad, Cameroon, Sudan, Eritrea, Somalia, Ethiopia, Kenya, and Tanzania are currently the primary harvesting locations for gum-producing Acacia species (BAN 2018).

By making holes in the bark, a substance known as Kordofan or Senegal gum is released when Acacia Senegal is tapped for gum. Seyal gum is extracted from naturally occurring extrusions on the bark of Acacia seyal, a species that is more common in East Africa. Semi-nomadic desert pastoralists have historically collected it as part of their transhumance cycle (BAN 2018). Mauritania, Niger, Chad, and Sudan are among the African countries that continue to export gum Arabic as a major commodity (BAN 2018). In the midst of the wet season (harvesting typically starts in July), the hardened extrusions are gathered, and at the beginning of the dry season (November), they are shipped. After recovering from the 1987–1989 and 2003–2005 crises brought on by the destruction of trees by the desert, it is projected that the total amount of gum Arabic exported worldwide in 2008 was around 60,000 tons' locust (BAN 2018). There have been talks to form a producers' cartel amongst Sudan, Chad, and Nigeria, which together accounted for 95% of global exports in 2007 (Navarro, 2008). With close to 80% of global trade, Sudan continues to be the biggest exporter, followed by Nigeria (BAN 2018). For industrial application, the dried saps are shipped to Western nations after being harvested as translucent masses, cleaned of impurities, and kibbled or powdered (BAN 2018).

In essence, there are two commercially accessible grades of GA, and the technique used to clean the impure gum tears determines their commercial value (BAN 2018). There are at least two common methods for processing gum tears (Roeper, 2013), as further illustrated in Tables 1 and 2;

Table 1: Grades of Commercially Cleaned Gum Arabic

Granules/lumps	Powdered	Spray dried
Ceroga 821 kordofan cleaned	ceroga 836 very fine White	Cerospray k/gum Arabic spray Dried white
Ceroga 812 cleaned ex acacia Senegal	Ceroga 834 light white	Cerospray n/gum Arabic spray Dried light
Ceroga 803 small lumps Acacia seyal	Ceroga 831 off-white	Cerospray b/gum Arabic spray Dried yellowish
Ceroga 800 technical	Ceroga 830 technical Dark	Cerospray f /gum Arabic spray Dried off-white

(Roeper, 2013)

The Ministry of Agriculture and Natural Resources, according to Okatahi and Onyibe (2015), has urged the following states—Adamawa, Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara—as well as portions of Plateau state, to engage in massive Acacia senegal production due to the potential they possess.

Table 2: Various Sources of Gum Arabic and Location

State	Where obtainable
Adamawa	Manr Yola
Bauchi	Manr, Bauchi
Borno	Manr, Department of Forestry Wild Life, and Federal Department of Forestry Field Office Maiduguri
Gombe	Manr, Gombe
Jigawa	Manr, Dutse
Kano	Manr, Technology Training School, Kano
Katsina	Manr, Katsina
Kebbi	Manr, and Department of Afforestation Program, Birnin Kebbi
Sokoto	Manr, and Department of Afforestation Program, Sokoto
Yobe	Manr, Technology Training School Gashua, Rubber Research Institute of Nigeria substation on Research and Development of Gum Arabic, Yobe.
Zamfara	Manr, Gusau

(Roeper, 2013)

Chemical Nature of Gum Arabic

GA, from Acacia Senegal is a complex branched heteropolyelectrolyte with a backbone of 1,3 linked β-galactopyranose units and side-chains of 1,6-linked galactopyranose units terminating in glucuronic acid or 4-O-methylglucuronic acid residues (Dickinson, 2003). GA consists of three fractions with distinct chemical structures, where the major one is a highly branched polysaccharide with a molecular weight of 3 × 105 g/mol. About 10 % (wt) of the total is a high molecular weight arabinogalactan protein complex (1 × 106 g/ml) and around 1 % (wt) of the total contains the highest protein content (50 wt %) (Dickinson, 2003). According to Idris *et al*. (1998), GA comprises of 39–42 % galactose, 24–27 % arabinose, 12– 16 % rhamnose, 15–16 % glucuronic acid, 1.5–2.6 % protein, 0.22–0.39 % nitrogen, and 12.5– 16.0 % moisture. The protein in GA is rich in hydroxypropyl, prolyl and seryl residues covalently linked to carbohydrate moieties (Dror and Yerushalmi-Rozen, 2006). The arabinogalactan protein complexes contain several polysaccharide units linked to a common protein core forming a compact spheroid structure according to the "wattle-blossom" model (Yadav *et al.*, 2007).

Another model for the structure of GA indicates the polysaccharide-protein complex as a twisted hairy rope of 150 nm length and 5 nm diameter (Qi and Lamport, 1991). Although the structure of the complex has not been fully resolved, it is possible to reconcile the two models. GA possesses remarkable surface active and rheological properties, being suggested that the emulsifying activity of GA is mostly due to its protein content and to trace levels of lipids (Al-Assaf, et al., 2009).

According to Al-Assaf *et al.*, (2006), the chemical makeup of GA can really differ slightly based on the tree's age, harvest season, environment, place of origin, and processing methods like spray dying. Consequently, the chemical makeup of the GA extracted from Acacia senegal and Acacia seyal differs in certain ways. Although

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the sugar residues in the two gums are identical, Acacia seyal gum contains more arabinose and 4-O-methyl glucuronic acid than Acacia senegalgum, and less rhamnose and glucuronic acid. Rather, it is known that Acacia seyalgum has a smaller amount of nitrogen, and certain rotations are also entirely different. By determining the latter factors, the two species' differences can be easily identified (Osman et al., 1993).

Tables 3 and 4, presents the chemical composition and some properties of both gums as reported by Osman *et al.*, (1993) and Williams and Phillips *et al*,.(2000). Despite having different protein content, amino acid composition is similar in both gums.

Table 3: Comparative chemical composition and some properties of Gum Arabic taken from *Acacia senegal* and *Acacia seyal* trees.

Parameter	***Acacia Senegal***	***Acacia seyal***
% Rhamnose	14	3
% Arabinose	29	41
% Galactose	36	32
%Glucoronic Acid	14.5	6.5
% Nitrogen	0.365	0.147
% Protein	2.41	0.97
Specific Rotation(degrees)	-30	+51
Average Molecular Mass (kDa)	380	850

Source: Mahendran et al., (2008), reported the GA amino acid composition in Acacia Senegal, being rich in hydroxyproline, serine, threonine, leucine, glycine, and histidine.

Table 4: Amino-acid content in Gum Arabic taken from Acacia Senegal

Amino acid	**(nmol/ mg) GA**	**% Amino acid**
Hydroxyproline	54.200	0.711
Serine	28.700	0.302
Threonine	15.900	0.208
Proline	15.600	0.180
Leucine	15.100	0.198
Histidine	10.700	0.166
Aspartic acid	10.600	0.141
Glutamic acid	8.290	0.122
Valine	7.290	0.085

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Phenylalanine	6.330	0.105
Lysine	5.130	0.075
Alanine	5.070	0.045
Isoleucine	2.380	0.031
Tyrosine	2.300	0.042
Arginine	2.120	0.037
Methionine	0.110	0.002
Cysteine	0.000	0.000
Tryptophan	0.000	0.000

Source: Mahendran *et al.*, (2008)

Mineral Constituents of Gum Arabic

Color, odor, moisture and ash content, viscosity, pH, specific rotation, tannins, and concentration of certain metals are some of the factors used to assess the quality of GA. Ca, Na, K, P, and trace amounts of Pb, Co, Cu, Zn, Ni, Cd, Cr, and Mn are the most common minerals. Therefore, a key factor in regulating quality is the element proportions. Ca2+, Mg2+, and K+ contents are very high in GA solutions (Nasir et al., 2008).

Chemical Properties of Gums

In terms of chemistry, GA is a complex mixture of macromolecules with varying sizes and compositions that are defined by a low percentage of proteins (<3%) and a large percentage of carbs (~97%), specifically D-galactose and L-arabinose. In 2018, Hassan et al. Depending on its origin, temperature, harvest season, tree age, and processing circumstances such spray dying, GA's chemical makeup varies slightly. The chemical makeup of the GA from Acacia senegal and Acacia seyal has been found to differ in a number of investigations; the most recent one was carried out by Lopez-Torrez et al. (2015). The same amino acids were present in both acacia gums, however A. Senegal had a larger protein level (2.7%) than A. seyal (1.0%) as seen in Table 5.

Table 5: Biochemical composition of A. Senegal and A. Seyal Gums in dry basis (mean standard deviation)

Component (mg/g)	A. Senegal	A. Seyal
Total dry matter	889.0 0.27	893.0 0.02
Sugars[a]	940.0	950.0
Galactose (%)[b]	35.8 1.20	36.9 1.05
Arabinose (%)[b]	30.3 2.50	47.6 0.60

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Rhamnose (%)[b]	15.5 0.35	3.0 0.30
Glucuronic acid (%)b	17.4 1.15	6.7 0.40
4-O-Me-glucuronic acid (%)[b]	1.0 0.05	5.8 0.55
Proteins	27.0 0.01	10.0 0.04
Minerals	33.0 0.24	40.0 0.07

[a]Total content of sugars was calculated by the difference of proteins and minerals from 1000 mg g^{-1} in dry basis.
[b]Sugar composition was determined by GC-MS

Source: Lopez-Torrez *et al.* (2015)

The most prevalent residues in his analysis were hydroxyproline, serine, leucine, and proline, which together accounted for about 55% of all the amino acids in each variation. Prior research on Acacia gums from various origins found similar amino acid patterns. According to Idris et al. (2012), the protein content of the A. Senegal gum samples is around double that of the A. seyal gum samples. An overview of GA's physicochemical characteristics may be seen below.

Physicochemical Properties of Gum Arabic

The origin and age of the trees, the exudation period, the storage method, and the environment can all affect GA's physicochemical characteristics (Mocak *et al.,* 1998). The hydrophilic and hydrophobic units of GA carbohydrate are made more soluble by the moisture concentration (Mocak et al., 1998). The threshold amounts of foreign matter, insoluble matter in acid, calcium, potassium, and magnesium are often ascertained using the total ash content (Mocak *et al.,* 1998). The precise concentrations of heavy metals in the gum arabic grade are shown by the cation compositions in the ash residue (Food and Agriculture Organization, 1996). The type and degree of polymerization of the sugar's constituents—arabinose, galactose, and rhamnose—which have strong binding qualities and are used as stabilizers and emulsifiers in the pharmaceutical industry's cough syrup production are determined by the volatile matter (Phillips and Williams, 2001). The energy needed to generate a certain amount of carbon by heating to 500 °C and releasing carbon dioxide is known as the GA internal energy. The nature of GA sugars and their manufacturing source are both ascertained by optical rotation.

Some physicochemical characteristics that are utilized as worldwide GA quality parameters are shown in Tables 2.6 and 2.7 (Montenegro *et al.,* 2012). For instance, gums derived from the acacia Senegal species in Sudan were examined for moisture, total ash content, volatile matter, and internal energy (Food and Agriculture Organization, 1996).

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Table 6: Physicochemical properties of Gum arabic

Property	Value
Moisture (%)	13 - 15
Ash content (%)	2 - 4
Internal energy (%)	30 - 39
Volatile Matter (%)	51 - 65
Optical rotation (degrees)	(-26) - (-34)
Nitrogen content (%)	0.26 - 0.39

Source: Montenegro *et al.,* 2012

Table 7: Cationic composition of total ash at 550 °C (International specifications of Gum Arabic quality, Food and Agriculture Organization, 1996).

Cation	Value
Copper (ppm)	52 - 66
Iron (ppm)	730 - 2490
Manganese (ppm)	69 - 117
Zinc (ppm)	45 - 111

Source: Montenegro *et al.,* 2012

Both Acacia senegal and Acacia seyal gums are composed of three main components, according to gel permeation chromatography studies of GA using refractive index and UV (260 nm) absorption detections (Islam et al., 1997; Idris et al., 1998; Williams and Phillips, 2000; Al Assaf 2006): a main fraction (88-90 %) of a polysaccharide of β-(1→3) galactose, which is highly branched with units of rhamnose, arabinose, and glucuronic acid (found in nature like salts of magnesium, potassium, and calcium). This fraction, known as Arabinogalactan (AG), has a molecular weight of 300 kDa and a low protein concentration of 0.35 % (Renard *et al.*, 2006). The complex Arabinogalactan-Protein (AGP) is represented by the second fraction, which makes up 10% of the total and has a molecular weight of 1400 kDa and an 11% protein content (Goodrum *et al.*, 2000). The final fraction, which makes up 1% of the total, is made up of a glycoprotein (GP), which has the highest protein content (50 weight percent) and a different amino acid composition than the complex AGP (Williams et al., 1990).

According to Williams *et al.*, (1990), the three components' total carbohydrate fraction contents are comparable; however, protein-rich fractions have a noticeably reduced glucuronic acid level. Only the AGP and GP components exhibit a secondary structure, according to circular dichroism tests done on various GA fractions (Renard *et al.*, 2006). After isolating the AGP fraction using gel filtration chromatography, the protein was separated by deglycosylation using hydrofluoric acid (HF) (Qi *et al.*, 1991). The AGP protein fraction had around 400 amino acids, of which 33% were hydroxyproline residues. Furthermore, it was demonstrated that the AGP portion is made up of carbohydrate blocks that are covalently bonded to the polypeptide chain via hydroproline and serine residues (Mahendran et al., 2008). Mahendran et al. (2008) suggested that the 400 amino acid

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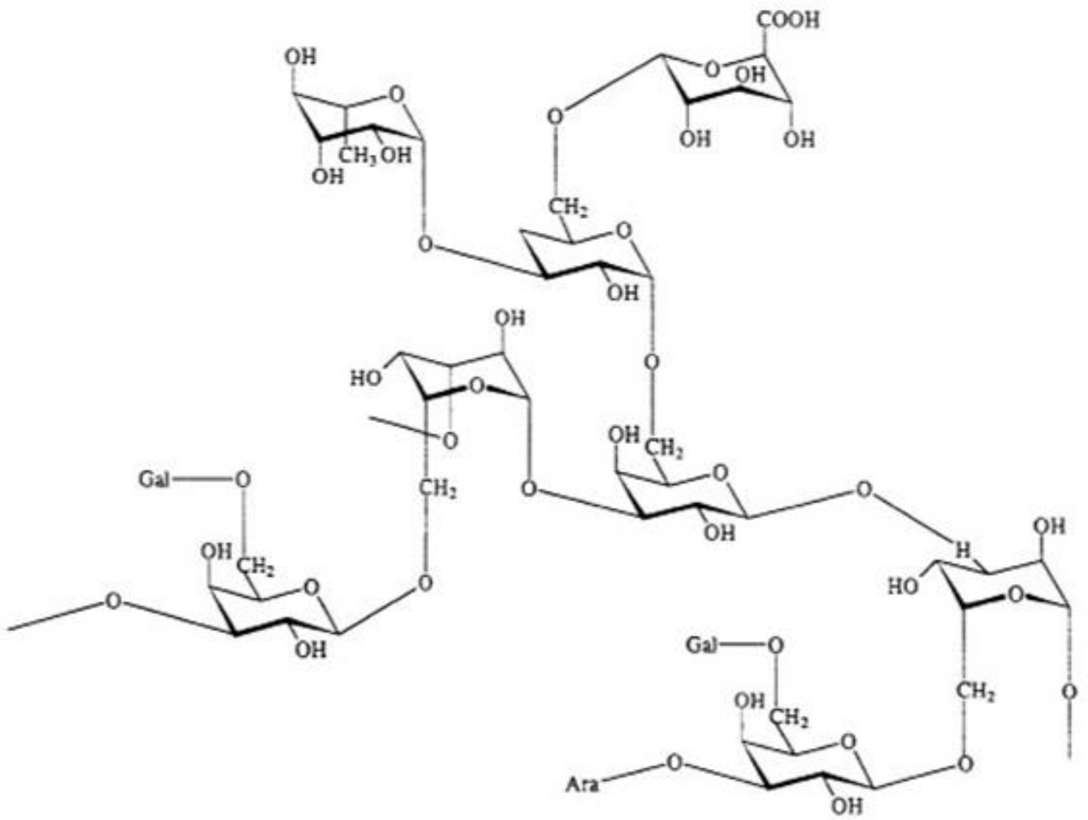
polypeptide chain in the structure of AGP serves as a "cable connection" for the 40 kDa carbohydrate pieces that are covalently bonded to the protein (the "wattle blossom" model).

Structure of Gum Arabic

Numerous studies have been carried out to uncover the molecular structure of GA and connect it to its remarkable rheological and emulsifying qualities. Arash et al. (2021) claimed that gum arabic contains monomeric units, while Arash et al. (2021) and Eqbal et al. (2013) described the molecular structure of gum arabic that demonstrates the glycosidic bond linkages of one monomeric unit to other units **II** and **III** respectively.



II

Source: *Arash et. al., (2021)*

When GA first comes into contact with the atmosphere, it is an amber, amorphous, and extremely viscous substance that solidifies. Depending on the type of acacia tree, the country of origin, and the storage conditions, it might have light yellow, red, or brown hues. It produces a uniform colloidal and colorless system and is non-toxic, odorless, tasteless, and soluble in water.

Weight of molecules

In addition to varying from sample to sample, the molecular weight of GA is also dependent on the estimation technique. According to Vedantu (2023), GA has an average molecular weight of about 250,000g.

pH of Gum Arabic

Vedantu (2023) states that the viscosity of a GA solution progressively reduces between pH values of 5 and 10, with the highest relative viscosity pH value falling between 4.5 and 6.30.

2.5.3 Aggregation and molecular association

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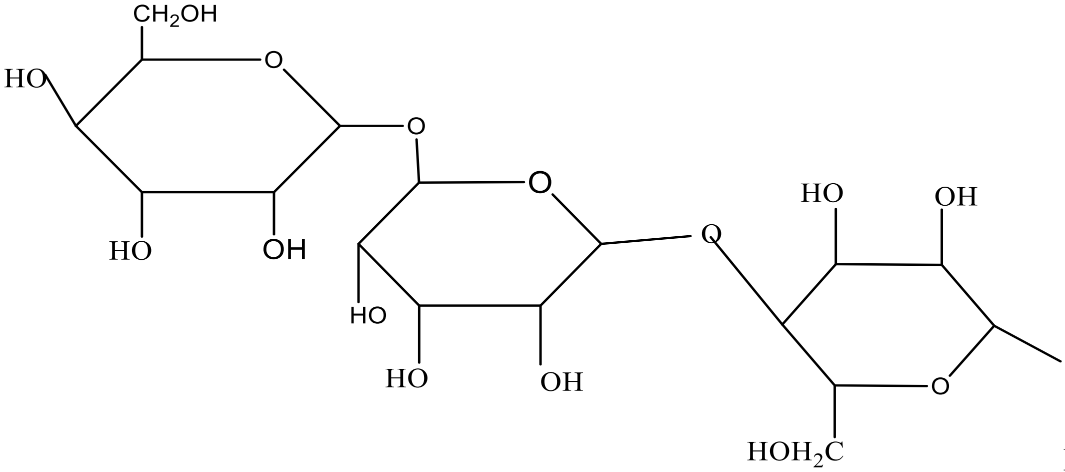
Because it impacts the molecular weight and size of the molecule, which also determines how the molecules interact with one another, certain polysaccharides have a tendency to associate in aqueous solution, which has an impact on their functioning and industrial applications.

According to Montenegro et al. (2012), gum Arabic possesses the concentration and presence of protein components that influence the formation of supramolecular complexes, including hydrogen bonding, hydrophobic association, and electrostatic interactions.

By maturing under regulated heat and humidity conditions, Al-Assaf et al. (2007) shown that molecular association in gum Arabic can result in an increase in molecular weight in the solid form. In a further investigation, Al-Assaf and his associates examined how the gum's protein components improved molecular interaction under various processing settings. These protein moieties have been found to enhance the emulsifying capacity of high molecular weight AGP by promoting molecular association through hydrophobic interactions that affect the protein's size and proportionality (Al-Assaf et al., 2009).

Uses of Gum Arabic



III

Source: Eqbal et al. (2013)

GA has been used since 5000 years ago. In Middle Eastern nations, GA has been considered a treatment for chronic kidney disorders (Nasir and Umbach, 2012). due to its strong water solubility, edibility, absence of aftertaste, generally regarded as safe (GRAS) rating, and other favorable qualities.

In the food business, GA has proven to be widely useful. It is used in food compositions such as jellies, sweets, soft drinks, beverages, syrups, and chewing gum because of its emulsifying, stabilizing, thickening, and binding properties. Additionally, it is widely known for its usage as an edible emulsifier in the flavor and essential oil industries, including the manufacturing of cola and citrus flavor oils for soft beverages (Hassan 2000 and Karamalla 1999). Gum Arabicis is used in dairy products to solidify frozen goods like ice and ice cream by absorbing water and giving them a finer texture. Gum Arabic is utilized in the cosmetics sector as an adhesive in face masks and face powders and as a smoother in lotions and protective creams (Verbeken et al., 2003).

It is perfect for glazes and coatings for confections because of its ability to create films. Because it can extend the shelf life of tastes, it is a desirable food addition. GA has been approved for use in food applications by the European Union. It has also been suggested by Codex alimentarius, a compilation of globally accepted standards, rules of practice, and guidelines. It coatings pills and lozenges used in pharmaceutical and natural remedies. Additionally, cosmeceuticals employ it to produce lotions and creams. It is an essential component in traditional lithography, printing, and water color paints because of its superior binding qualities. Because GA can increase the tensile strength of fibers, it has also been used in the textile sector. Given this, it would be beneficial to monitor the advancements in GA technology over the past ten years and to predict how they will develop in the future.

GA has been proven to be particularly helpful in the fields of textiles, ceramics, lithography, cosmetics, paints, and papermaking, according to Verbeken et al. (2003) and Elmanan et al. (2008). Among the several hydrocolloids, acacia gums are special because they alter and regulate the rheological characteristics of aqueous food systems by functioning as thickeners, stabilizers, film formers, suspending agents, flocculants, and emulsifiers. This makes them particularly useful in the food industry. Due to its superior emulsifying qualities over A. seyal gum, A. senegal gum is most frequently employed in culinary applications (Jani *et al*., 2009).

Factors limiting GA research and why it matters

Gum Arabic research is advancing (new formulations, nano-materials, agroecology), but important knowledge gaps (climate resilience, genetics, standardization, processing tech, value-chain economics, and toxicology characterization) and commercialisation barriers (supply volatility, concentration of exports, weak local processing, quality or certification gaps, logistics & finance, and political risk) are slowing value capture from producing countries (Mohamed *et al.*, 2025). There are certain factors that affects extensive research on GA production and commercialization, some of these factors are as highlighted;

climate change impacts and adaptation strategies: Robust, regionally explicit projections of Acacia species distribution under future climates and field trials of tapping periods. Without predictive ecology and adaptation trials, producers and policymakers can't plan for long-term supply resilience (Edouard *et al.*, 2024). There is need to produce high-resolution maps and scenario planning for the "gum belt" (Sahel/Sudan) so governments of producing countries and donors can prioritize conservation and planting.

Genetic diversity and domestication studies on GA: There are systematic genetic surveys, breeding trials for desirable gum yield and disease/drought tolerance, plus germplasm banks and propagation protocols. There is emphasis on wild sourcing, a process which lacks organised breeding programs. This possess as a barrier to stabilised yields and improved gum quality (Prasad et al, 2022). Also, there is harmonised, large-scale studies comparing physicochemical, rheological and impurity profiles of GA from different varieties and how processing and storage change functionality. The lack of standardized methods makes it hard for producers and processors to meet tight food and pharmaceutical specifications and for researchers to compare results (Mohamed *et al.*, 2025). To resolve this issue, the producers can fund germplasm collection, provenance trials, and propagation methods (nurseries) to select higher-yielding, drought-resilient genotypes.

Food, pharmaceutical and toxicological safety data gaps for novel applications: Thorough toxicology, allergenicity and long-term safety studies for high-concentration or novel GA Nano formulations and other GA derivatised products such as nanoparticles and drug suspensions and carriers. Many recent formulations were observed to highlight potential application of GA, but few provide comprehensive safety profiles such as required by regulators (Mohamed *et al.*, 2025). A setup funding of GLP toxicology and long-term exposure studies for the derived GA formulations to unlock biotech markets would be of good advantage. (Prasad et al., 2022).

Lack of process engineering and scalable, low-cost value-addition technologies: affordable, decentralized primary processing (washing, drying, milling) and intermediate technologies that improve grade without heavy capital. Most value addition still happens outside producing countries because the local processing technology is limited. Engineering research oriented towards low capital and local contexts is scarce (Dayoub, 2025). The development of scalable, low-energy washing, drying and milling units suitable for cooperatives. Pilot demonstration sites and business models would definitely go a long way to at least limit this inadequacy.

Gum Arabic commercialisation barriers

Despite the difficulty encountered in the harvesting and sourcing of GA from the producing countries, certain factors where observed to limit adequate sales and distribution of GA from its source. Some of these factors are as highlighted;

Inadequate Supply and concentration risk: GA Supply is concentrated just within few countries mostly Sudan and Chad with limited amounts distributed in other countries that make up the gum belt of west Africa. Hence

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there is conflict in GA sales and prices, policy shifts and climatic changes leading to sharp export shocks and price swings. Recent reports document how conflict and instability in Sudan have disrupted global supplies. (Atar, 2025). Buyers demand stable volumes and predictable quality; volatility pushes firms to look for alternatives or hold high safety stoc*ks.*

***There is GA quality inconsistency & weak standards enforcement*: **Variable tapping methods, contamination from soil particles, inconsistent drying and packing procedures produce mixed grades. International buyers require narrow specs for food/pharma uses; inconsistent quality forces discounts or rejection (Wouw, 2025).

Limited local processing and devaluation: Processing and downstream formulation such as encapsulation and pharma grade purification often occur outside producing countries while primary producers get low farm gate prices. Hence, increasing local processing capacity at point of harvest would retain more value domestically (Dayoub, 2025). Small scale producers often lack aggregation mechanisms, working capital, storage, and bargaining power. Producer association capacity is uneven; many interventions remain project-based and not scaled. Also, Costly transport from remote drylands, and the expense/complexity of meeting EU/US food safety, traceability and sustainability certification, limits access to high-value markets (Wouw, 2025).

The diversification of the sourcing process and encouraging planting programs to reduce geopolitical supply risk within te gum producer belt (Senegal, Nigeria, Ethiopia alongside Sudan and Chad). Climatic and market reports encourage geographic diversification (Wouw, 2025).

Application of Gum Arabic in Building and Construction

Compressed stabilized earth blocks are a new type of building material that has replaced the earth blocks known as adobe (composed of earth and organic ingredients), according to Alladjo et al. (2021). However, because of the greenhouse gas emissions and the high cost of these materials, not everyone can afford them, the use of cement or lime to stabilize these blocks poses a serious environmental risk. Therefore, it is critical to discover a natural, eco-friendly substitute for these stabilizing ingredients, such as renewable materials, biopolymers, or natural binders, of which GA turned out to be the most suitable.

In his research, GA enhanced the blocks' compressive strength, dry density, and water absorption; blocks with 2% cement and 8% GA produced the greatest results. According to him, one of the most crucial factors in assessing the performance of blocks is the water absorption test. The blocks' absorption rate determines their strength and longevity (Muhwezi et al., 2019). Water absorption is a measure of an earthen block's resistance to immersion and is used to evaluate how long it will last in a damp environment (Salih *et al.*, 2020).

Water absorption is one of the most important characteristics of brickwork, according to Bakar et al. (2017). It may have an impact on the blocks' quality (after they are produced) and, subsequently, on the strength of the connection between the blocks and mortar in a masonry construction. Consequently, the materials The block's water absorption capacity should be as low as feasible. The emulsifying property of GA, which enables it to fill the voids in the cement microstructure, increase the density of the material, and create bonds between different particles, thereby reducing the voids between the different particles, explains this decrease in the percentage of water absorption obtained for blocks with GA (Jang 2020, Joga 2020, Mohamed 2017 & 2018). Furthermore, GA is a stabilizer and waterproofing ingredient used in mud coatings, according to Vissac (2017).

Because of this, GA is typically employed as a binder in mud plasters to shield homes from the damaging effects of intense rains (Eltahir, 2013). In fact, the creation of "hydrogel" stabilizes biopolymer-based soils by fortifying the particle bonding and guaranteeing the waterproofing of the resulting material (Jang 2020 & Joga 2020, Muguda et al., 2017, Chang et al., 2015, Ayeldeen 2019). In other words, GA's emulsifying ability causes it to fill gaps and form linkages between various particles (Joga 2020, Mohamed 2017). These results suggest that blocks with good water absorption performance (2%C+8%GA and 2%C+10%GA) could be utilized for construction, since the durability of blocks is correlated with their water absorption rate (Medvey & Dobszay, 2020, Randall et al., 1988). For example, when compared to the control blocks with 2% cement, the compressive strength at 28 days rose by 27.81%. The results of this study suggest that GA can be used as a binder to create laterite blocks in a sustainable manner.

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This indicates that GA has a beneficial effect on earthen blocks' ability to withstand water deterioration. Guar and xanthan gums have been used as stabilisers in earthen blocks in the past, and research has shown that they improve the blocks' resistance to water (Muguda et al., 2020). Additionally, it may be inferred from earlier studies that GA would not affect the hygroscopic qualities of clay blocks, in contrast to cement (Muguda et al., 2020).

Medical and Health Benefits of Gum Arabic

Benefits of GA Ingestion

GA is the ideal candidate for a natural prebiotic since it occurs naturally as an edible biopolymer (Mehrab and Karima, 2018). GA has the ability to counteract the stomach's acidic influence and the large intestine's alkaline bile salt and other digestive enzyme effects. According to McLean et al. (1984), it is regarded as a full-spectrum probiotic because it ferments entirely inside the large intestine, selectively stimulates intestinal bacterial growth and/or activity for the removal of pathogenic bacteria, and greatly strengthens the mucosal barrier, which keeps pathogenic bacteria from invading the gastrointestinal tract. Thus, GA is noteworthy for having a major influence on the body's immune system development.

Research has revealed that rat and human feces fed acacia gum do not contain any acacia gum, suggesting that the human gut flora fully ferments this. Consuming adequate levels of probiotics, which are live microorganisms included in certain food products and supplements, can improve or restore the gut flora and hence improve health. As a result, probiotics support the GI tract's bacterial balance. Strains of Lactobacillus and Bifidobacterium, occasionally in combination with Streptococcus thermophilus, are the most prevalent forms of probiotic bacteria. Cherbut et al. (2003) and Calame et al. (2008). These probiotics are often usually found in fermented dairy products. Therefore, adding fermentable fiber sources like GA to our diets may enhance the absorption of minerals, particularly calcium. When GA is present in the human diet as a prebiotic oligosaccharide, it may have a beneficial influence on mineral absorption through a number of possible pathways.It might considerably lessen the negative consequences of chronic renal failure. (Bliss and others, 1996). It can absorb water, increasing the volume of stool, and has affinities for the specific adsorption of ammonia, urea, creatinine, bile acids, and phosphate bond agent (Bliss et al., 1996 and Al-Mosawi, 2006). When dissolved, it provides additional protection in the digestive tract by forming a sticky gel that acts as a protective cover and inhibits harmful substances. Gum Arabic and other fermentable natural fibers function as probiotics by enhancing the absorption of minerals, particularly calcium, and assisting in the preservation of a balanced population of bacteria in the gastrointestinal system.

According to epidemiological research, consuming enough fiber consistently lowers the risk of coronary heart disease and cardiovascular disease, mostly via lowering low-density lipoprotein levels. Although the findings of randomized clinical trials are mixed, they indicate that fiber may help lower blood pressure, Apo lipoprotein levels, and C-reactive protein all of which are indicators for heart disease (Tiss et al., 2001; Glover et al., 2009). Gum Arabic possesses appealing antioxidant qualities and is the best supplier of vital amino acids. The antioxidant and protein fraction are associated, according to experimental data, mostly by amino acid residues like histidine, tyrosine, and lysine, which are typically regarded as compounds that are antioxidants (Marcuse, 1960).

Nutritional benefit of GA

Gum Arabic is a natural, non-genetically modified, 100% vegetable biopolymer that is listed as a food additive that is approved in Europe and has no quantitative restrictions on consumption. Kardi and Dashtdar (2018).

Additionally, the US Food and Drug Administration has approved it. With only 1.5 kcal/g, acacia gum has a significant edge in the global battle against obesity. Because of its low carbohydrate content, it is regarded as a non-cariogenic additive. On the contrary, the Acacia gum has a high content of water-soluble fibers and vegetables (85%, according to the Association of Official Agricultural Chemists method), which enhances its nutritional and functional value and helps people consume liquid foods in a balanced manner.

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GA's Clinical Benefits

Although there is little information on the advantages of gum Arabic for a single kidney in harmful circumstances, research has shown that long-term gum Arabic use not only has no negative effects but also shields multiple organs from drug side effects and the effects of underlying illnesses, such as inflammatory, vascular, renal, and dental disorders. Kardi and Dashtdar (2018).

As an anti-toxicity agent

Toxicity, also known as oxidative stress, is characterized as a stressful state that disrupts the equilibrium between pro-oxidants and antioxidants, resulting in biochemical and physiological alterations.
Drugs or chemicals found in the environment can expose people to toxins.
Excessive formation of free radicals brought on by toxic exposure alters the amounts of oxidative stress bio-makers. Gum Arabic's protecting and healing qualities in numerous drunken situations have led to its recognition as a natural antioxidant. It has been noted that GA can stop the harmful side effects of several medications, such as chemotherapy and analgesics. It has been demonstrated that GA can shield the various bodily system and organs against the systemic toxicity of an indomethacin overdose. It was discovered that regular GA use in in cases of indomethacin toxicity can improve the coagulation profile and the overall blood picture by reducing renal and hepatic toxicity and altering the morphological alterations of the retina (Said, 2018). The intoxicating effects of acetaminophen toxicity can also be effectively avoided by GA Consequently, the liver is protected by lowering oxidative stress, nitric acid scavenging, and hepatic macrophage function blockage.

Furthermore, the combination of GA and aspirin may preserve the intestinal content of iron and zinc, balance t he pancreatic and intestinal enzymes, and shield the intestinal mucosa from the inflammatory effects of aspirin, by neutralizing the reactive oxygen metabolites of cyclophosphamide, GA can reduce the cytotoxicity of the bladder and help minimize the negative effects of chemotherapy intoxication. Furthermore, GA lessens the nephrotoxic effects of irradiation (γ-radiation) and chemotherapy, which are used to treat cancer. Lastly, GA has been shown to be a strong antioxidant and Reno protective substance that aids doctors in overcoming the negative effects of chemotherapy. One of the most dangerous indicators of drug toxicity is the nephrotoxic effect of aminoglycoside antibiotics, which GA helps to prevent (Said, 2018).

Regarding the toxicity of chemicals, GA has been shown to eradicate the lung toxicity brought on by paraquat intoxication, one of the most harmful herbicidal substances. Additionally, GA protects against the dangers of mercury intoxication and its many manifestations. According to Said (2018), mercury is regarded as an industrial and environmental toxin that causes serious systemic changes throughout the body. These changes start with acute renal failure, which is brought on by a decrease in glutathione levels and an increase in reactive oxygen levels like hydrogen peroxide (H_2O_2). The nephrotoxic effect of mercuric chloride is then modulated.

The applications for this biopolymer are incredibly numerous. Here is a quick rundown of the latest innovations. The applications validated until now have been presented in table 8.

Table 8: Various Applications of Gum Arabic

Gum Arabic Applications	**Specific uses**	**References**
Food additive	Enhances the emulsions, viscosity and stability Improves consistency and shell-life of puree, spreads and preserves. Stabilizes water in oil-in-water emulsions;	Makri and Doxastakis, 2006; Pua *et al.*, 2007;

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	As emulsifier provides flavor, color, and turbidity to juices and beverages; Helps immobilize α-amylase in industrial bioreactors	Su *et al.*, 2008; Mirhosseini *et al.*, 2008; Egwim and Oloyede, 2011.
In nanotechnology	Shows promising ability to disperse nanoparticles in aqueous solutions, stabilizing, and enhancing biocompatibility (γ -Al_2O_3); Interesting for diagnostic and therapeutic applications in nanomedicine (AuNPs); Enhances biomolecular attachment of magnetic nanoparticles; Offers fast microbial detection by magnetic nanoparticles; Forms films with desirable polar properties; Reduces surface energy and improves the tensile strength of starch film	Williams *et al.*, 2006; Wu and Chen, 2010; Kattumuri *et al.*, 2007; Zhang *et al.*, 2007; Roque and Wilson, 2008; Chockalingam *et al.*, 2010; Onyari *et al.*, 2008; Vigneshwaran *et al.*, 2011.

Drug delivery agent	Shows promise in tissue engineering and drug delivery; Helps in sustained release of drugs (FeSO4, naproxen, primaquine); Amenable to modification for development of pH- responsive and high cross-linking density hydrogel; Augments colloidal stability and promotes cellular uptake of Nano-medicine	Paulino *et al.*, 2010; Batra *et al.*, 1994; Lu *et al.*, 2003; Reis *et al.*, 2006; Nishi *et al.*, 2007b; Zhang *et al.*, 2009; Avadi *et al.*, 2010
Shelf-life enhancer	Alone or in combination with chitosan, wax, glycerol it's used as edible coatings on fruits and vegetables, e.g., bananas, apples, mushrooms. It delayed change in weight loss, firmness, titratable acidity, total soluble solids, decay, and color;	Maqbool *et al.*, 2011a; El-Anany *et al.*, 2009; Jiang *et al.*, 2013;

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	With essential oils (lemongrass, cinnamon), it exerts synergistic action on *Colletotrichum* spp. mycelia inhibition	Maqbool *et al.*, 2011b.
Microencapsulator	Stabilize freeze-dried strawberry powder by reducing hygroscopicity. Also it stabilizes oleoresin (cardamom, cumin, oregano), ginkgo leaf polyphenols.	Mosquera *et al.*, 2011; Krishnan *et al.*, 2005; Kanakdande *et al.*, 2007; Haidong *et al.*, 2012
Antimicrobial agent	Shows inhibition against fungal pathogen *Candida albicans* and *Cryptococcus neoformans*, and leishmania causative agent *Leishmania donovani*; Attenuates the level of parasites in blood *Plasmodium falciparum*	Nishi *et al.*, 2007a; Ballal *et al.*, 2011
Inducer of satiety and anti-obesity	Causes significant reduction in energy intake; Reduces age-dependent fat deposition by β3-adrenergic stimulation of adipocytes	Calame *et al.*, 2011; Ushida *et al.*, 2011
Cardio-, reno-, gut-, dental protective	Decreases systolic blood pressure; Increases intestinal and renal excretion of Mg^{2+} and Ca^{2+}, enhances creatinine clearance and urinary antidiuretic hormone excretion, while decreasing Na^{+} excretion; Decreases plasma phosphate and urea concentrations; Enhances remineralization of teeth and protects against the harshness of acids	Glover *et al.*, 2009; Nasir *et al.*, 2008; Nasir *et al.*, 2012; Onishi *et al.*, 2008; Beyer *et al.*, 2010
Anti-inflammatory agent and anticoagulant	Boosts the NF-κB p65 activity of cathartics; Protects gut against the adverse effects of drug Meloxicam; Ameliorates the oxidative stress and DNA damage; Exerts significant anticoagulation effect	Wapnir *et al.*, 2008; Abd El-Mawla and Osman, 2011; Ali *et al.*, 2013; Hadi *et al.*, 2010
Sensor and tumor Imaging	Manifests ideal properties (electrically active, watersoluble, and redox) for semiconductor sensor devices.	Tiwari, (2007).

Gum Arabic Modification Methods and Its Application

Modified GA in Nanochemistry

According to Baran and Mentes (2020), GA and its derivatives are an affordable stabilizer for the synthesis of different metal nanoparticles because of their important characteristics, which include low viscosity, water solu

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bility, nontoxicity, and biocompatibility.GA was chemically altered with Schiff as part of his research to create materials based on polysaccharides that would stabilize the creation of palladium nanoparticles. He By agitating a combination comprising 2 g of GA and 5 mL of 3-Aminopropyltriethoxysilane in 40 mL of toluene for 24 hours, NH_2-functionalized GA was created (GA-Silane couple). To create Schiff base modified GA (GA-Sch), 1 g of GA-Si and 4 ml of 2-pyridinecarboxaldehyde were then added to 30 ml of ethanol and refluxed for 48 hours.

In order to prepare the palladium catalyst, GA-Sch was finally filtered out, cleaned with ethanol and dried. Using $NaBH_4$ in water, the resulting GA-Sch-Pd nanocatalyst was then successfully employed as a heterogeneous catalyst against the reductions of organic dye pollutants like congo red, methylene blue and methyl orange, as well as hazardous nitro compounds like o-nitroaniline, p-nitrophenol, p-nitro-o-phenylenediamine, and p-nitroaniline. According to his research, the catalyst created by modifying gum Arabic (GA-Sch-Pd nanocatalyst) exhibited significant activity against the reduction of organic colors and nitroarenes at extremely brief reaction times. Additionally, it was simple to extract and reuse the Schiff-based Arabic palladium nanocatalyst multiple times. According to this study, the GA-Sch-Pd nanocatalyst has a great deal of promise for cleaning up wastewater that contains environmental contaminants. In order to explore GA's potential as a magnetic biomaterial and an intelligent hydrogel, Paulino et al. (2010) changed GA by creating a modified gum arabic-based hydrogel that is sensitive to magnetic fields (smart hydrogel). This was accomplished by using magnetite (Fe3O4) nanoparticles in conjunction with a standard cross-linking/co-polymerization synthesis of modified gum arabic, acrylamide, and potassium acrylate. This was made possible by the fact that hydrogels made by embedding magnetite (Fe3O4) nanoparticles within a network of polymers are appealing because of their demonstrated biocompatibility, rapid reaction, and sensitivity to an external magnetic field that is delivered remotely (Paulino et al., 2010). His method involved dissolving known volumes of purified GA at 60°C in a 500 mL beaker filled with 480 mL of distilled water. To reach pH 3.50, a concentrated HCl solution was gradually added to the mixture. Following that, 1.30 mL of glycidyl methacrylate was added, and the mixture was swirled for 24 hours while maintaining a temperature of 50 °C. To get rid of any remaining contaminants, the final product was precipitated three times in ethanol. Centrifugation was used to separate the whitened precipitate, which was then dialyzed in Milli-Q water at 5°C. Over the course of 72 hours, the water was changed every 6 hours. Lastly, lyophilization was used to dry the modified gum arabic for 24 hours at -60°C. The required smart hydrogel was then made using the modified GA that was obtained. They proposed that the produced smart hydrogels could be used as biomaterials in tissue engineering, cell cancer treatment, therapeutic implants, soil conditioners, magnetic biosorbents, magnetic biosensors, remote controlled release, and even other scientific and technological fields.

Gum Arabic Modification for Environmentally Friendly Semiconductor

By employing peroxydisulfate as an initiator and oxidant in a physical radical copolymerization of gum Arabic and polyaniline, Tiwari (2007) altered GA. First, a dispersion of GA was made. For four to six hours, known quantities of biopolymer powder were dissolved in deionized water while being gently stirred at 40 ± 2oC. It was discovered that the initial pH of the 1% GA dispersion was 4.6. Additionally, ammonium peroxydisulfate in aqueous HCl (1 M) was employed as an oxidant at 4oC to perform oxidative polymerization of doubly distilled aniline dissolved in aqueous HCl (1 M) to create the polyaniline used in the coplymerization. Then, in a 150 ml flask, a calculated quantity of the GA was dissolved in a minimum amount of distilled water to create gum Arabic-graft-polyaniline (GA-g-PANI). A measured quantity of hydrochloric acid (HCl) and aniline were added to this solution, bringing the total volume to 25 milliliters. As shown in the image below, the flask was continuously stirred while being thermostated at 40 + 0.2 ^{o}C.

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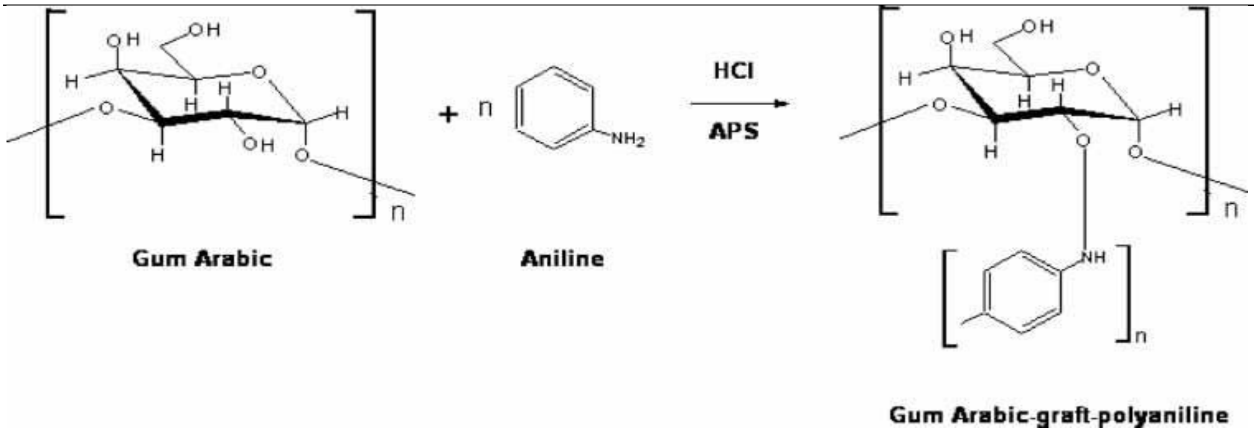


Gum Arabic-graft-polyaniline formed from the chemical oxidative-free radical copolymerization.

Source: Tiwari (2007).

A specific quantity of peroxydisulfate was added after 30 minutes, which was considered zero time. Grafting had been permitted for two hours. Absolute ethanol was used to precipitate the copolymer after 5% aqueous NaOH neutralized the reaction mixture. The polyaniline (homopolymer) was separated from the copolymer by washing the resultant precipitate with N-Methyl-2-pyrrolidone. Low molecular weight polyaniline oligomers were extracted from GA-g-PANI by soxhlation with acetone after the copolymer was finely powdered. Lastly, a vacuum oven set at 50 degrees Celsius was used to dry the goods for a few days. The percentage and efficiency of grafting were calculated by the following equations:

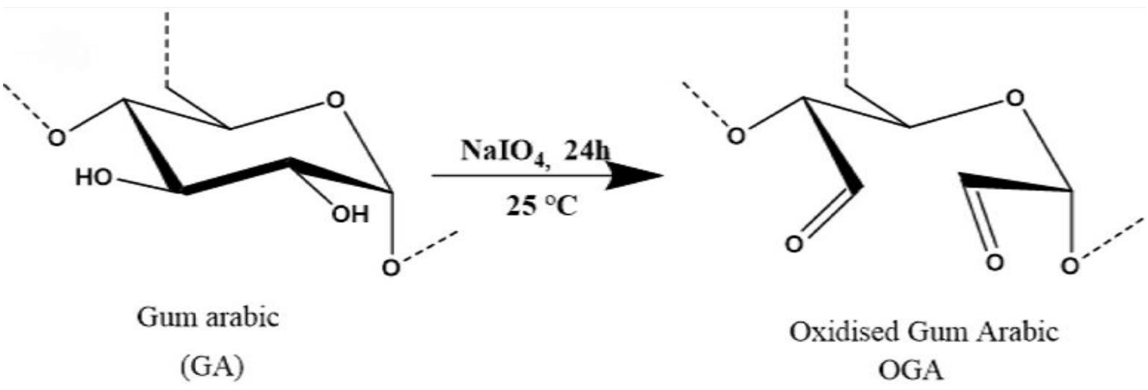
$$\% \text{ Grafting } (\%G) = \frac{W_1 - W_2}{W_0} \text{ X } 100$$

$$\% \text{ Efficiency } (\%E) = \frac{W_1 - W_2}{W_2} \text{ X } 100$$

Where $W_{1,}$ W_0 and W_2 denote the weight of the GA-g-PANI, respectively, the weight of GA and weight of the aniline monomer were used. The grafted copolymer that is produced has hybrid characteristics of polyaniline and gum Arabic biopolymer. According to the study's findings, grafted biopolymers from biodegradable plant sources, like gum Arabic, can be effectively used to produce environmentally friendly semiconductor devices through polyaniline grafting. They would also be a novel biomaterial for the creation of various electrical industry sensors.

Modified GA in Drug Delivery

Ashiq *et al.*, (2019) modified GA my chemical oxidation, treating the biopolymer with 4.67 mmol concentrations of $NaIO_4$ at 25^{o}C for 24 hours achieving a 6.16% degree of the GA oxidation and 4.37 mmol/g aldehyde content as seen below;



Source: Ashiq *et al.*, (2019)

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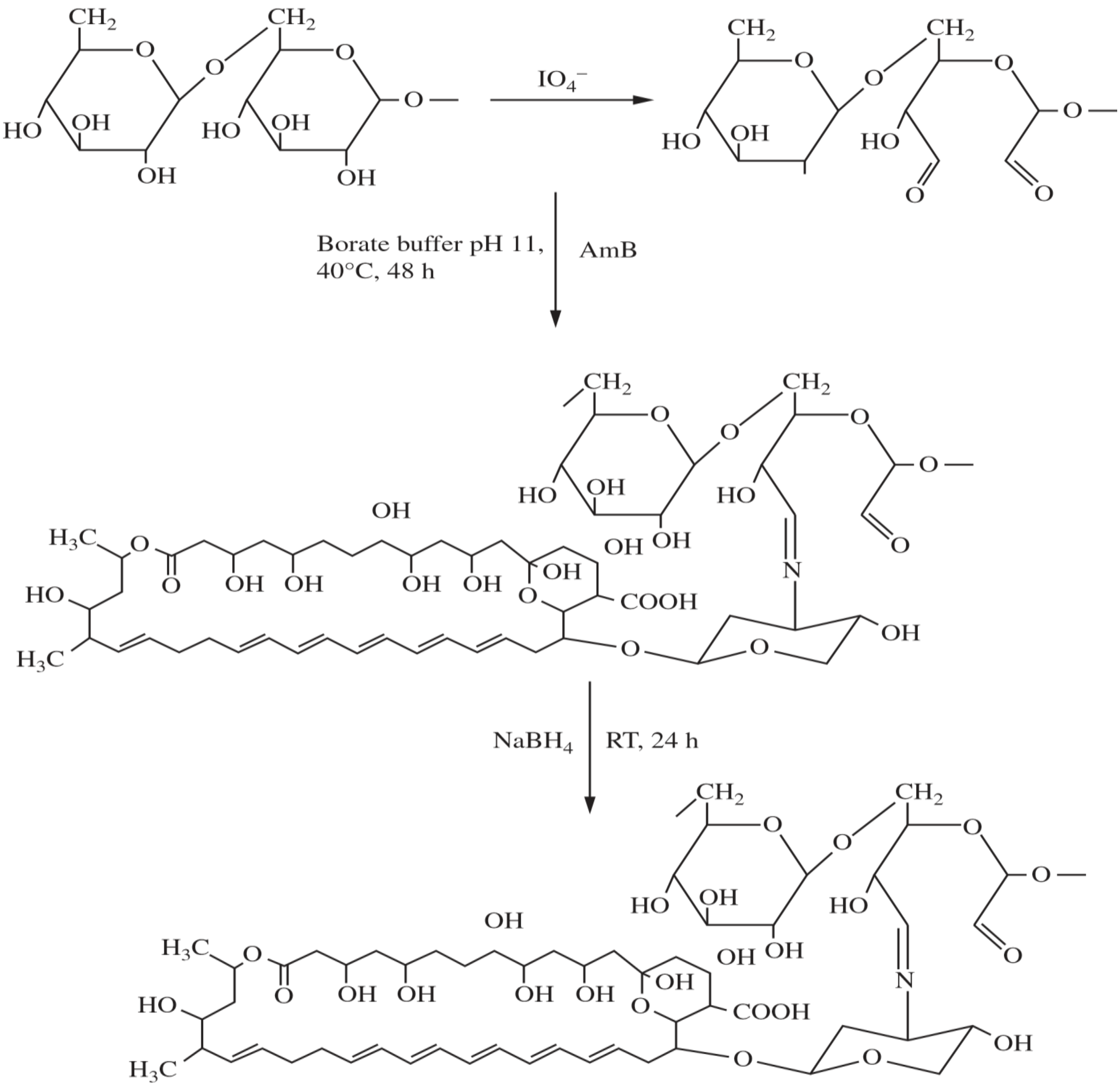
Then, for the first time, smart polyvinyl alcohol (PVA)-based hydrogels were created using the modified GA as a naturally occurring, nontoxic, and pH-responsive cross-linker. High mechanical qualities, excellent porosity, and pH sensitivity were all displayed by the final hydrogel formulations, making them suitable as potential biomaterials for long-term folic acid administration. The findings of his investigation indicate that these hydrogels could be used in the field of drug delivery and serve as an effective photoprotective material.

Another work by Nishi *et al.* (2007) used oxidation to modify GA. In their investigation, sodium metaperiodate was used to oxidize GA. 2.5 g of periodate (0.0116 mol) was added to 100 mL of a 10% solution of gum arabic (0.058 mol) in distilled water to achieve 20% oxidization. The mixture was then magnetically agitated for six hours at 20 °C in the dark. After six hours, the degree of oxidation was assessed iodometrically. Following the reaction, the contents were dialyzed against distilled water for 48 hours with multiple water changes until the dialysate was clear of periodate (using a dialysis membrane MWCO 6000–8000). After that, the solution was frozen, lyophilized until it was completely dry, and kept in the desiccator at 4°C until it was needed. The yield was typically between 75 and 80%. Additionally, the study used Schiff linkages to combine an amphotericin B (AmB) medication with the oxidized gum Arabic as seen the reaction scheme below;



According to the study, when tested on animals, the resultant conjugates were stable, non-hemolytic, and harmless to the internal organs. They also shown good antifungal and anti-leishmanial efficacy in vitro. The release of AmB from the conjugates was therefore confirmed by the fact that AmB conjugated to a high molecular weight polysaccharide, such gum arabic, was still non-hemolytic, non-toxic, and showed anti-fungal and anti-leishmanial activity. Interestingly, when administered intravenously, AmB remained accessible despite the polysaccharide's high molecular weight. Seven days after a single injection, mice's internal organs were

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evaluated for drug residue. The results showed that the spleen still had the highest drug content, suggesting that anti-leishmanial therapy may be possible. It was discovered that the conjugates remained stable for eight months when stored as lyophilized powder. An excellent potential polymer for polymer therapies would be gum arabic, a highly branched polysaccharide that is used extensively in the food and pharmaceutical industries and is also less expensive.

He proposed that more research be done on the antileishmanial potential of these conjugates when given orally to male albino mice infected with L. donovani, as the oral efficacy of AmB is still a problem for treating leishmaniasis mass.

Modified GA in Drug Release

Toti *et al.* (2004) synthesized polyacrylamide-grafted acacia gum to modify GA. They created polymers with varying release properties by grafting acrylamide onto acacia gum in various monomer ratios (1: 1, 1: 3, and 1: 5). The procedure involved dissolving 2 g of GA in 50 mL of water, stirring the mixture for 24 hours, and then de-aerating it for roughly 2 hours by running nitrogen gas through it. At 70°C, the necessary quantity of acrylamide was added and swirled for a further two hours. 25 mL of solution containing 0.15 g of ammonium persulfate (initiator) was added to the resultant solution, and it was agitated for an additional three hours. The study found that using larger concentrations of acrylamide, such as AG-2 (1: 3 ratio of acacia gum to acrylamide) and AG-3 (1: 5 ratio of acacia gum to acrylamide), significantly increased the solution viscosity during the graft copolymer preparation process. As a result, it was quite challenging to achieve uniform mixing. Over the course of three hours, 50 mL of distilled water was added in aliquots of 10 mL each to reduce the viscosity. After cooling the reaction mixture, a little amount of quinhydrone was added to stop the reaction. Following the use of acetone as a non-solvent to precipitate the polymer, the unreacted monomers and the acrylamide homopolymer were eliminated by washing the polymer with 30% aqueous methanol. The resulting solid polymer was dried at 40°C in a vacuum oven. The % grafting, % grafting efficiency, and % conversion of acrylamide-grafted-acacia gum were calculated, respectively, using the following equations;

$$\%\ \text{Grafting} = \frac{mass\ of\ acrylamide\ in\ the\ polymer}{mass\ of\ graft\ polymer} \times 100$$

$$\%\ \text{Grafting efficiency} = \frac{mass\ of\ acrylamide\ in\ the\ polymer}{\text{Mass of (polymer + acrylamide)}} \times 100$$

$$\%\ \text{Conversion} = \frac{mass\ of\ acrylamide\ in\ the\ polymer}{mass\ of\ acrylamide\ taken} \times 100$$

Different monomer ratios were used to accomplish the grafting, resulting in polymers with various release properties. Tablets containing both water-soluble (diltiazem hydrochloride) and water-insoluble (nifedipine) medications were created by further processing these polymers. To assess erosion-controlled medication release from the tablets, the in vitro release data were examined. According to Toti et al. ($200), if a close association could be established between laboratory in vitro investigations and in vivo studies on animal models, the findings of this study might be useful when scaling up operations.

In order to obtain the best crosslinked GA for use in the encapsulation of Cymbopogon citratus essential oil, Ribeiro et al. (2014) changed GA with varying amounts of sodium trimetaphosphate (STMP). The investigation involved purifying GA materials, preparing a 20% (w/v) solution, and homogenizing it in an ultra-turrax (IKA, T25 digital) at 20,000 rounds per minute for one minute. Then, for three hours at 40°C (pH 12 with 2M NaOH), the crosslinking agent, STMP, was applied in varying quantities of 1%, 3%, 6%, and 9% while being stirred. The solution was adjusted to pH 7 at the conclusion of the crosslinking procedure. Centrifugation at 10,000 rpm for 10 minutes and subsequent washing in a solution of ethyl alcohol and acetone (1:1) were used to remove the uncrosslinked material.

The reaction scheme is as shown below;

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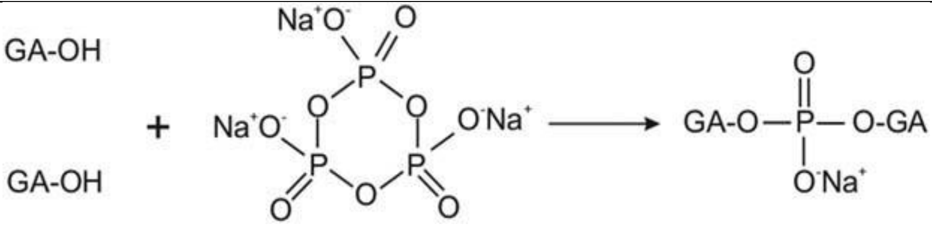


Crosslinking reaction of gum Arabic with sodium trimetaphosphate

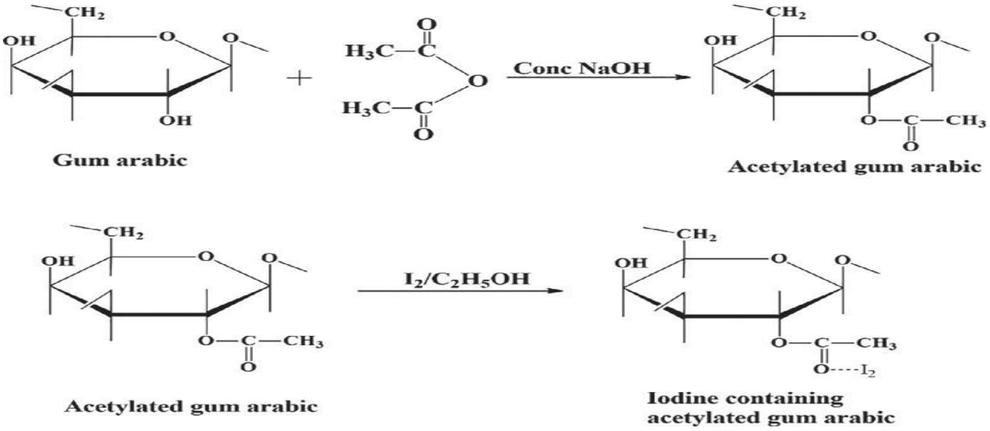
Source: Ribeiro et al., (2014).

Lastly, the crosslinked material spent 48 hours in a desiccator. Additionally, the study assessed the physical and physicochemical changes in the chemically modified GA, which produced favorable outcomes for the physicochemical modifications in the gum arabic cross-linking for highly effective essential oil encapsulation. According to their research, adding sodium trimetaphosphate to gum arabic produced favorable viscosity, swelling, and particle size distribution characteristics that led to an effective encapsulation of the essential oil of Cymbopogon citratus.

GA Modification as a source of Iodide ions

An edible plant-produced biopolymer called gum Arabic was used by Ganie *et al.*, (2015) to create a natural biopolymer-based iodine release chemical. Using acetyl chloride and a base under various reaction conditions, acetylated gum arabic derivatives with diverse degrees of substitution were created in his work after GA was first chemically changed by reacting with an acetylating agent. The resulting Arabic derivatives of acetylated gum took the shape of microspheres. Additionally, the iodine derivative of the acetylated gum was generated by reacting the microspheres that were produced in the preceding step with iodine monochloride, an iodinating agent, to produce stable iodine products.

Because the natural biopolymer gum-iodine complex is non-vaporizing, thermally stable, and releases iodine in a nutritious form, it may be beneficial as a dietary supplement. Iodine has been complexed with polymers that can bind to it, including GA, according to Ahmad et al. (2013), who used GA modification in another medicinal application. Their work was intended to overcome the disadvantages of iodine, such as its insolubility in water. In his research, he chemically altered GA by introducing new reactive groups that readily interact with tiny molecules using an acetylation reaction of gum arabic with acetic anhydride, followed by iodination in ethanol solution to create an iodine complex. To achieve the highest yield of acetylated product, 3.25 g of GA was combined with acetic anhydride in a 100 ml round-bottom flask at a weight ratio of 1:4. Ten milliliters of a 50% (w/v) aqueous solution of sodium hydroxide, which serves as a catalyst, was added after the mixture had been stirred for thirty minutes at 80 °C. The reaction was conducted at 80 °C for several durations (30, 60, and 120 minutes). To stop the reaction, too much ice was put into the reactor. The creamy white substance that comprised the acetyl derivative of GA was dried at about 50 ◦C as shown in the reaction scheme below;



Acetylation reaction of gum arabic and interaction between iodine and C]O groups of gum arabic.

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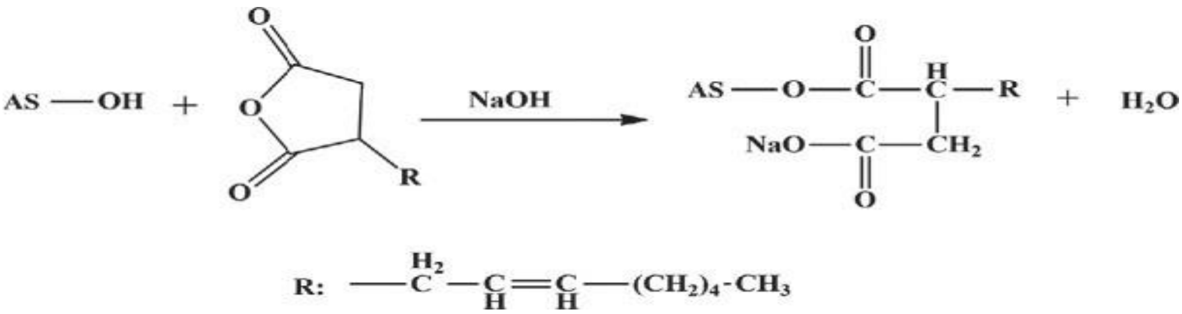
The produced iodine-containing acetylated gum Arabic complexes' antibacterial qualities and iodine release experiments were also conducted. They came to the conclusion that the iodine-gum Arabic complexes release several kinds of iodine species and exhibit antibacterial activities against Escherichia coli.

Another study by Shi et al. (2017) used octenyl succinate anhydride and Acacia seyal gum to modify Arabic gum by an esterification reaction. They mostly carried out four reactions using varying octenyl succinate anhydride concentrations. In their investigation, a 30% (w/v) solution was made by dispersing dry weight GA (30.00 g) in deionized water. A 0.5 M NaOH solution was used to bring the pH down to 8.00. After being diluted with ethanol and applied at 25°C, octenyl succinate anhydride (weight percentage based on the weight of dry GA) was used in four different reactions: 0, 1%, 2%, and 3%. For ninety minutes, the mixes were left to react at 40°C while the pH was kept at 8. The reactions were then stopped by using a 0.1 M HCl solution to bring the pH down to 6. Spray drying was used to create the GA modified by octenyl succinate anhydride. After further dispersing the product in deionized water to create a 10% (w/v) solution, the product was washed with 100% ethanol to get rid of any remaining octenyl succinate anhydride. Five times, this procedure was carried out. The last solid part was oven-dried for 24 hours at 40°C. Four distinct products were produced, which, in weight percentage based on the weight of dry GA, corresponded to 0, 1%, 2%, and 3% octenyl succinate anhydride, respectively.



According to the study's findings, gum arabic modified with octenyl succinate anhydride has better emulsifying qualities than gum arabic, which suggests that it could be used in microencapsulation and emulsions requiring long-term stability.

GA Modification for Graphene Production - A physical approach

Gum arabic was identified by Chabot et al. (2013) as a sustainable alternative to exfoliating crystalline carbon (or graphite) in order to create graphene in water. According to him, physical methods such as sonicating graphite with eco-friendly biopolymers like gum arabic create a viable path toward the production of inexpensive graphene.

As a result, they used GA to create dispersions with mild sonication that contained 0.5–0.6 mg/ml of few layer graphene in DI-H2O. They were able to obtain pure graphene powder following an acid hydrolysis process and a freeze-dryer. In comparison to reduced graphene oxide, graphene has a significantly greater electrical conductivity and is nearly defect-free.

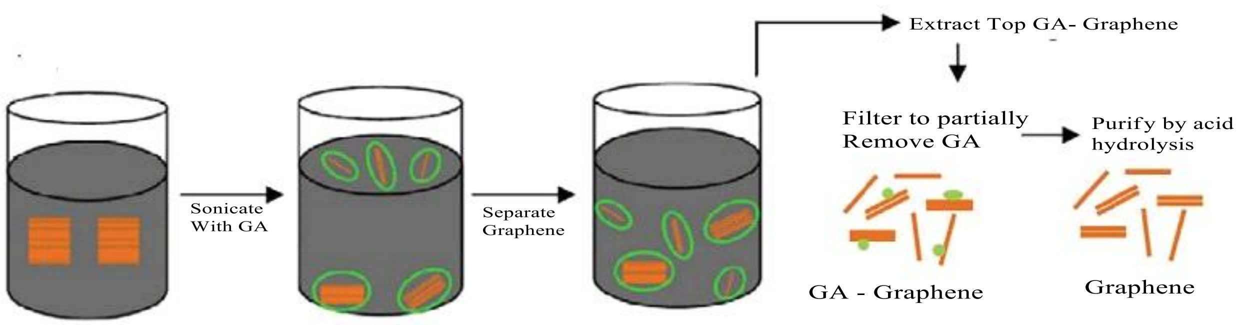


Plate IV: Method of graphene fabrication using gum arabic

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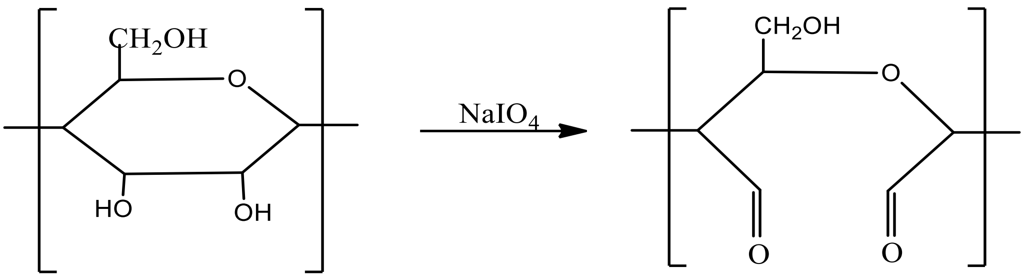
Source: Chabot et al., (2013)

This solution-based method helps bring reasonably priced graphene goods to the market, is scalable, and requires little in the way of chemicals and equipment. Therefore, this is the first report of pure graphene being produced using the sonication method. By oxidizing GA with periodate and cleaving the diols in the sugar units, Akbar et al. (2017) studied the chemical modification of gum Arabic to create aldehyde functional groups. Malaprade oxidation is a well-known reaction that occurs when neighboring diols in a particular polysaccharide are oxidized with periodic acid or its salt in an aqueous solution (Wang, 2010). As a result of the reaction, sugar residues' C2-C3 or C3-C4 bonds are broken, and many aldehyde groups are added to the polymer chains. Using varying concentrations of sodium meta-periodate, GA was oxidized in his study to produce 19.68–50.19 percent oxidized gum (the degree of oxidation indicates the percentage of total monosaccharide units that reacted with periodate to undergo oxidative degradation). This equated to 5.15–40.42 percent aldehyde contents in the dialdehyde-gum solutions. According to his findings, the degree of oxidation and the amount of aldehyde in the oxidized gum increased as the concentration of periodate increased. The structure elucidation of the iodine complexes proved beyond a reasonable doubt that iodine monochloride molecules attached themselves to the -CHO functional groups. Additionally, the author believed that larger levels of oxidation occurred with increasing periodate concentration, leading to higher aldehyde contents in the oxidized gum.

In his research, Olatunji (2018) also looked at the chemical modification of GA by the use of gelatine to crosslink it. He saw that merely combining gum Arabic and gelatine would not create a cross-linked polymer; rather, it would produce a blend with weak or nonexistent chemical connections between the protein and carbohydrate structure. Therefore, the gum Arabic was first oxidized with periodate to produce gum Arabic aldehyde in order to create a chemical cross-link (Olajide 2018). The scheme below shows this reaction, along with a summary of how gelatine and gum Arabic are cross-linked.



Oxidation of a carbohydrate unit with sodium periodate to form an aldehyde.

Unlike the unmodified gum Arabic, the gum Arabic aldehyde can undergo a Schiff base reaction with the gelatine due to the reaction between the aldehyde group and the amino groups of the gelatine (Sarika *et al.*, 2014). The alcohol group of the carbohydrate unit has been converted into an aldehyde unit. This makes this region more reactive, allowing it to react with the amino unit of the protein, (Stefano, 2003).

Regulatory concerns of modified gum Arabic and novel formulations

Any chemical modification such as phosphorylation and esterification, physical-chemical derivatization (chemical crosslinking, grafting), or incorporation of non-GRAS entities (metal/metal-oxide nanoparticles, carbon nanotubes, synthetic polymers) creates a *new* material from a regulatory perspective.

Regulators treat such materials as new food additives, novel excipients, or new cosmetic ingredients and require safety dossiers (toxicology, ADME, impurities, manufacturing controls). Simple statement: *"modified GA ≠ approved GA"* unless the specific modification is evaluated and accepted (Mohamed et al., 2025). Since some chemical modification routes use hazardous reagents/solvents or energy-intensive processes. For scaling up, *green chemistry* approaches (aqueous chemistries, enzyme-mediated grafting, solventless processes) and life-cycle assessments (LCAs) are necessary to ensure the modified product retains a lower environmental footprint than petrochemical alternatives. Recent literature emphasizes green synthesis routes but comprehensive LCAs are scarce (Mohamed et al., 2025).

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Likely regulatory pathways

For *food use* of a chemically modified GA (or composites with nanoparticles), one must submit a novel food/food-additive dossier (EFSA in EU; FDA food-additive petition or GRAS notification in the US) including compositional data, process controls, intake estimates and toxicology (usually including genotoxicity, repeated-dose toxicity, ADME) (Wouw, 2025).

For *pharmaceutical excipients or drug delivery uses* (e.g., GA-based nanoparticles for oral/parenteral delivery), regulators require GLP toxicology, pharmacokinetics, and possibly clinical safety depending on exposure route. (Mohamed et al., 2025).

End users concern for *modified* GA

***The Safety profile of native GA*:** was certified to generally have low toxicity. The native GA is a high-molecular-weight, non-digested polysaccharide (dietary fiber) that is often fermented in the colon. Evaluations by EFSA, JECFA and national bodies have not identified any form of Geno toxicity or major systemic toxicity for conventional exposures. That is why it is widely used in food, cosmetics and feed (Wouw, 2025). Though, certain toxicology concerns may arise after modification such as the introduction of new chemical moieties and impurities in the GA. Since chemical modifications (phosphorylation, esterification and use of other crosslinkers) may introduce low-molecular-weight residues, reagents, catalysts, or by-products (unreacted reagents, solvent residues, low-MM oligomers) that can be toxic or genotoxic. Regulators require identification and specification limits for such impurities. Without validated impurity profiling, the material can't be considered the same as native GA (Mohamed et al., 2025).

GA is widely used as a stabilizer/coating for nanoparticles or to make GA-based nano-carriers. Nanoparticle behavior (absorption, tissue distribution, surface reactivity, oxidative stress potential) depends on the particle core (iron oxide, CNTs, silver, among others) and the coating. The coating may modify toxicity but does *not* automatically make nanomaterials safe: nanotoxicology data (size, shape, surface chemistry, agglomeration, dissolution, ROS generation) are usually required. Papers showing GA-based nanocomposites with biological activity (such as anti-leukemic in vitro) highlight promise but also the need for in vivo GLP toxicology before clinical/food use (Abdel Halim et al., 2024).

Dose specification issues: Oral ingestion of modified GA may be largely handled by gut fermentation, but systemic exposure is possible for low-MM fractions or nanoparticles. Hence, regulators want absorption, distribution, metabolism, excretion (ADME) data specific to the modified material. For parenteral uses (injectable carriers), systemic safety data are extensive and mandatory (Mohamed et al., 2025). Structural changes can alter immunogenic potential or how the material interacts with gut microbiota. There is limited long-term data on how heavily modified or high-dose formulations change microbiome composition or induce immune responses. Targeted studies on allergenicity and microbiome are therefore recommended.

Factors to consider by a regulator / buyer before accepting to buy a modified GA product

For buyers and regulators to convincingly accept a modified GA product, there is need for the modifier to provide the comprehensive characterization, GLP toxicology / ADME data showing acceptable safety margins for the intended exposure route. EFSA (European Food Safety Authority), The manufacturing controls & impurity specifications demonstrating reproducible, contaminant-free production, the traceable, ethically sourced supply chain (particularly for major buyers worried about conflict-linked supply) and lastly, an evidence that modification does not create higher environmental footprint (Omokhafe et al., 2019).

RECOMMENDATION

The use of Gum Arabic as additives has found various application in the production of quality and durable finished products in food, beverages and drugs were a little modification of the biopolymer would be an added advantage. Thus, the hydroxyl functional groups in the Gum Arabic additive has to be capped, reduced or converted to any unreactive end group with reduced inference in the desired end product. Therefore, modification of biopolymers like GA becomes a new and interesting field for researchers to develop novel sustainable and biocompatible materials, and hence development of new modification methods is an area of keen interest. These modified biopolymers have shown advanced and desirable properties as compared with its parent material (the unmodified biopolymer) and hence this broadens their applicability in different fields of study and application. The commercial applications of modified GA in various end products would bring about new products of desired property and quality. Therefore, this review has highlighted some important and recent methodologies for the modification of biopolymers that will become a source of compiled information for researchers working on natural biopolymers.

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