EPA Public Access

Author manuscript

Biotechnol Adv. Author manuscript; available in PMC 2019 November 15.

About author manuscripts

Submit a manuscript

Published in final edited form as:

Biotechnol Adv. 2018 November 15; 36(7): 1984–2016. doi:10.1016/j.biotechadv.2018.08.008.

Tree gum-based renewable materials: Sustainable applications in nanotechnology, biomedical and environmental fields

Vinod V. T. Padil^{1,*}, Stanisław Wacławek¹, Miroslav Cerník^{1,*}, and Rajender S Varma^{2,3,*}

¹Department of Nanomaterials in Natural Sciences, Institute for Nanomaterials, Advanced Technologies and Innovation, Technical University of Liberec, Studentská 1402/2, Liberec 1, Czech Republic, 461 17; Telephone: +420 485 353 017;

²Water Resource Recovery Branch, Water Systems Division, National Risk Management Research Laboratory, U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, MS 483, Cincinnati, Ohio 45268, USA

³Regional Centre of Advanced Technologies and Materials, Department of Physical Chemistry, Faculty of Science, Palacký University in Olomouc, Šlechtitelů 27, 783 71 Olomouc, Czech Republic.

Abstract

The prospective uses of tree gum polysaccharides and their nanostructures in various aspects of food, water, energy, biotechnology, environment and medicine industries, have garnered a great deal of attention recently. In addition to extensive applications of tree gums in food, there are substantial non-food applications of these commercial gums, which have gained widespread attention due to their availability, structural diversity and remarkable properties as ‘green’ bio-based renewable materials. Tree gums are obtainable as natural polysaccharides from various tree genera possessing exceptional properties, including their renewable, biocompatible, biodegradable, and non-toxic nature and their ability to undergo easy chemical modifications. This review focuses on non-food applications of several important commercially available gums (arabic, karaya, tragacanth, ghatti and kondagogu) for the greener synthesis and stabilization of metal/metal oxide NPs, production of electrospun fibers, environmental bioremediation, bio-catalysis, biosensors, coordination complexes of metal–hydrogels, and for antimicrobial and biomedical applications. Furthermore, polysaccharides acquired from botanical, seaweed, animal, and microbial origins are briefly compared with the characteristics of tree gum exudates.

Graphical Abstract

*Corresponding Authors' vinod.padil@tul.cz; miroslav.cernik@tul.cz; Varma.Rajender@epa.gov.

Disclaimer

The views expressed in this article are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Declaration of interest: None

Keywords

Tree gums; Nanoparticles and nanofibers; Greener synthesis; Hydrogel; Environmental bioremediation; Biosensors; Antibacterial; Biomedical

1. Introduction

Nanoparticles (NPs) and nanofibers (NFs) have been successfully applied in diverse fields, such as energy and the environment, water treatment, pharmaceuticals, automobiles and health care (Colvin, 2003; Fryxell and Cao, 2007; Matlack, 2010; Thavasi et al., 2008; Vigneswaran, 2009). However, the majority of the procedures presently used for the production of NPs and NFs are reliant on non-ecological materials and produce harmful waste. Green nanotechnology, the fusion of nanotechnology developments embracing green chemistry principles, is a rational approach that embraces the aspects vital for developing an ecologically sustainable society. Green chemistry is a set of principles or practices that encourages the design of products and processes with an emphasis on the use of renewable chemicals that overall reduce or eliminate the use and generation of hazardous substances (Anastas and Warner, 1998; Luque and Varma, 2012; Rickerby, 2013). Nanomaterials offer varied applications that prevent pollution by their use as nano-catalysts, which generate less waste, enable effective sensing of pollutants in water and the environment, and eliminate harmful chemicals and microorganisms (Dwivedi et al., 2015; Grassian, 2008; Sharma et al., 2015; Varma, 2016, 2014). Current greener nanotechnology practices often tend to involve the use of natural resources, non-hazardous solvents, and biodegradable and biocompatible materials via energy-reliant processes in the synthesis of NPs and NFs (Hebbalalu et al., 2013; Iravani, 2011; Perea et al., 2016; Raveendran et al., 2003; Virkutyte and Varma, 2011).

Natural polysaccharides with their unique structure and functionality open up a new area of nanostructured material creation. Bio-templating and bio-replication of metal oxide nanostructures by polysaccharides have been shaped naturally as well as by man (Boury and Plumejeau, 2015). Tree gum polysaccharides or gum hydrocolloids are natural and versatile

green materials encompassing diverse functional and structural properties to assemble varied nanostructures. Over the past few years, many new gum exudates have been introduced in the literature from various sources, with proper structures and functional characterization including specific applications. Tree gums represent a largely unexplored source of valuable natural products and contribute to diversity as an important component of global foodstuff, therapeutic, paper, fabric and other markets (Nussinovitch, 2010). Depending on their major industrial applications, plant gums may be broadly classified as ‘food’ and ‘non-food’ or ‘technological grade’ gums. Natural gum hydrocolloids are classified into various groups depending on their origin, structural-functional properties, and applications namely botanicals (locust bean gum, guar gum, and pectin), tree gums (arabic, karaya, tragacanth, ghatti, and kondagogu), seaweed polysaccharides (alginate, carrageenan, and agar), and bacterial polysaccharides (xanthan, dextran and gellan gum) (Williams et al., 2011). The surface properties of tree gums are unique due to their ability to decrease interfacial tension between different systems such as gas-liquid, liquid-liquid, and solid-liquid, which imparts stability via steric, electrostatic interaction and hydration forces. Tree gums can stabilize NPs akin to their superior use in food emulsions rivalled by other stabilizing agents (Adamson and Gast, 1997; Redgwell et al., 2005). Tree gum exudates have been used for food applications as an emulsifier, thickening, and stabilizing agent, but there are no comprehensive reviews on the emerging applications such as environmental, biosensor, catalytic, or biomedical uses. The present review highlights the various applications of tree gums and describes their specific applications with detailed explanations as to how these gums can be incorporated into nanostructured products (Fig. 1). Specifically, the importance of five major gums [gum arabic (GA), gum tragacanth (GT), gum karaya (GK), gum ghatti (GG), and kondagogu gum (KG)], which are among the most widely utilized gums in various applications, is summarized. A detailed comparison of sources and the functional applications of various commercial gum hydrocolloids guar gum (Das et al., 2015; Kumar et al., 2012; Pal et al., 2015; Prado et al., 2005; Prajapati et al., 2013; Pramanik et al., 2015; Vaghela et al., 2014), locust bean gum (Dufficy et al., 2015; Murali et al., 2016b; Prado et al., 2005; Prajapati et al., 2013; Tagad et al., 2014; Ventura et al., 2015), pectin (Attallah et al., 2016; Chen et al., 2015; Munarin et al., 2012; Neves et al., 2015; A. J. Wang et al., 2012; Williams et al., 2011), agar (Xuefeng Li et al., 2017; Rhein-Knudsen et al., 2015; Williams et al., 2011; Yang et al., 2014), alginates (Davis et al., 2003; Finotelli et al., 2010; Leslie et al., 2013; Liu et al., 2015; Paul and Sharma, 2004; Ryou et al., 2013; Sari-Chmayssem et al., 2016; Wei et al., 2015; Williams et al., 2011), carrageenan (Chaudhary et al., 2016; Li et al., 2014; Nair et al., 2016; Williams et al., 2011; Xue et al., 2017), xanthan gum (Flickinger, 2010; Izawa and Kadokawa, 2010; Katzbauer, 1998; Palaniraj and Jayaraman, 2011; Petri, 2015; Qiu et al., 2016; Williams et al., 2011), and gellan gum (Bacelar et al., 2016; Dhar et al., 2012; Ferris and Panhuis, 2009; Hungerford et al., 2012; Keller et al., 2017; Stevens et al., 2016; Williams et al., 2011), including tree gums such as GA (Augustin and Hemar, 2009; Bandyopadhyaya et al., 2002; Bosnea et al., 2017; Chabot et al., 2013; Fan et al., 2012; X. Li et al., 2017; Ribeiro de Barros et al., 2016; Sanchez et al., 2017; L. Wang et al., 2012a, 2012b; Williams et al., 2011; Xhanari et al., 2017; Xu et al., 2017; Zhou et al., 2017), GG (Deshmukh et al., 2012; K. Sharma et al., 2015a, 2015b, 2014; Kashma Sharma et al., 2014; Williams et al., 2011), GK (Bie et al., 2017; Jakóvik-Kolon et al., 2017; Kumar et al., 2016; Nussinovitch, 2010; Singh and Pal, 2008; Williams et al., 2011), GT (Asghari-

Varzaneh et al., 2017; López-Castejón et al., 2016; Mallakpour et al., 2018; Mostafavi et al., 2016; Niknia and Kadkhodaei, 2017; Singh and Sharma, 2017, 2014a; Williams et al., 2011) and KG (Dasari and Guttena, 2016; Nussinovitch, 2010; Puskuri et al., 2017; Rastogi et al., 2014; Rathore et al., 2016; Saravanan et al., 2012) are illustrated in Table 1.

Various international bodies, including the US Environmental Protection Agency (Committee on toxicology, 2001), clearly stipulate limits on the presence of heavy metals in drinking water so that they do not exceed their permissible levels. Common techniques used for the elimination of metallic impurities include adsorption, ion exchange, chemical precipitation, and reverse osmosis (Juang and Shiau, 2000; Yan and Viraraghavan, 2001; Matheickal et al., 1999). However, certain drawbacks of these techniques include partial metal elimination, generation of toxic slurry and involvement of expensive chemicals or methods. From this perspective, the advance of biological product-based entities as sustainable and inexpensive bio-sorbents is crucial. Biosorption can be a procedure that exploits cheaper bio-resources to capture toxic pollutants. In contrast to conventional methods, biosorption processes have the advantages of low investment and operational costs, with a reduction in the volumes of chemical and/or biological sludge generated. Furthermore, this process enhances effectiveness in decontaminating dilute effluents as it eradicates the problems of the toxicity of the applied materials and the loss of nutrients or cultures needed for microbial-based procedures (Davis et al., 2003; Kratochvil and Volesky, 1998). The use of natural product-based polymers is of specific economic interest as the biomaterials are essentially drop-in substitutes for synthetic adsorbents or ion exchangers, whereby embracing the philosophy of green chemistry (Klimmek et al., 2001).

Many researchers are looking for safe, active and cost-effective alternatives for the management of wastewater comprising toxic metals and other contaminants. However, many adsorbent materials bearing a variety of affixed well-designed chemical groups have been reported for this purpose (Falcato et al., 2016; Lu and Astruc, 2018; Volesky, 2007). Naturally occurring biopolymers have been identified, which exhibit an excellent adsorption ability for multivalent metal ions. This may be exemplified by several materials, including chitin, chitosan, lignin, sea weed, wool wastes, agricultural wastes, sugarcane bagasse, biomass by-products, polysaccharides based flocculants, and algae etc., which have been employed for the exclusion of deadly contaminants from aqueous wastewater streams (Aydin and Aksoy, 2009; Davis et al., 2003; Salehizadeh et al., 2018; Varma et al., 2004). Alginic acid, present in brown seaweeds, is a biopolymer adorning carboxyl functionality capable of forming coordination complexes with metal ions (Gok and Aytas, 2009). Effective biosorption is determined in particular by active sites for the binding of the bio-sorbent, the chemical state of the binding sites and the binding strength.

2. Green chemistry and nanomaterials

One of the central problems facing human society today emanates from increasing environmental pollution due to various industrial and human activities (Wacławek et al., 2017). Many alternative sources of chemical entities available from starch, cellulose and synthetic polysaccharides or their derivatives have been developed as substitutes for food and non-food materials over the years, but tree gums have retained their uniqueness as they

possess a distinct niche in terms of their properties and applications, which are much superior in comparison (Table 1 and Table 2).

There are many naturally occurring materials that can effectively serve as a reducing and coating mediator for the production and stabilization of NPs (Huang et al., 2015). Critical reviews on the greener assembly of nanoparticles using both living and various parts of plants materials have been summarized (Akhtar et al., 2013; Dauthal and Mukhopadhyay, 2016; Hebbalalu et al., 2013; Iravani, 2011; Mittal et al., 2013; Mohammadinejad et al., 2016). An eco-friendly assemblage characteristic for the fabrication of extensively used Ag NPs has been created, which evaluates the cost effective, biogenic and scale-up production of the NPs utilizing plant-based biomolecules (Cinelli et al., 2015). Plant extracts *Lippia citriodora* (Elemike et al., 2017), xerophytes—*Bryophyllum* sp., mesophytes—*Cyperus* sp. and hydrophytes—*Hydrilla* sp. (Jha et al., 2009), *Pelargonium graveolens* (Shankar et al., 2003), living plants (*Aloe vera* (Chandran et al., 2006), *Carica papaya* (Mude et al., 2009), *Magnolia Kobus* (Song et al., 2009), *Diospyros kaki* (Song et al., 2009), *Medicago sativa* (Lukman et al., 2011), *Cymbopogon Flexuosus* (Singh et al., 2006), *Azadirachta indica* (Shiv Shankar et al., 2004), *Avena sativa* (Armendariz et al., 2004), Lemongrass (Shiv Shankar et al., 2004), *Pelargonium graveolens* (Shankar et al., 2003), *Chilopsis linearis* (Rodriguez et al., 2007), *Tamarindus indica* (Correa et al., 2016; Singh et al., 2017), *Gardenia jasminoides* (Khan et al., 2014), *Pinus resinosa* (Coccia et al., 2012), *Camellia sinensis* (Ahmmad et al., 2013), and *Curcuma longa* (Sathishkumar et al., 2009); biopolymers {starch (El-Rafie et al., 2011; Sarma and Chattopadhyay, 2004; Vigneshwaran et al., 2006), chitosan (Long et al., 2013; Reicha et al., 2012), alginate (Yang and Pan, 2012; _S1_Reference451X. Zhao et al., 2014), cellulose (Lokanathan et al., 2014) dextran (Bankura et al., 2012), pullulan (Kanmani and Lim, 2013)}, vitamin B₁ (Nadagouda et al., 2009), vitamin B₂ (Nadagouda and Varma, 2008, 2006), vitamin C (Nadagouda and Varma, 2007) sugars (Nadagouda and Varma, 2007; Raveendran et al., 2006, 2003), glutathione (Baruwati et al., 2009), tea and coffee extracts (Nadagouda et al., 2008), beet juice (Kou and Varma, 2012a, 2012b), glycerol (Kou et al., 2013), red grape pomace (Baruwati and Varma, 2009), blackberry, blueberry, pomegranate, turmeric extracts (Nadagouda et al., 2014), tree-based gums {GA (Kong et al., 2014), GK (Padil and erník, 2015; Thekkae Padil and erník, 2013), KG (Kora et al., 2010; Padil et al., 2015c; Saravanan et al., 2012; Vinod et al., 2011a), GT (Rao et al., 2017), and GG (Kora et al., 2012; Kora and Rastogi, 2015; Kora and Sashidhar, 2015; Mittal and Mishra, 2014)} are examples of such greener alternatives, which offer chemical properties bearing useful functionalities and which have been successfully used for the production and stabilization of NPs.

3. Tree gums: Structural and functional properties

Tree gums, found in virtually every biosphere on Earth, like plants, animals and many bacteria, are hydrocolloids with complex structural features and macromolecules (Anderson and Wang, 1990; Anderson and Bridgeman, 1985; Anderson and Weiping, 1992), whose complex chemical composition depends on the source and its age. Chemically, hydrocolloids are polysaccharides with multifaceted structures encompassing glycosidic bonds with a large number of groups (-OH) repeatedly adorning the backbone of the molecule. They facilitate the networking assemblies with metal ions via templating the polymeric bonds composed

and making multidimensional structures. The key chemical functionalities recognized in most of the gums are hydroxyl (OH-), ether (C-O-C), acetyl (CH₃CO-), carboxyl (-COO⁻), aliphatic (-CH), carbonyl (-C=O) groups and those originating from protein fractions. As the name suggests, the simplest interaction of hydrocolloids is with water and this is the main reason for their use in food products. In view of the excess hydroxyl groups, water is held not only within the lattice arrangement via hydrogen bonding, but also inside the spaces creating composite molecular conformation (Anderson and McDougall, 1987; Hall, 2009; Philips and Williams, 2001). The most significant tree gum exudates that find widespread applications are GA, GK, GT, KG and GG; their morphological appearance and constituent sugar moieties are presented in Fig. 2 and their physical and chemical properties and molecular characterization are shown in Table 2. Extensive research has been conducted on various characteristics including their accessibility, molecular weight assignments, structural linkages, well-designed characteristics (rheological, hydration behavior, self-assembly, and surface properties), food and non-food applications (Anderson and Wang, 1990; Anderson et al., 1985a, 1985b, 1983; Anderson and Bridgeman, 1985; Anderson and Grant, 1988; Anderson and McDougall, 1987; Anderson and Stoddart, 1966; Anderson and Weiping, 1992; Brito et al., 2004; de Brito et al., 2005; Fauconnier et al., 2000; Hall, 2009; Janaki and Sashidhar, 2000, 1998; Kumbhare and Bhargava, 1999.; Le Cerf et al., 1990; Mahendran et al., 2008; Osman et al., 1995, 1993a, 1993b; Padala et al., 2009; Philips and Williams, 2001; Phillips and Williams, 2009, 2000, Randall et al., 1989, 1988; Singh and Sharma, 2014b; Stephen et al., 2006; Vegi et al., 2009; Verbeken et al., 2003; Vinod et al., 2008a, 2008b; Weiping, 2000; Whistler and BeMiller, 1993). Tree gums are typically grown under geographically-favorable climatic (excessive heat, shortage of moisture and at higher elevations) and soil conditions (Stephen et al., 2006; Verbeken et al., 2003). Furthermore, gum yield and quality are dictated by the time and intensity of tapping, fluctuations in temperature and rainfall during gum collection. The main countries producing GK, KG, GG, and GT are Sudan, Nigeria, Chad, Mali, and Senegal, India, Pakistan Sudan, Senegal, Mali, Turkey, Iran, Iraq, Syria, Lebanon, Afghanistan, Pakistan, and Russia. KG and GG are tree gum exudate plants that grow naturally in Indian forests (Nussinovitch, 2010; Verbeken et al., 2003; Vinod et al., 2008b).

3.1: Gum arabic (*Acacia senegal*) (GA)

Gum arabic (*Acacia senegal*) (GA) is a branched structure encompassing metal cations (calcium, magnesium, and potassium), and a complex polysaccharide. The molecular mainstay comprises 1→3-linked β-D-galactopyranosyl parts, whereas the side chain consists of two to five 1→3-linked β-D-galactopyranosyl units (as lateral chains) appended to the backbone via 1→6-linkages. The whole structure is made up of α-L-arabinofuranosyl, α-L-rhamnopyranosyl, β-D-glucuronopyranosyl and 4-O-methyl-β-D-glucuronopyranosyl segments, the last two being the end-terminal units (Anderson et al., 1985a; Fauconnier et al., 2000; Mahendran et al., 2008; Osman et al., 1995, 1993a, 1993b; Philips and Williams, 2001; Phillips and Williams, 2000; Randall et al., 1989; Verbeken et al., 2003). GA is structurally fabricated by high molecular fractions of carbohydrate masses (approx. 2.5×10⁵ Da) chains being attached separately to a polypeptide sequence (Anderson et al., 1985a; Fauconnier et al., 2000; Osman et al., 1993a). Hence, GA is structurally made up of three molecular fractions, namely (i) arabinogalactan-peptide (AGp); (ii)

arabinogalactan-protein (AGP); and (iii) glycoprotein (GP) complexes. The surface properties of GA, such as adsorption at solid-liquid interfaces, could be utilized to stabilize nanoparticles, such as carbon nanotubes, metal nanoparticles (Au, Ag, Fe), ceramics, and latex nanoparticles (Aberkane et al., 2012; Amiri et al., 2012; Batalha et al., 2010; Gashua et al., 2016; Gils et al., 2010; Kannan et al., 2012; Kattumuri et al., 2007; Ma et al., 2012; Song et al., 2011). Furthermore, GA-magnetic NPs have been explored for biomedical applications, namely as MRI contrasting agents for cell-labelling and production of Au NPs for diagnostic and therapeutic applications (Kattumuri et al., 2007; Kong et al., 2014; Palma et al., 2015). GA has a minimal Newtonian viscosity even at elevated gum concentrations, and its intercalating capability to interact with diverse molecular entities, namely proteins, minerals and polyphenols, mainly depends on its unique structural properties (carbohydrate-protein macrostructure); therefore, GA is extensively used as an additive, emulsifier, or thickener because of such remarkable properties (Sanchez et al., 2017) (Table 2). As a food additive, GA is used to prevent sugar crystallization, which assists in the beverage industry, confectionary, food emulsion, flavor encapsulation and bakery and brewing, whereas non-food applications concentrate on pharmacological, lithography, fabric, and cosmetic industries (Nussinovitch, 2010; Verbeken et al., 2003).

3.2: Gum karaya (*Sterculia urens*) (GK)

Gum karaya (*Sterculia urens*) (GK) is structurally branched and essentially comprises of a partially acetylated carbohydrate polymer secured as a magnesium and calcium salt with high molecular mass (1.6×10^6 Da) (Anderson et al., 1985b, 1983; Philips and Williams, 2001; Phillips and Williams, 2000). The leading structure is made up of α -D-galacturonic acid and α -L-rhamnose moieties and is connected to side chains (1,2-linkage of β -D-galactose or by 1,3-linkage of β -D-glucuronic acid), with a preponderance of rhamnose residues being linked to the core structure via 1,4-linkages of β -D-galactose (Anderson et al., 1983; Brito et al., 2004; de Brito et al., 2005; Le Cerf et al., 1990; Verbeken et al., 2003; Weiping, 2000; Whistler and BeMiller, 1993). The major sugar residues found in GK are galactose (13–26 %) and % rhamnose (15–30 %); the latter being higher than other exudate gums. Although the protein content (~1 %) is comparatively low, another compositional material is 40 % of uronic acid (β -D-glucuronic and D-galacturonic acid). Native GK is insoluble in water and its swelling characteristics are due to the presence of the high acetyl content (~8 %) of its structure (Janaki and Sashidhar, 2000, 1998; Kumbhare and Bhargava, n.d.). Le Cerf et al. (Le Cerf et al., 1990) differentiated three portions of GK and found that the native gum (~10 %) was solubilized in cold water, increasing to 30 % in hot water; whereas, after deacetylation via treatment with NH_3 or sodium hydroxide, 90 % of GA could be solubilized in an aqueous medium (Le Cerf et al., 1990; Stephen et al., 2006; Verbeken et al., 2003). GK has recently been investigated for Si-based anodes in Li-ion batteries as a binder and also as a bio-nanocomposite for effective removal of rhodamine 6G from water (Bie et al., 2017; Kumar et al., 2016).

3.3: Kondagogu gum (*Cochlospermum gossypium*) (KG)

Kondagogu gum (*Cochlospermum gossypium*) (KG) is extracted from the Kondagogu tree, found in India. The various grades of gums and their physical and chemical, structural, solution, medical formulations and creaming properties have been described (Naidu et al.,

2009; Vegi et al., 2009; Vinod et al., 2008a, 2008b). Toxicity studies have determined that the KG is non-hazardous and has a prospective use as a dietary supplement (Janaki and Sashidhar, 1998; Kumbhare and Bhargava, 2009; Puskuri et al., 2017). Various neutral sugars (glucose, arabinose, galactose, rhamnose, and mannose) and acidic sugars (galacturonic acid and glucuronic acid) comprise the structure of KG, with their complex arrangement being composed of structural linkages, namely (1 → 2) β-D-Gal p, (1 → 6)-β-D-Gal p, (1 → 4) β-D-Glc p A, 4-O-Me-α-D-Glc p A, (1 → 2) α-L-Rha and (1 → 4) α-D-Gal p A (Vinod et al., 2008a, 2008b, 2010).

KG has shown significant differences in its properties pertaining to elemental contents, sugar composition, and amino- and fatty acid profiles compared to other well-known tree gums such as GA, GK and GT (Vinod et al., 2010). KG, a gum with a major constituent of uronic acid, differs from other natural gums such as GA, GK and GT in terms of its amino acid profile. The Zeta potential of native KG (−23.4 mv) indicates the existence of negatively charged functionalities, which may explain the biosorption mechanisms for sequestration of heavy metals involving complexation between metal ions and KG structures with other adsorption mechanisms (adsorption, surface micro-precipitation and ion-exchange etc.) (Vinod et al., 2008b).

3.4: Gum ghatti (*Anogeissus latifolia*) (GG)

Gum ghatti (*Anogeissus latifolia*) (GG) is a gum polysaccharide extracted mainly from *Anogeissus latifolia* (Combretaceae, Myrtales) (Davidson, 1980; Glicksman, 1982; Katayama et al., 2008). GG is available as a calcium-magnesium salt composed of D-mannose, D-xylose, D-galactose, L-arabinose, and D-glucuronic acid and less than 1 % of 6-deoxyhexose, and is used as an emulsifier, thickener, binder and stabilizer in food industries (Castellani et al., 2010; Ido et al., 2008). The gum serves as a buffer and reverts to its normal pH of approximately 4.8. GG contains an arabinogalactan-type polymeric structure consisting of (1 → 4) β-D-GlcA, and (1 → 2)-α-D-Man residues as the backbone structure. The side chain is composed of (1 → 3)- and (1 → 6)-connected galactose units, and mannose residues are present as double branch-points (Stephen et al., 2006; Tischer et al., 2002b). The structural, conformation and functional relationship of various GG fractions via size exclusion chromatography, static and dynamic light scattering methods have been examined (Kang et al., 2015a, 2015b, 2014). The structural assignments of GG using methylation analysis were established via mass spectroscopy and 2D NMR spectroscopy (COSY, TOCSY, HMQC, and HMBC). The arabinogalactan chain in GG composed of 1 → 4)-Glc p A(1 → 6)-Gal p(1 → and → 2)-L-Araf-(1 → connections) and detailed structural assignments have been reported (Kang et al., 2011a, 2011b, 2011c).

The complex structural units and functional properties of GG can easily undergo chemical modification or grafting to create intricate molecular structures, with desirable properties for use in adsorption/complexation of metal ions, electrical conducting materials, as a sorbent for sequestration of contaminated heavy metal ions or dyes from water or industrial effluents, and biomedical applications, among others (Kaith et al., 2014; Mittal et al., 2015; Mittal et al., 2015b; K. Sharma et al., 2015b, 2014; Sharma et al., 2013).

3.5: Gum tragacanth (*Astragalus gummifer*) (GT)

Gum tragacanth (*Astragalus gummifer*) (GT) is mostly used in food and pharmaceutical fields because of its attractive features and exceptional attributes (stabilizing, thickening, emulsifying, adhesive, suspending agent and fat replacer with a long shelf life), biodegradability, non-toxicity, natural availability, and elevated resistance to microbial attacks. GT is a high molecular weight (8.4×10^5 Da) complex macrostructure, branched, heterogeneous and has an anionic nature consisting of magnesium, calcium and potassium salts (Singh and Sharma, 2014b; Verbeken et al., 2003; Weiping, 2000). Two portions make up the composition of the GT, namely tragacanthin and tragacanthic acid or bassorin, the latter being insoluble in water but having a gelling capability due to swelling. GT is a typical branched arabinogalactan (tragacanthin) comprising (1→6)- and (1→3)-linked galactose and terminal (1→2)-, (1→3)-, and (1→5)-linked L- arabinose. Tragacanthic acid, a pectic type of structure, is the major constituent of GT with structural linkages such as (1→4)-linked α -D-galacturonan substituted at O-3 by β -D-xylose (Balaghi et al., 2011; Gavlighi et al., 2013a, 2013b; Singh and Sharma, 2014b; Tischler et al., 2002a; Verbeken et al., 2003). The proteinaceous materials and methoxyl groups are present in both fractions of GT, albeit in smaller amounts (Verbeken et al., 2003; Weiping, 2000). The remarkable structural and functional properties of GT have recently been exploited in many non-food applications, such as tunable drug delivery systems, hydrogels, cryogel and xerogel blends, micro-encapsulations, nanocomposites for heavy metal ions removal, bioplastics, edible blend films and coatings and grafting copolymer flocculants for destabilization of carbon nano-tubes (Asghari-Varzaneh et al., 2017; López-Castejón et al., 2016; Mallakpour et al., 2018; Mostafavi et al., 2016; Niknia and Kadkhodaei, 2017; Pal et al., 2017; Singh and Sharma, 2017, 2014a).

4. Tree gums in greener synthesis (gum–metal salt interactions) of nanoparticles (NPs)

Lately, much attention has been devoted to the use of natural products for the synthesis of nanomaterials as opposed to synthetic compounds. In addition to their application as processing materials, another part of green nanotechnology is the development of environmentally-friendly sustainable processes, e.g. exploitation of non-toxic, eco-friendly solvents; water and supercritical carbon dioxide have been investigated as alternatives to organic solvents (Ji et al., 1999; Shah et al., 2000).

The use of gums as natural bio-sorbents aimed at the sorption of toxic metals and as renewable, inexpensive and non-toxic reducing and stabilizing agents for the synthesizing of NPs has been explored (Kong et al., 2014; Kora et al., 2012, 2010; Kora and Rastogi, 2015; Mittal and Mishra, 2014; Padil et al., 2015c; Padil and Šeránek, 2015; Reddy et al., 2015; Saravanan et al., 2012; Padil and Šeránek, 2013; Vinod et al., 2011a). In general, the respective gum solutions are simply admixed with a solution of the corresponding metal salts to produce metal NPs (Fig. 3).

Synthesis of NPs is affected by the concentration of the precursor salts and gum, pH, temperature, basic electrolyte and contact time (Kong et al., 2014; Kora et al., 2012, 2010;

Kora and Rastogi, 2015; Mittal and Mishra, 2014; Padil et al., 2015c; Padil and erník, 2015; Reddy et al., 2015; Saravanan et al., 2012; Thekkae Padil and erník, 2013; Vinod et al., 2011a).

Table 4 summarizes the NPs synthesized using various gums, their synthetic conditions and characterizations (particle size, shape, crystalline nature). (Table 4)

4.1. Synthesis and stabilization of NPs using gum arabic (GA)

The production of Au NPs, with varying shapes and sizes, was achieved by mixing an Au precursor (KAuBr_4 or HAuCl_4), reducing agents (catechol, ascorbic acid, and NaBH_4) and GA (a capping agent) under sonication for 20 min. at room temperature (Wang et al., 2012a). By changing the concentration of the precursors (1.0 mM to 20 mM) and reducing agents, Au NPs could be fabricated in shapes such as flower, cauliflower, raspberry, urchin, and confeito (Fig. 4 a). GA was deemed as the best capping agent for the growth of various architectures of Au NPs via the particle-mediated aggregation model (Fang et al., 2010; Li et al., 2007; Wang and Halas, 2008) in contrast to polyvinylpyrrolidone (PVP), which afforded particles of irregular sizes.

An efficient strategy for the direct assembly of 'Au nanoflowers' was developed by sonicating the mixture of a GA solution (0.01 g, 5 mL) with KAuBr_4 (20 mM, 5 mL) and ascorbic acid (0.1 M, 5mL) for 5 s at room temperature. GA played a prominent role in directing the shapes and stabilization of Au nanostructures, which were stable for six months in an aqueous medium at room temperature (Wang et al., 2012b). The glycol protein, hydroxyproline, present in the GA was found to act as a steric stabilizer to protect the ensuing Au NP architectures, which can be exploited for bio-sensing and biomedical applications.

An aqueous dispersible Au nanocomposite was prepared by one-pot mechanical stirring of GA with poly (3,4-ethylenedioxythiophene) (PEDOT) and HAuCl_4 , where GA served as a stabilizer and a medium for dispersion of an Au- PEDOT nanocomposite. The color of the Au-PEDOT nanocomposite is directly proportional to the concentration of GA in the suspension as well as the corresponding size of the Au NPs (Fig. 4b) (Rocha et al., 2014). In addition to delineation of GA stabilization mechanism, this research established a benchmark for the rational and targeted design of novel uniform-sized nanoparticles in complex systems without aggregation.

Biocompatible Au NPs were produced via continuous mixing of an aqueous GA solution (0.2 %), with phosphine amino acid (THPAL), and NaAuCl_4 . GA stabilized Au NPs (GA-Au NPs), targeted as a molecular imaging contrast agent using an X-ray CT scan, displayed in vitro and in vivo durability for months in aqueous, salt and buffered solutions (Kattumuri et al., 2007).

A facile method utilizing GA has produced monodispersed Pd NPs (average size; 9.1 ± 0.3 nm) at an optimum temperature (100°C). A higher concentration of GA led to smaller-sized NPs, which were stable for more than five months. Presumably, the $-\text{COO}^-$ and $-\text{OH}$ groups of the GA structure, emanating from polysaccharide, proteins and fatty acid moieties, are

responsible for encapsulating Pd NPs via steric stabilization and electrostatic repulsion (Devi et al., 2011). GA stabilized Au NPs (GA-Au NPs) with excellent stability in varying biological pHs were prepared by NaBH_4 reduction of an aqueous AuCl_4^- solution at 25°C . The resultant NPs were found to be exceptionally stable at both highly acidic pH (pH = 1.2 or gastric) and under neutral pH (pH=6.8) in vitro stability conditions (Ribeiro de Barros et al., 2016). Furthermore, GA-Au NPs were evaluated for changes in the viability, proliferation and morphology in various cell lines. The inherent structural components of GA bearing glycoprotein and arabinogalactan-protein (AGP) with variabilities of functional groups ($-\text{OH}$, $-\text{COO}^-$ and $-\text{NH}_2$) may control the size of NPs growth and enhanced colloidal stabilization via steric interaction (Cornelsen et al., 2015; Quintanilha et al., 2014; Rocha et al., 2014).

Magnetic NPs based on a GA support were synthesized by intermixing $\text{Fe}^{2+}/\text{Fe}^{3+}$ ions using an ammonia solution under hydro-thermal conditions (Banerjee and Chen, 2007a). In another variation, glucose grafted GA-magnetic NPs were prepared by coupling GA-magnetic NPs with maltose and reductive amination using NaBH_3CN (Banerjee and Chen, 2007b). The GA-magnetic NPs could be used for the exclusion of Cu^{2+} ions from water via their complexation with $-\text{NH}_2$ and $-\text{OH}$ groups of GA and magnetic NPs, respectively. The glucose grafted GA-magnetic NPs were applied to bind to a glucose binding protein, concanavalin A (Con A). Con A interacted with the glucose grafted GA-magnetic NPs, wherein the $-\text{OH}$ groups of glucose and the $-\text{NH}$ groups or oxygens from asparagine in Con A forged the hydrogen bond.

A spontaneous reaction of Ag NPs in the presence of GA occurs without the addition of any distinctive reducing agent by mixing equal amounts of GA (0.5 wt%) and silver nitrate aqueous solutions (Mohan et al., 2007). Ag NPs (particle size ~ 5 nm) were obtained where GA served as a good stabilizer for a period of more than five months. Mechanistically, mixing of Ag^+ cations with the aqueous GA solution resulted in an ion-exchange process and the carboxylate group ($-\text{COO}^-$) of GA was converted into $-\text{COOAg}$. Ag^+ cations attached to carboxylate groups were later converted *in situ* into Ag NPs and consequently stabilized by the GA.

The synthesis of translucently separable Ag NPs via the hydrothermal method using GA as a reducing and functional coating agent and various factors, such as the reaction temperature, mass ratio of GA to AgNO_3 of 1:1, concentration (10 mmol/L) and reaction time, were studied, and Ag NPs with different morphological characteristics could be produced (Li et al., 2015). The temperature and GA played a vital role in the production of mono-disperse Ag NPs, due to the interaction of GA charged groups ($-\text{COOH}$ and $-\text{NH}_2$) with Ag^+ resulting in an (Ag^+ -GA) complex. Furthermore, the reduction of Ag^+ to Ag^0 occurred due to easy cleavage of C-C bonds in GA, which released the electrons at elevated temperatures ($> 100^\circ\text{C}$) when the (Ag^+ -GA) complex was reduced to Ag^0 -GA. Subsequently, GA polymer chains provided Ag NPs with excellent diffusion properties via the steric effect.

Extremely stable and water dispersed, re-dispersible Ag NPs were produced by applying γ -ray radiolysis of an Ag^+ solution with GA as a capping agent via steric stabilization (Fig. 5 f) (Rao et al., 2010). The major factors influencing the formation of uniform-sized Ag NPs

were the radiation dosage, GA to Ag⁺ ratio and the ionic strength of the reaction conditions. At higher doses of radiation, face-centered cubic (FCC) crystalline NPs (XRD) with a maximum particle size of less than 3 nm (HR-TEM) were generated.

The synthesis of Ag NPs, within a PVA-GA hydrogel medium, via γ -radiation tempted scaffolding has been reported (Juby et al., 2012). The work revealed that the degree of swelling of the hydrogel and the percolating of Ag NPs from the composite hydrogel depends on the GA concentration. The ensuing NPs were found to be in the range of 10–40 nm, where an interaction of hydroxyl and carboxyl groups of GA and PVA with Ag NPs was demonstrated by FTIR. TGA study revealed that the Ag- PVA-GA linkage was thermally more stable than the hydrogel without the Ag NPs, silver loading being proportional to the cross-linking. The Ag NP hydrogels showed superior antibacterial action against *E. coli* bacteria, which implies that the radiation-induced synthesis can be used for various biomedical applications.

A greener synthesis of Au NPs on the surface of GA-functionalized Fe₃O₄ NPs (Wu and Chen, 2012) has been described. A thin coating of ~2 nm Au NPs was deposited on the surface of GA-Fe₃O₄ NPs. The nanocomposite demonstrated good catalytic efficiencies for the reduction of C₆H₅NO₃ (4-nitrophenol) with NaBH₄ and virtuous stability lasting more than five recycles. The kinetic data suggested that this catalytic response was diffusion-controlled and the outcome bodes well for the development and application of magnetically recoverable Au nano-catalysts.

Selenium NPs (Se NPs) have been prepared by using GA as the stabilizer where the particle size, shape, aggregation behavior and in vitro antioxidant performance of the Se NPs were established by TEM (Fig. 5a), HR-TEM (Fig. 5 b), DLS, FTIR, AFM and UV-Vis spectroscopy (Kong et al., 2014). The stability of Se NPs (particle size of ~35 nm) in water was established for nearly one month. The Se NPs without GA were aggregated and presented in Fig. 5 c and d. The study illustrates how a simple food additive with a high molecular mass and branched structure bearing abundant functional groups could be used to prepare and stabilize Se NPs.

4.2. Synthesis and stabilization of NPs using gum Karaya (GK)

The synthesis of GK-stabilized Au NPs and their application in the delivery of anticancer drugs have been studied (Pooja et al., 2015). The addition of HAuCl₄ (10 mM) to a GK solution (15 mg/mL) and stirring for 1 h at 90 °C produced gum-stabilized NPs (GK-Au NPs), which were found to be biocompatible during cytotoxic and hemolysis studies. The GK-Au NP conjugate showed efficacy as a drug carrier as well as enhanced colloidal stability for Au NPs, with better anticancer activity, inhibition of colony formation and ROS induction against human lung cancer cells superior to the drug, gemcitabine hydrochloride, being determined. These results also corroborated recent clinical studies with a natural gum arabic-Au NP conjugate (GA-AuNPs), which displayed bio-compatibility and non-toxicity in mammalian systems (Chanda et al., 2014). In addition, many natural polysaccharides, such as pectin (Devendiran et al., 2016), alginate (Jaouen et al., 2010; Kодиyan et al., 2012), dextran (Jang et al., 2014), β -glucan (Liu et al., 2017) and chitosan (Hortigüela et al., 2011; Jeong et al., 2011), have been conjugated with Au NPs via greener pathways to minimize the

associated toxicity and hazardous nature, while being pragmatic for environmental, biological and medical applications.

A colloid-thermal synthesis of CuO NPs (Fig. 6 d) using GK (10 mg/L) with varying quantities of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (1 mM to 3 mM) has been described at 75 °C, wherein single-phase CuO with a monoclinic structure, CuO NPs, were uniformly disseminated on the external of the gum matrix (Thekkai Padil and Senthil Kumar, 2013). The ensuing smaller CuO NPs (4.8 ± 1.6 nm) were found to be exceedingly stable and displayed significantly better antibacterial proficiency on *E. coli* and the *S. aureus* relative to larger CuO NPs (7.8 ± 2.3 nm).

4.3. Synthesis and stabilization of NPs using Kondagogu gum (KG)

KG has been extensively applied for the synthesis of various NPs with the typical dual advantages of KG as a reducing and stabilizing agent (Kora et al., 2010; Kora and Sashidhar, 2014; Rastogi et al., 2017, 2015, 2014; Saravanan et al., 2012; Vinod et al., 2011a). Although the literature on tree gums-assisted nanoparticle synthesis is sparse relative to other biopolymers of a natural origin such as chitosan, alginate, hyaluronan, starch, cellulose, dextran, pectin, carrageenan, guar gum, pullulan, agar, and xanthan gum etc., recent studies have started to exploit the use of tree gums in view of their availability as an economic commodity and their distinctive structural-functional properties (Deshmukh et al., 2012; Fan et al., 2012; Riedo et al., 2013; Sanchez et al., 2017; Kashma Sharma et al., 2014; Khanari et al., 2017).

Ag NPs (Fig. 6 a) and Au NPs (Fig. 6 c) were prepared from their salts ($\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ and AgNO_3 ; 5×10^{-3} M each) and a KG aqueous solution was produced by agitation at a selected pH and 65 °C (Ag NPs) and 75 °C (Au NPs) for 1 h (Vinod et al., 2011a). Color changes and UV-Vis spectroscopic measurements (absorbance maxima at 516 and 420 nm for Ag and Au, respectively) aided the progress of the reaction. Similarly, Pt NPs (Fig. 6 b) were synthesized from salt and a KG solution by autoclaving at 0.15 MPa for 15 min. The mean diameters of the crystalline NPs were quantitatively determined by TEM to be 2.4 ± 0.7 nm, 7.8 ± 2.3 nm and 10.5 ± 3.5 nm for Pt, Au and Ag NPs, respectively. In another study (Vinod et al., 2017), GK was used for the fabrication and scaffolding for zerovalent iron nanoparticles (ZVI) (Fig. 6 e and f) and the mechanism of stabilization of ZVI was further delineated (Fig. 6 g and h).

A simplistic and sustainable method by autoclaving a mixture of Ag NO_3 (1.0 mM) and GK (0.5 wt %) at 121 °C and 15 psi for 60 min has been demonstrated (Kora et al., 2010). Nearly monodispersed NPs of ~ 3 nm Ag NPs ensued where the KG served as a reductant and stabilizing agent. In terms of antibacterial evaluation, the results highlighted a higher antibacterial efficiency for the Gram-positive bacteria (*Staphylococcus aureus*) with a larger zone of inhibition compared to Gram-negative bacterial strains (*E. coli* and *Pseudomonas aeruginosa*). The proposed mechanism of Ag NP production involved the reductive action of –OH, –CO– and –COO[–] functional groups present in the KG structure, which facilitated the complexation with Ag ions and utilized the –OH groups to convert Ag ions into Ag NPs at the expense of the –CO groups. Capping of the Ag NPs was performed by the polysaccharide-protein and fatty acid moieties present in the KG via steric stabilization. A

similar mechanism of synthesis and the capping effect of various NPs such as Au, Ag, and Pt have been studied for GA, starch, and alginate (Devi et al., 2011; Luque et al., 2013; Vigneshwaran et al., 2006).

Ag NPs (mean size of 5.1 ± 2.8 nm; KG-Ag NPs) have been produced by autoclaving 1 mM Ag NO₃ solutions with of KG (0.5 %) at 121°C under 0.1 MPa for 60 min, and they were found to be stable at various pH (4–11) and quantity of NaCl (5–100 mM) (Rastogi et al., 2014). Their utility for the colorimetric detection of Hg²⁺ ions at ppb levels in water was not influenced by the common ions present in drinking water. In addition to tree gums, bio-sensing of metal ions or hazardous vapors using other gum-stabilized Ag or Au hydrocolloids, such as locust bean gum, and guar gum, has been shown (Pandey et al., 2012; Tagad et al., 2014).

KG-modified spherical magnetite (Fe₃O₄) NPs have been fabricated by mixing Fe²⁺ and Fe³⁺ ions in an alkaline solution in the occurrence of KG (Saravanan et al., 2012). The produced NPs (KG- Fe₃O₄; ~ 8 to 15 nm diameters) demonstrated ferromagnetic behavior with a magnetic permeation (~60 emu/g).

4.4. Synthesis and stabilization of NPs using gum Tragacanth (GT)

The formation of Ag NPs on a cotton fabric via interaction between Ag NO₃, GT, citric acid and cellulose (from cotton) has been demonstrated (Montazer et al., 2016). Mechanistically, the formation of Ag NPs occurred as abundant –OH groups from the cotton fabric and –COO[–] from the GT reduced the Ag⁺ ions to Ag NPs (particle size ~77.5 nm) on the surface of the cotton fabric. The treated cotton textile with GT-AgNPs was found to be highly effective in killing bacterial colonies, such as *E. coli* and *S. aureus*, whereby producing antibacterial cotton fabrics.

GT has been used for the preparation of urchin-like hexagonal ZnO nanorods (GT-ZnO NR) at a low-temperature using ultrasonic irradiation (Ghayempour et al., 2016). The ensuing ZnO NR (55–80 nm size) was produced with a length of 240 nm (FE-SEM, XRD, FTIR and UV-Vis analysis). GT-ZnO NR displayed good photocatalytic activity for the degradation of methylene blue. Furthermore, GT-ZnO NR showed antibacterial effectiveness against *S. aureus* and *E. coli* and antifungal action against *C. albicans*, respectively.

Au NPs were generated by heating a mixture of HAuCl₄·3H₂O with GT for 240 min. at 65 °C and their stability was examined by mixing with varying concentrations of salt, acidic and basic conditions and with human blood plasma (Rao et al., 2017). Furthermore, naringin-loaded GT-AU NPs proved to be a highly effective delivery route for naringin against both the *B. subtilis* and *M. luteus* and *E. coli* and *P. aeruginosa* bacterial strains, with superior bactericidal activity as well as loading efficacy being displayed.

4.5. Synthesis and stabilization of NPs using gum Ghatti (GG)

GG (1 % w/v) produced Au NPs upon mixing with HAuCl₄ (0.1 M) and heating (70 – 90°C). The process was controlled by various independent parameters such as gum and metal salt concentrations, and temperature and dependent variables (particle size, PDI, and zeta potential), which were evaluated via a Box-Behnken-based statistical model (Alam et

al., 2017). The study showed that temperature was critical for the synthesis of Au NPs, as it controlled the size, PDI, and zeta potential of the GG stabilized or capped Au NPs.

A facile greener synthesis of almost monodispersed and uniform spherical Ag NPs (5.7 ± 0.2 nm) has been reported from silver nitrate using GG, which displayed substantial antibacterial activity (Kora et al., 2012).

Nanocomposite, GG-based iron oxide magnetic NPs cross-linked with poly (acrylic acid-co-acrylamide), have been produced via free radical polymerization and exploited for the adsorption of rhodamine B (adsorption capacity = 654.8 mg/g) from water (Mittal and Mishra, 2014). The adsorptions isotherms, kinetic studies and desorption efficiency of the adsorbent were established. Other composite materials with natural biopolymers based on xanthan gum, gum arabic, guar gum, alginate and chitosan have been used for the environmental remediation of toxic heavy metal and organic dyes from water (Banerjee and Chen, 2007a; Chang and Chen, 2005; Lim et al., 2009; Sand et al., 2010; Singh et al., 2009; Yan et al., 2012).

5. Electrospun fibers from gum hydrocolloids

Electrospinning is an elegant method for producing fibers in micro- or nanometer sizes with a pronounced surface area to volume ratio (Greiner and Wendorff, 2007; Jayaraman et al., n.d.). Critical parameters of the process include solution assets (chain entanglement, molecular weight, dielectric constant, purity, solubility, concentration, viscosity, surface tension, distribution of charged groups, thickening effect, and conductivity), handling factors (applied field voltage, humidity, solution movement rate, tip-to-collector distance, and accumulator geometry) and ambient factors (moisture, movement of air and temperature) (Haider and Park, 2009; Lubambo et al., 2013; Nie et al., 2008; Mahanta et al., 2011; Toskas et al., 2011; Wang et al., 2013). The attainment of an ecologically-responsive electrospinning technology dictates the use of non-hazardous, cheaper, and more ecological solvents and spinnable resources. Compared to the present-day electrospinning method, which frequently uses harmful, corrosive and volatile organic solvents, the application of aqueous-based solvents, ionic liquids, deep eutectic solvents (DESs) or polymers make the electrospinning processes both more ecologically favorable and economical (Abbott et al., 2003; Barber et al., 2013; Freire et al., 2011; Grassian, 2008; Raveendran et al., 2003; Thavasi et al., 2008; Varma, 2016; Viswanathan et al., 2006; Zhang et al., 2012).

Electrospun fibers of natural polymers have tremendous practicability in biomedical fields (material engineering, drug carriers, biosensor and drug delivery (Sridhar et al., 2015) and encapsulation of bioactive compounds in the food industry (Liang et al., 2007; Wen et al., 2017). Numerous natural hydrocolloids including food proteins and polysaccharides (Mendes et al., 2017a), alone or blended with other natural/synthetic formulations, have been applied for electrospinning, which successfully generates uniform nanofibers (Alborzi et al., 2014, 2013; Atila et al., 2015; Bonino et al., 2011; Chang et al., 2012; Cui et al., 2017, 2016; Fu et al., 2016; Ignatova et al., 2016; Islam et al., 2012; Islam and Karim, 2010; Kong and Ziegler, 2014; Lin et al., 2013; López-Rubio et al., 2012; Lubambo et al., 2015, 2013; Mendes et al., 2017b; Nie et al., 2008; Nista et al., 2015; Padil et al., 2016, 2015a, 2015c;

Padil and ěrnĳk, 2015; Qian et al., 2016; Ranjbar-Mohammadi et al., 2016c, 2013; Ranjbar-Mohammadi and Bahrami, 2016; Rezaei et al., 2016; Rockwell et al., 2014; Shalumon et al., 2011; Shekarforoush et al., 2017; Sousa et al., 2015a, 2015b; Stone et al., 2013; Tsai et al., 2015; Vashisth et al., 2017, 2016, 2014; Yang et al., 2014; Zarekhalili et al., 2017). An illustrative review of natural gum hydrocolloids, such as guar gum (Lubambo et al., 2015, 2013), alginates (Bonino et al., 2011; Chang et al., 2012; Fu et al., 2016; Islam and Karim, 2010; Nie et al., 2008; Nista et al., 2015; Shalumon et al., 2011; Stone et al., 2013), pullulan (Atila et al., 2015; Islam et al., 2012; Kong and Ziegler, 2014; L3pez-Rubio et al., 2012; Qian et al., 2016), almond gum (Rezaei et al., 2016), pectin (Cui et al., 2017, 2016; Rockwell et al., 2014), agar (Sousa et al., 2015a, 2015b; Yang et al., 2014), carrageenan (Ignatova et al., 2016), xanthan gum (Mendes et al., 2017b; Shekarforoush et al., 2017), gellan gum (Vashisth et al., 2017, 2016, 2014), GA (Padil et al., 2016; Tsai et al., 2015), GT (Ranjbar-Mohammadi et al., 2016c, 2013; Ranjbar-Mohammadi and Bahrami, 2016; Zarekhalili et al., 2017), GK (Padil et al., 2016; Padil and ěrnĳk, 2015), and KG (Padil et al., 2016, 2015a, 2015c) and their spinning combinations (both carriers and solvents), and prospective applications are presented in Table 3.

With their excellent mechanical strength and numerous physical and chemical properties, nanofibers have remarkable applications in many diverse fields including energy conversion (dye-sensitized solar cells, organic and hybrid solar and fuel cells), energy storage devices (for hydrogen storage and super capacitors), optoelectronics, transistors, personal respiratory protection from biological and chemical agents, acoustics, biotechnologies, medical fields (drug delivery, nerve and tissue engineering, wound healing), and catalysis (Frenot and Chronakis, 2003; Greiner and Wendorff, 2007; Sill and von Recum, 2008; Yoon et al., 2008). In the environmental domain, their applications include air filtration, dust capture, liquid filtration for removal of suspended solids and bacteria, heavy metal ion and organic compounds adsorption and treatment, ion exchange, membrane technologies and sensors for both liquid contaminants and gas detection (Desai et al., 2009; Homayoni et al., 2009; Lee et al., 2009; Li et al., 2011; Matsumoto and Tanioka, 2011; Minato et al., 2006; Reneker et al., 2007; Teo and Ramakrishna, 2006; Thavasi et al., 2008; Thompson et al., 2007; Vashisth et al., 2014).

The electrospinning of natural polymers and their applications in medicine has increased due to their biocompatibility, non-toxicity, biodegradability and economic profitability compared to synthetic polymers (Ramakrishna et al., 2005; Shenoy et al., 2005; Venugopal and Ramakrishna, 2005; Wang et al., 2009; Yu et al., 2006). The major areas in biomedical (scaffolding, wound dressing and drug delivery), ecological and antibacterial applications involve the use of natural electrospun fibers (Bonino et al., 2011; Matthews et al., 2002; Torres-Giner et al., 2008; Wang et al., 2005). The choice of solvent, molecular configuration, and distribution and spinning environment, are some of the critical factors that still need to be addressed on the way to advance the electrospinning of biological polymers (silk fibroin, hyaluronic acid, chitin, chitosan, collagen, cellulose, and alginates) (Bonino et al., 2011; Elsabee et al., 2012; Lubambo et al., 2013; Matthews et al., 2002; Ranjbar-Mohammadi et al., 2013; Shenoy et al., 2005; Toskas et al., 2011; Yu et al., 2006).

Developing the electrospinning process consuming greener materials and aqueous-based solvents makes the process sustainable and opens up pathway for engineering manufacture. Natural polysaccharides (alginate, dextrose, hyaluronic acid, cellulose, chitin, and chitosan); proteins (gelatin, collagen, and silk,); DNA, and derivatives of polysaccharides (cellulose acetate, and hydroxypropyl cellulose) and composites (hydroxyapatite/ cellulose acetate and PVA/ cellulose acetate) have all been electrospun efficaciously (Cao et al., 2013; Ji et al., 2012; Konwarh et al., 2013; Schiffman and Schauer, 2008; Sencadas et al., 2012; Singh et al., 2016). The major applications of nanofibrous biopolymers have been in medical (wound dressings and scaffolds in tissue engineering) and pharmaceutical areas (Khadka and Haynie, 2012; Kim et al., 2003; Kriegel et al., 2008; Nguyen et al., 2011; Ramakrishna et al., 2010; Zhou et al., 2013). In addition, specific applications in biotechnology, food industry, water treatment, environment protection and the energy sector have remarkably increased (Baptista et al., 2011; Ki et al., 2007; Rafique et al., 2016; Samad et al., 2013; Tian et al., 2011; Wongsasulak et al., 2010; R. Zhao et al., 2014).

Nanofibers have been fabricated via electrospinning of purified guar gum by removal of the insoluble fractions (crude fiber, proteins and ash etc.) and ethanol precipitation of the soluble fraction (Lubambo et al., 2013). Subsequent cloth filtration and removal of aggregated particles followed by membrane filtration achieves a reduction in the pore size and increases the fiber homogeneity and solubility.

Guar gum crosslinked with PVA and various concentrations of Fe_3O_4 NPs have been electrospun onto fibers under alkaline and non-alkaline conditions (Lubambo et al., 2015). The study revealed that the nanofibers incorporated with magnetite NPs produced under alkaline conditions was superior in the size distribution and homogeneity of the nanoparticles compared to the non-alkaline fibers, further enhancing the therapeutic efficiency of alkaline guar gum/PVA/ Fe_3O_4 fibers.

The area of 'greener electrospinning' for the production of nanofibers and nanomembranes, using natural gums such as GA, GT, GK and KG blended with synthetic biocompatible polymers like poly(vinyl alcohol) (PVA), poly(ϵ -caprolactone) (PCL), poly(ethylene oxide) (PEO), poly(L-lactic acid) (PLLA) and poly(lactic glycolic acid) (PLGA) has been explored (Padil et al., 2016; Ranjbar-Mohammadi et al., 2016a, 2016c, 2013; Ranjbar-Mohammadi and Bahrami, 2015; Zarekhalili et al., 2017). Gums (GA, GK and KG) mixed with PVA in varying wt % of blend solutions were successfully electrospun and the resulting fibers are shown in Fig. 7. These synthetic polymers enhanced the solubility of the gum and subsequently improved the spinnability of the solution. The general understanding is that PVA can interact with the natural polymers via hydrogen bonding and disturbing the molecular configuration, resulting in improved chain entanglement and viscosity modification of the blended solution (Agarwal et al., 2008; Bhattarai et al., 2006; Bhattarai and Zhang, 2007). These efforts result in the production of smooth nanofibers with a uniform diameter and membranes with high biocompatibility and good mechanical properties. An aqueous PVA solution (12 wt%) was alternatively mixed with GA (10 wt%), GK or KG (both deacetylated; 3 wt%) in different weight proportions (PVA to gum ratios from 50/50 to 100/0) to test the spinnability and uniformity of the produced nanofibers (Padil et al., 2016). The influence of the weight proportions on the conductivity, viscosity

and surface tension of the resulting blends was also determined. A proportion of PVA of 70 to 90 % represented the ideal intermingling solution in the direction of engineering to yield uniform and blobless nanofibers with a typical diameter of ~ 220 nm. PVA was found to be a better polymer partner or these three gums than PEO. PEO, which can make hydrogen bonds with gums via its oxygen groups, can interact with the gums culminating in lower chain entanglement and higher intermolecular interactions, a trait that led to the rejection of PEO as an appropriate polymer for manufacture ideal combinations with the gum. Other natural polysaccharides (alginate, gellan, green seaweed (*Ulva Rigida*), tragacanth, guar and chitosan) have been blended with PVA or PEO for electrospinning purposes (Bonino et al., 2011; Elsabee et al., 2012; Lubambo et al., 2013; Ranjbar-Mohammadi et al., 2013; Toskas et al., 2011; Vashisth et al., 2014).

GA has been used for viscosity modulation to improve the electrospinning properties of gelatin-chitosan hybrid fibers fabricated in an aqueous/acetic acid solvent medium utilizing GA and PVA as copolymers (Tsai et al., 2015). GA and an acetic acid/water combination is a greener medium, which influences the electrospinning parameters and enhances the incorporation of a higher gelatin-chitosan (~16 %) content in the final electrospun product, thereby reducing the cost of production by discarding expensive and harmful solvents (trifluoroacetic acid or hexafluoroisopropanol) for the production of gelatin-chitosan fibers. The higher content of gelatin-chitosan in the electrospun fibers may also play an important role in tissue engineering applications (Sahay et al., 2012).

Electrospun fibers with a combinations of GT and two copolymers (PCL and PVA) have been produced by a co-electrospinning process, which produces nanofibers with an optimum diameter of 131.6 ± 27.5 nm (Zarekhalili et al., 2017). The antibacterial efficiency of the hybrid fibers was tested against *E. coli*, and *S. aureus*. *E.coli* were further vulnerable to nanofibers due the action of the sugar residues, such as L-arabinose and L-fucose, present in GT (Ranjbar-Mohammadi et al., 2013). The results determined that hybrid nanostructures can have superior proliferations and non-toxicity action towards MTT assay and NIH3T3 cells.

Aligned and random morphological nanofiber scaffolds based on GT and poly (L-lactic acid) have been produced (Ranjbar-Mohammadi et al., 2016a). Among other things, the aligned PLLA/GT (3 %; 75:25 ratio) fibers were found to display excellent physical and chemical as well as mechanical properties and could be effectively applied to nerve tissue regeneration.

In another report, GT (7 %), PCL (20 %) and varying amounts of curcumin (1 – 24 %) were mixed together in acetic acid/water (90 % v/v) and the whole solution was agitated at room temperature, and GT/PCL/curcumin hybrid fibers were subsequently formulated via electrospinning (Ranjbar-Mohammadi et al., 2016b; Ranjbar-Mohammadi and Bahrami, 2016). The antibacterial properties, curcumin release and wound healing properties were systematically studied with these GT/PCL/curcumin fibers, where the efficacy in diabetic wound healing in rat models was discerned.

Electrospun fibers of GT/PCL with excellent antibacterial properties, mechanical strength, porosity, hydrophilicity and degradation behavior have been produced (Ranjbar-Mohammadi and Bahrami, 2015). Acetic acid was used a solvent for electrospinning of GT/PCL [(3:1; 7 % (GT), 10– 20 % (PCL)] to produce an electrospun scaffold with an average diameter of 156 ± 25 nm. The results on cytotoxicity and antibacterial potencies of these GT/PCL fibers showed that this could be effective application in biomedical areas as skin and wound-healing scaffolds.

Electrospun fibers of GT/PVA have been created by mixing three concentrations of GT/PVA (3, 6 and 9 wt.%) in a various combinations (GT/PVA; 0/100 to 100/0) (Ranjbar-Mohammadi et al., 2013). Many electrospinning parameters (including processes, systems and ambient) were controlled for the smooth production of nanofibers at 40/60 ratio of GT/PVA. Excellent antibacterial efficacy of GT/PVA was found towards Gram-negative bacteria (*P. aeruginosa*) with superb cell proliferation and biological compatibility of the nanofibers.

An electrospun drug delivery device has been fabricated by combining GT, PLGA and TCH via blending and coaxial electrospinning (Ranjbar-Mohammadi et al., 2016c). PLGA/GT was prepared in three different formulations (PLGA: GT; 100:0, 75:25 and 50:50 wt. %) in a HEP solvent where TCH (5% w/w) was added into a polymeric mixture and stirred for 30 min. Three types of electrospun fibers, i.e. PLGA, PLGA/GT core shell, and PLGA/GT-TCH core shell, were produced. The study revealed that the higher the amount of GT in the electrospinning mixture, the smaller the diameter of the ensuing nanofibers. Nanofiber stability, TCH releasing behavior, cell culture and proliferation studies of the nanofibers were evaluated and PLGA/GT-TCH core shell nanofibers were found to be efficient for the treatment of periodontal disease.

The electrospinning of natural polysaccharides and tree exudates is a complex process, where several factors such as solution parameters (viscosity, surface tension, conductivity, and polymer concentration), polymer properties (solubility in various solvents, molecular weight, and rheological) and process considerations (electrical voltage, temperature, humidity) influence the overall success of the electrospinning process (Grein-Iankovski et al., 2016).

6. Applications for gum-grafted hydrogels, NPs and NFs

The greener synthesis of NFs and NPs and several eco-friendly applications in environmental and medical fields have been recognized. Materials such as NPs with various morphologies, functionalized NPs and NFs and membranes are extensively applied in water treatment and environmental remediation as a tool for detection and removal of hazardous gases, organic pesticides, aliphatic and aromatic volatile chemicals, adsorption/removal of heavy metals, toxic microorganisms and radioactive nuclides etc. (Das et al., 2017; Khin et al., 2012; Simeonidis et al., 2016).

6.1: Environmental applications of the gum-metal complexes, hydrogels and electrospun fibers.

Naturally occurring biopolymers have exhibited excellent adsorption abilities for multivalent metal ions. Many natural materials like chitin, chitosan, lignin, sea weed, wool wastes, agricultural wastes, sugarcane bagasse, biomass by-products, *Sargassum* algae etc., have been utilized for the elimination of noxious heavy metals from aqueous wastewater streams (Aydin and Aksoy, 2009; Davis et al., 2003; Varma et al., 2004). Nanofibrous membranes are potential applications of these biopolymers for heavy metal removal. A schematic representation of the adsorption/removal of toxic metals and their interaction with gum structures is shown in Fig. 8.

The simplicity of membrane construction, the assortment of materials appropriate for use, and their ensuing structures favor membranes for environmental applications such as the capture and degradation of pollutants (Fryxell and Cao, 2007; Lee et al., 2009; Mishra and Clark, 2013; Pereao et al., 2016; Ranjbar-Mohammadi et al., 2016a, 2013; Sahraei and Ghaemy, 2017; Thavasi et al., 2008). Two main benefits of electrospun nanofibers are that they have both adsorption and separation properties. From this viewpoint, electrospun fibers and membranes are emerging as truly novel green materials for an array of environmental bioremediation applications. In addition, NF membranes may offer a viable and smart means of removing toxic metals and nanoparticulate matter.

Toxic metal contamination of water bodies is a severe environmental problem often addressed by two important methods, namely adsorption and filtration. In a recent study, gums and their functional materials were successfully used for the elimination of these toxic metal contaminants from manufacturing effluents (Banerjee and Chen, 2007a; Masoumi and Ghaemy, 2014; Mittal and Mishra, 2014; Sahraei and Ghaemy, 2017; Saravanan et al., 2012; Sashidhar et al., 2015; Vinod et al., 2009; Vinod et al., 2010b; Vinod et al., 2010; Vinod et al., 2011a, 2011b).

FTIR examination of the gums determined the presence of numerous functional groups such as ether (C-O-C), acetyl (CH₃CO-), aliphatic (-CH), carboxyl (R-COO⁻), hydroxyl (OH⁻), and carbonyl (C=O) groups, which collectively represent the key interacting groups accountable for metal biosorption. The results illustrated that chemisorption, ion-exchange, functional group exchanges, surface adsorption, physisorption, higher surface area and enhanced surface characteristics were all implicated in the sequestration of toxic metals by gums. Furthermore, adsorption studies were conducted to examine the consequence of process parameters like primary metal ion quantity, pH, and sorbent amount and contact time. The adsorption results closely fitted to *Langmuir*, *Freundlich*, *Tempkin* and *Dubinin-Radushkevich* isotherm models and the kinetic data to pseudo-first order and second order kinetic models.

Among the various techniques, the morphological changes of gum structures as a result of metal biosorption have been evaluated by microscopy (SEM-EDXA mainly), functional groups involvement in metal biosorption by FTIR and XPS analysis, and the nature of the physical forms (amorphous and crystalline) by XRD.

Engineered nanoparticles pose environmental and health risks due to their ever-increasing occurrence in marketable products (Dwivedi et al., 2015; Louie et al., 2016). Currently, most nanotechnology domains are emerging rapidly in an unregulated manner, in an atmosphere that is well suited for entrepreneurship; however, a lack of disposal guidelines will inevitably lead to potential contamination of water resources and ecosystems (Philippe and Schaumann, 2014). Studies are still ongoing in the following three areas: (i) monitoring of the fate, transport and transformation of nanoparticles/nanocomposites (Dwivedi et al., 2015) (ii) their bioavailability and (iii) exposure of humans and other living species to these potentially toxic materials (Colvin, 2003; Sharma et al., 2015).

Table 5 provides a summary of the literature pertaining to natural gum fibers, metal/metal oxide NPS functionalized gums, gum-grafted polymeric hydrogel and their electrospun fibers for the adsorption/removal of environmental contaminants (organic dyes, heavy metals, radioactive materials, and NPs) from aqueous and industrial effluents. (Table 5)

Significant progress has been made in the use of both gum conjugated polymeric hydrogels and functionalized electrospun fibers for environmental applications. Both GA-templated graphene (G) and Ag NPs-hybrid (GA-G-Ag) graphene have been prepared by the sonication of GA-G (0.1 mg/mL), addition of Ag NO₃ (2 mg/mL) and subsequent heating of the mixture for 3h-6h at 80 °C to affect the formation of a GA-G- Ag hybrid (Fan et al., 2012). In this greener synthesis of a GA-G-Ag composite, GA serves as a reducing and stabilizing agent to provide straight phase exfoliation in an aqueous medium. In addition, the composite materials would be able to detect 4-aminothiophenol (concentration level; 10⁻⁶ M) in water using SERS (Surface Enhanced Raman Spectroscopy).

GT-based Ag NPs, graphene oxide composites, polyamidoxime nanohydrogel and poly (methyl methacrylate)/Fe₃O₄ NPs have all been exploited for the adsorption and elimination of metal ions (Pb²⁺, Cd²⁺, Ag⁺, Co²⁺, Zn²⁺, Cr³⁺ & Cr⁶⁺) as well as dyes (methylene blue and Congo red) from aqueous solutions (Masoumi and Ghaemy, 2014; Sadeghi et al., 2014; Sahraei and Ghaemy, 2017).

GT grafted poly (methyl methacrylate) and bentonite (GT-g-PMMA/B) have been formulated for the removal of anionic azo dyes [Congo red (CR), methyl orange (MO), and acid blue 113 (AR-113)] from water, with the maximum adsorption capacity for CR, MO and AR-113 being 900, 750 and 8.5 mg/g, respectively (Sadeghi et al., 2015). The adsorption of these anionic azo dyes onto GT-g-PMMA/B composite materials was represented as kinetic models (pseudo second-order and intra-particle diffusion) and Langmuir adsorption isotherms.

In further research by the same authors (Sahraei and Ghaemy, 2017), graphene oxide (GO) was integrated onto nanocomposite hydrogels consisting of GT-grafted 2-methylpropanesulphonic acid (AMPS). The GT-AMPS was prepared via radical polymerization using ceric ammonium nitrate and *N,N*-methylene bisacrylamide (MBA) as an initiator and cross-linker, respectively. The hydrogel nanocomposite was found to be an exceedingly effective adsorbent for the exclusion of metal ions (Pb²⁺, Cd²⁺ and Ag⁺) from water.

A microwave-buoyed grafting of GT with diallyldimethylammonium chloride (DADMAC) has been reported, with the latter being fashioned and applied as a flocculent for the destabilization of aqueous, multi-walled carbon nanotubes from industrial effluents (Pal et al., 2017). Natural gum-functionalized materials as carriers for the operative medium in the eradication of nanoparticle toxicity from the environment were highlighted.

The use of poly (methyl methacrylate) embedded CT and amended magnetite NPs in the selective sequestration of Cr (VI) from industrial effluents has been demonstrated (Sadeghi et al., 2014). Composites could be highly selective for particular ions and even species and applicable over a wider pH range.

A bio-composite hybrid hydrogel comprising modified GT, graphene oxide, PVA and magnetite NPs has been synthesized and utilized for the removal of heavy metals (Pb^{2+} , Cu^{2+}) and both cationic (crystal violet, CV) and anionic (Congo red, CR) dyes (Sahraei et al., 2017). The adsorption kinetics and isotherms were effectively followed using pseudo-second order and Langmuir models with maximum adsorption capacities of Pb^{2+} (81.7 mg/g), Cu^{2+} (69.6 mg/g), CV (94 mg/g) and CR (101.7 mg/g), respectively.

A bio-nanocomposite encompassing GK, polyacrylamide (PAAm) and nickel sulfide ($\text{NiS}/\text{Ni}_3\text{S}_4$) NPs has been synthesized and employed for the adsorption of Rhodamine 6 G dye (Rh 6G) from water (Kumar et al., 2016). The GK-PAAm hydrogel, prepared via graft copolymerization and $\text{NiS}/\text{Ni}_3\text{S}_4$, was merged into the composite gel and its adsorption capability for Rh 6G (1,224.7 mg/g), which followed Langmuir isotherm behavior and pseudo-second order kinetics, was confirmed with the added advantage of its reusability for three sequential phases of the task.

The following materials viz. GK fibers; GK-functionalized NPs [GK/poly (acrylamide co-acrylic acid)/ Fe_3O_4 ; GK/poly (acrylic acid)/SiC; GK/ poly (acrylic acid-acrylamide)/ SiO_2 ; GK/ Fe_3O_4] and GK/PVA electrospun membranes have shown promise as competent adsorbents for the abstraction of heavy metal (Hg^{2+} , Pb^{2+} , Cr^{3+} , $\text{Cr}_2\text{O}_7^{2-}$ and Ni^{2+}) and NPs (Ag, Au, Pt, Fe_3O_4 and CuO) as well as for the eradication of organic dyes (malachite green and Rhodamine B) and radioactive ^{32}P effluent (Hemant Mittal et al., 2015a; Mittal et al., 2016; Mittal and Mishra, 2014; Padil et al., 2015c; Padil and erník, 2015). A graft polymerization method has been demonstrated for the synthesis of nanocomposites comprising GK, poly (acrylic acid) and silicon carbide NPs, with the ensuing hydrogel composite finding application for the exclusion of dyes (Malachite Green and Rhodamine B) from wastewater (Mittal et al., 2016).

In another study (Hemant Mittal et al., 2015a), the adsorptive sequestration of MB from industrial wastewater was shown by GK-grafted poly (acrylic acid-acrylamide) with silica nanocomposite hybrid materials. A high adsorption capacity of the composite (1,408.6 mg/g) for abstraction of dyes from the aqueous environment was feasible.

An ecological hydrogel viz. GG-grafted poly (acrylamide-co-acrylonitrile), GG-g-Poly AAm-co-AN, attained via free radical polymerization has also been utilized for the exclusion or adsorption of metal ions (Pb^{2+} and Cu^{2+}) from water (Hemant Mittal et al., 2015b). The adsorption was pH dependent and agreed well with the isotherm Langmuir

model. The maximum adsorption capabilities of the complex hydrogels for the metal ions, Pb^{2+} (384.6 mg/g) and Cu^{2+} (203.7 mg/g) were established.

The microwave-promoted production of a conducting hydrogel based on GG; N,N' -methylene-bis-acrylamide has been reported. Aniline in the form of ammonium peroxydisulfate as an initiator or cross-linking agent generated a polyacrylamide/GG/polyaniline interpenetrating network that facilitated the removal of malachite green (MG) from wastewater (Sharma et al., 2013).

Moreover, GG-stabilized Pd NPs have been studied for probing the reduction of dyes such as Coomassie Brilliant Blue G-250, methylene blue and methyl orange. The 4-nitrophenol and GG crosslinked with poly (acrylic acid-co-acrylamide) and armored with iron oxide magnetic NPs has also been employed for the exclusion of rhodamine B (Kora and Rastogi, 2015; Mittal and Mishra, 2014).

Materials based on KG, including nanocomposites and electrospun fibers, have been utilized for the remediation of heavy metals (Cd, Cu, Fe, Pb, Hg, As, Cr, Ni, Zn, Se and U), nuclear power station effluents, radioactive waste generated from ^{32}P labelled nucleotide production and heavy metals from industrial effluents (Sashidhar et al., 2015; Vinod et al., 2009, 2010a, 2010b).

NFs have been treated with plasma methane to improve their physical and chemical properties, enhancing their adsorption capacities towards NPs (Au, Ag, Pt, CuO and Fe_3O_4); (Padil et al., 2016, 2015c; Padil and erník, 2015). Membrane adsorption capacity descended in the following order $Pt > Au > Ag > CuO > Fe_3O_4$. Among other things, adsorption mechanisms pertaining to nanoparticle adsorption onto nanofibers include sorption, functional group interfaces and coordination complex reactions between NPs and various functional groups inherent in the NFs (Fig. 9). Additional adsorption mechanisms may relate to improved surface characteristics, which are mainly dictated by the hydrophilicity or hydrophobicity of the fibers, interfacial free energy and the relative superficial capacity of the plasma-modified membranes (Padil et al., 2015c; Padil and erník, 2015).

6.2: Gum-metal/metal oxide (organic - inorganic complexes) NPs and NFs for anti-bacterial applications.

NPs produced with the help of natural products and applied as mediators for the synthesis and stabilization have tremendous potential for applications in many fields. Applications in antibacterial fields have a number of potential advantages over chemogenic NPs produced by utilizing various chemical reductants (e.g. sodium borohydride, citrate or hydrazine) and/or other organic materials as capping and stabilizing agents (e.g. dodecyl sulphate, cetyltrimethylammonium chloride and polyvinylpyrrolidone).

Varieties of NPs (Ag, Au, Cu, ZnO and CuO) or organic agents like dodecenylsuccinic anhydride (DDSA) incorporated with tree gums have been used as an antibacterial mediator for biotechnology and antibacterial performance (Bajpai et al., 2016; Bajpai and Kumari, 2015; Deshmukh et al., 2012; Kattumuri et al., 2007; Kora et al., 2012, 2010; Kora and

Rastogi, 2015; Kora and Sashidhar, 2015; Mittal et al., 2013; Montazer et al., 2016; Padil et al., 2015a, 2015b; Pooja et al., 2015; Ranjbar-Mohammadi and Bahrami, 2015; Sahraei and Ghaemy, 2017; Thekkae Padil and ernfk, 2013).

Table 6 illustrates the antibacterial activity of metal/metal oxide NPs synthesized using many gums and the interaction of NPs of various sizes stabilized by gums and their electrospun fibers with model test strains (Gram-positive and Gram-negative bacteria). Antibacterial susceptibilities were determined mainly by the well diffusion method (zone of inhibition, ZOI) and the micro broth dilution methods (MIC and MBC) of the bacterial strains toward the actions of the NPs have also been presented, with the NPs synthesized using gum fibers and the membranes both displaying significant antibacterial action on both Gram classes of bacteria. Their promising antibacterial efficiency and surface adaptation mean that these NPs can be modified to be bio-compatible or cytotoxic in various biomedical and pharmaceutical applications. Ag NPs are the most commonly used NPs as antibacterial agents in various fields, e.g. antibacterial clothing (Table 6) (Monti et al., 2004; Navaladian et al., 2008; Thomas et al., 2007; Zhang et al., 2013).

A major problem confronting human health today is that most bacteria are becoming resistant to antibacterial drugs (Hajipour et al., 2012; Zheng et al., 2018). Biogenic Ag NPs exercise a synergistic effect in conjunction with varieties of antibiotics (erythromycin, chloramphenicol, ampicillin and kanamycin) towards Gram-negative and Gram positive bacteria (Devi and Joshi, 2012). Rastogi et al. (Rastogi et al., 2015) showed that suitable NPs synthesized using gums can fight against specific bacteria. Gum-assisted biogenic Ag NPs were highly stable and displayed superior antibacterial action on both Gram classes of bacteria. The ZOI values observed at a concentration of 5 µg of Ag NP were found to be higher in comparison with the corresponding values for Ag NPs synthesized by chemical agents (Pinto et al., 2010; Sadeghi et al., 2014; Thakkar et al., 2010). Furthermore, Ag NPs synthesized using KG and GT were reported to be more potent anti-bacterial agents in terms of MIC and MBC (Kora and Rastogi, 2015).

A ZnO NP integrated GA-sodium alginate hydrogel composite has been observed to kill bacterial colonies comprising *Pseudomonas aeruginosa* and *Bacillus cereus* (Raguvaran et al., 2017). The cytotoxicity effect of this hydrogel composite was much lower than ZnO NPs without any bio-polymeric (GA and sodium alginate) shield and showed higher biocompatibility than the unprotected NPs (Raguvaran et al., 2017).

GK-stabilized CuO NPs of varying sizes, 4.8 ± 1.6 nm, 5.5 ± 2.5 nm, and 7.8 ± 2.3 nm, have been prepared. The antibacterial efficiency of the smallest synthesized NPs was verified against *E. coli* and *S. aureus*. ZOI of 14.5 ± 0.8 mm and 16.2 ± 0.8 mm were perceived for the *S. aureus* and *E. coli* and cultures, respectively. Further experimental results confirmed that MBC (minimum bactericidal concentrations) depended on size and had values of 125 ± 5.5 µg/mL and 135 ± 8.8 µg/mL for *E. coli* and *S. aureus*, respectively for the smallest NPs (Thekkae Padil and ernfk, 2013).

Ag NPs have been synthesized using KG, and were subsequently appraised for their elevated antibacterial and antibiofilm potencies, in combination with various antibiotics (e.g.

ciprofloxacin, streptomycin and gentamicin) against Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli* and *Pseudomonas aeruginosa*) bacteria (Rastogi et al., 2015). The combination resulted in enhanced antibacterial action with biocompatibility of up to 2.5 µg/mL as evaluated by MTT assay on a HeLa cell line. The findings suggest that KG/Ag NPs could possibly be used as 'in vivo' antibacterial agents in combination with antibiotics to combat the acute problem of antibiotic resistance (Rastogi et al., 2014).

KG-stabilized Ag NPs have been employed for antibacterial action via a variety of vulnerability assays (micro-broth dilution, growth kinetics, antibiofilm activity, cytoplasmic content leakage and membrane permeabilization) etc. The generation of reactive oxygen species (ROS) and cell surface damage during the interaction of bacteria with Ag NPs was demonstrated using various assays (dichlorodihydro fluorescein diacetate and *N*-acetylcysteine) (Kora and Rastogi, 2015).

Lyophilized forms of deacetylated GK, KG and GT were used for the preparation of DDSA/GK composite and DDSA/KG/PVA and DDSA/GT/PVA membranes (Padil et al., 2015a, 2015b; Ranjbar-Mohammadi et al., 2013). The improved antimicrobial actions of these membranes were related to two factors, i.e. the ratio of hydrophilicity/hydrophobicity and the intensified surface unevenness after chemical modification with DDSA, which facilitated an increase in the interaction between the planes of the material and the bacteria. In terms of their non-toxicity, the derivatized natural gums can be promoted as antibacterial agents, which could realistically replace CuO-based polymeric materials (along with their toxic Ag and Cu constituents) in the crucial battle against microbes (Padil et al., 2015a, 2015b; Ranjbar-Mohammadi et al., 2013).

6.3 . Biosensors for environmental and medical application

An exceedingly profound and fastidious process has been reported for the direct colorimetric detection of Hg²⁺ in aqueous systems by KG-Ag NPs (Rastogi et al., 2014). The size of the KG-Ag NPs was 5.07±2.8 nm, and the NPs were stable over a large pH range of 4 –11 and salt concentrations of 5 to 100 mM. More importantly, detection of Hg²⁺ in water was highly selective as the absorption spectra were not influenced by the presence of other common metals (Na, K, Mg, Ca, Cu, Ni, Co, As, Fe and Cd).

Stable palladium nanoparticles (Pd NPs) synthesized using KG have been reported (Rastogi et al., 2017) and their inherent peroxidase-type response was utilized for the colorimetric detection of glucose in biological samples. The peroxidase catalytic activity was observed to be dependent on the pH, temperature and quantity of the NPs.

6.4. Biomedical applications of the gum matrix- metal/metal oxide NPs coordination complexes and NFs.

The biomedical importance of gum functionalized metal/metal oxide NPs has been reported in many areas such as drug transport, diagnosis, imaging and bio-sensing. Their great water solubility, biocompatibility, biodegradability and the simplicity of furnishing chemical medications in water media make gum hydrogels and their electrospun membranes eminently attractive polymers in the synthesis of scaffolds for applications in tissue

engineering. The functionalization of various natural polymeric materials including gums, mucilage and their amended hydrogel formulas for the development of drug delivery systems has also been highlighted (Das and Pal, 2015; De France et al., 2017; Forget et al., 2016; Liu et al., 2017; Mano et al., 2007; Prajapati et al., 2013; Rana et al., 2011; Shukla et al., 2016; Silva et al., 2017; Sridhar et al., 2015; Woehl et al., 2014).

Natural/synthetic polymer-supported hydrogels have been utilized in emerging applications, such as stem cell and cancer therapy research, tissue engineering, drug delivery, wound restoration, and 3D printable hydrogels etc. (Hoffman, 2002; Jungst et al., 2016; Li and Mooney, 2016; Ratheesh et al., 2017; Seliktar, 2012; Vashist et al., 2014).

6.4.1. Biomedical application of GA—A natural hydrogel based on sundew mucilage has been synthesized by a combination of GA and sodium alginate using Ca salt as a cross-linking agent and subsequently examined for drug transport and wound healing applications (Li et al., 2017).

Poly (dialdehyde) amended GA with a collagen and melatonin-based fusion scaffold (PGA/C/M) has been developed with good biocompatibility (Murali et al., 2016a). GA was converted into poly (dialdehyde) by oxidation with sodium iodate and coupled with amine functionality from a collagen forming PGA/C/M hybrid complex, and this material was applied to in vitro and in vivo tissue rejuvenation and wound remedial applications (Murali et al., 2016b; Takei et al., 2010). The high content of the poly (dialdehyde) GA was shown to have exceptional properties (high thermal stability, porosity, and swelling capacity and biodegradable and biocompatible characteristics) suitable for biomedical fields.

An oxidized form of GA has been prepared, which after conjugation with primaquine was studied for its controlled delivery in malaria or leishmaniasis (Nishi and Jayakrishnan, 2007). The complex formation, via Schiff's base creation, was confirmed between the aldehyde (GA aldehyde) and amine groups (primaquine). The drug loading efficiency, stability of the conjugate and swelling performance etc. were evaluated, and the prepared complex gel exhibited a better performance than dextran-based drug delivery materials (Sokolsky-Papkov et al., 2006).

A magnetite-based nanocomposite material using GA and functionalized it for magnetic hyperthermia therapy has been produced (Horst et al., 2017). The GA-Fe₃O₄ NPs had an appropriate size, polydispersity and stability in an aqueous solution, which may be highly desirable for magnetic therapy.

The potential application of curcumin, also known as turmeric, an ancient spice-based drug, depends on its transport to the cytoplasm of Hep G2 and MCF-7 cells. (Sarika et al., 2015) GA was conjugated to enhance its solubility and stability. When dispersed in an aqueous media, the conjugate self-assembled into spherical nanomicelles (270 ± 5 nm, as determined by FE-SEM and TEM), due to the hydrophilic and hydrophobic interactions between the GA and the curcumin. This effect significantly enhanced the solubility (900x) and stability of the curcumin under physiological pH conditions. The conjugate exhibited anticancer activity, which was found to be greater in human hepatocellular carcinoma (Hep G2) cells relative to

human breast carcinoma (MCF-7) cells. Due to the targeting efficiency of galactose groups present in GA, Hep G2 cells exhibit enhanced accumulation of GA/Cur NPs, thereby circumventing the obstacles previously associated with curcumin and augurs well for its usage in a promising drug delivery system.

The synthesis of hydrogels using GA and cross-linked polyacrylic acid, carbopol has been reported (Singh et al., 2013). The research highlighted the production of novel hydrogel wound bandages for the slow release of gentamicin (an antibiotic drug) and to develop the wound restorative capabilities. Various factors such as antioxidant activity, blood compatibility, antimicrobial activity, mucoadhesion, oxygen/water vapor permeability, microbial penetration and mechanical properties (burst and tensile strength, resilience, relaxation and folding endurance) of the hydrogel have been assessed. Wound healing experiments carried out on Swiss Balb C strain albino mice showed that in the case of wounds covered with hydrogel dressings, speedy wound healing coupled with the formation of well-developed fibroblasts and blood capillaries ensued, compared to open wounds. The biomedical properties indicated that hydrogel films are non-thrombogenic and non-haemolytic, while being antioxidant and mucoadhesive in character. In addition, these wound healing hydrogel films are also porous to oxygen and moisture while being resistant to microbes. The replicated fluid uptake in wounds and the discharge of antibiotics in the wound fluid indicated that hydrogel dressings could absorb high volumes of fluid. Their water absorption capacity (simulated wound fluid) is to the extent of 8.772 ± 0.184 g/g of film. Release of a gentamicin drug from the wound dressings took place courtesy of a Fickian diffusion mechanism in studies involving a simulated wound fluid. They are, therefore, appropriate for moderately to highly exuding wounds, given that they could discharge the antibiotics in a controlled manner.

Hydrogels have been prepared via free-radical polymerization of acrylamide with GA and studied for the discharge of nitrogen-containing bisphosphonate (BP) (Aderibigbe et al., 2015). They exhibited high swelling ratios at a pH of 7.4 and low at a pH of 1.2, and the release mechanism could be examined using UV-vis via complex formation with Fe(III) ions. Furthermore, these hydrogels can be used for the controlled delivery of bisphosphonate to the gastrointestinal region, wherein the presence of GA improves their swelling ability.

6.4.2. GK-based hydrogels for biomedical applications—Modification of GK deploying *N,N'*-methylenebisacrylamide as the crosslinker and ammonium persulfate as an initiator for the development of hydrogels has been reported (Singh and Sharma, 2008). The discharge kinetics of an anti-ulcer drug (ranitidine hydrochloride), incorporated into such hydrogels has been investigated.

Thiolated GK was prepared by reacting the GK with thioglycolic acid (~80 %) (Bahulkar et al., 2015) and it was found to exhibit longer disintegration times as well as greater swelling and mucoadhesion, with an increase in the pH of the medium that simulates the intestinal and gastric environment— in stark contrast to unmodified GK. Controlled drug release for more than 24 h by Fickian diffusion was observed with metoprolol succinate as a model drug. Furthermore, synthesized thiolated GK displayed no cytotoxicity, as determined by the Hep G2 cell line.

The preparation of pH-sensitive microparticles (MP) based on GK using the aforementioned spraying technique, employing aqueous solvents has been reported (Raizaday et al., 2015). MPs can be used for treating various conditions such as chronic hypertension, ulcerative colitis and diverticulitis.

An interpenetrating polymer network (IPN) composed of Zn-pectinate and GK for gastroretentive ziprasidone HCl delivery has been reported (Bera et al., 2015). The development of IPN beads was proficient via concurrent ionotropic gelation and covalent crosslinking. Optimized IPN beads were found to demonstrate superb mucoadhesion and buoyant properties, with a slower drug release profile. The studies suggested that the development of pectinate-based GK hydrogel beads shows enormous potential in drug delivery and tissue engineering applications. The production of GK stabilized Au NPs (GK/Au NPs) and their application as nanocarriers in the delivery of the anti-cancer drug, gemcitabine hydrochloride (GEM) has been reported (Pooja et al., 2015). Cytotoxic and hemolysis evaluations revealed their biocompatible nature, wherein GEM/GK/Au NPs showed better anti-cancer activity, colony construction and ROS stimulation against human lung cancer cells than bare GEM.

6.4.3. GT hydrogel and electrospun fibers—The addition of GT to calcium alginate (CA) generated beads that found significant application for the encapsulation of bone cells (Kulanthaivel et al., 2017). High cell proliferation, sustainability and distinction were observed in bone cells encapsulated by GT-CA beads, which may have tissue engineering applications in addition to newer drug formulations.

A magnetic surface molecularly imprinted by polymeric nanogel (MIPN) with core-shell morphology has been reported (Hemmati et al., 2016), where quercetin (QC) served as template, using $\text{Fe}_3\text{O}_4/\text{SiO}_2$ NPs as a magnetic core with *N*-vinyl imidazole as a functional monomer and GT as cross-linker via radical polymerization. The application of the QC template as a drug carrier was affirmed by its great binding interaction, specific binding choosiness and speedy adsorption dynamic rate, compared to a non-imprinted magnetic polymeric gel.

A biocompatible GT-PVP based hydrogel has been prepared via graft polymerization of GT and PVP in the presence of *N,N'*-methylenebisacrylamide as a cross-linker and ammonium persulfate (APS) as an initiator (Singh and Sharma, 2014a) The drug discharge ability of the GT-PVP hydrogel was evaluated by incorporating the antifungal drug, fluconazole, which was shown to be non-thrombogenic with good blood compatibility and mucoadhesive properties.

Electrospun fibers (both random and aligned) of poly (L-lactic acid)/GT (PLLA/GT) both 3 % (w/v) and in various ratios (100:0, 75:25 and 50:50) have been produced by electrospinning (Ranjbar-Mohammadi et al., 2016a). PLLA/GT aligned nanofibres at a ratio of 75:25 displayed the well-adjusted properties and were used for an in vitro culture of nerve cells (PC-12) to assess the potential for using these scaffolds as substrates for nerve regeneration.

GT and PVA deionized water solutions at various weight ratios (from pure GT to pure PVA) were electrospun to produce nanofibers (Ranjbar-Mohammadi et al., 2013). For the ideal GT/PVA ratio (40/60), the hydrogen bonding between PVA and GT was confirmed by FTIR analysis. Human fibroblast cells were found to have adhered and proliferated well onto the GT/PVA nanofiber scaffolds. MTT assays confirmed that GT/PVA NF showed cell viability and biological compatibility. The biocompatibility and antibacterial properties of these NFs indicated that they are effective as a wound dressing because they can protect the affected area from its surroundings, so as to avoid infection and dehydration.

NFs based on GT, poly (ϵ -caprolactone) (GT/PCL) and acetic acid (solvent for electrospinning), were produced at various blend ratios (Ranjbar-Mohammadi and Bahrami, 2015) and were used for the in vitro cell culture of human fibroblast cell lines AGO and NIH 3T3. SEM results and MTT assays indicated that bio-composite mats heightened fibroblast adhesion and proliferation to a greater extent than the PCL scaffolds.

A drug delivery device was fabricated via electrospinning (both blend and coaxial) material comprising GT, poly lactic glycolic acid (PLGA) and tetracycline hydrochloride (TCH) as a model hydrophilic drug (in altered combinations) (Ranjbar-Mohammadi et al., 2016c). Scanning electron microscopic analysis indicated that the produced PLGA, blended GT-PLGA and core shell GT-PLGA fibers possessed smooth and beadless morphologies with diameters (180 – 460 nm).

Drug delivery studies indicated that both fractions of GT within blended NFs and core-shell structures can meaningfully regulate the TCH discharge degree from the nano-membranes. Through the integration of TCH into core-shell NFs, drug conveyance could be continued for 75 days with only 19 % of burst release within the first 120 min. This sustained drug discharge, together with the demonstrated biocompatibility as well as the mechanical and antibacterial properties, make these drug-bearing core-shell nanofibers favorable candidates for use as drug delivery systems in combating periodontal diseases.

Electrospun curcumin (Cur) loaded poly (ϵ -caprolactone) together with GT was tested for wound curing in diabetic rats (Ranjbar-Mohammadi et al., 2016b). These scaffolds possessing antibacterial properties against methicillin resistant *Staphylococcus aureus* (as gram positive) and β - lactamase (as gram negative) were used in acellular and cell-seeded forms. The pathological study revealed that the deployment of these NFs caused decidedly swift wound healing with well-formed granulation tissue governed by collagen deposition, fibroblast proliferation, formation of sweat glands and hair and complete regeneration of the epithelial layer.

Ciprofloxacin-loaded GT based hydrogels have been reported to improve the drug delivery of diverticulitis, where GT was grafted with synthetic polymers comprising acrylic acid, PVP, ammonium persulfate (initiator) and a cross-linking agent (*N,N'*-methylenebisacrylamide) (Singh and Sharma, 2017). The mechanical strength and network structure of the hydrogel were affected by the pH, thereby highlighting the remarkable pH-responsive and mucoadhesive assets that could be exploited for spot-specific drug delivery applications.

GT and poly (acrylic acid) based polymer hydrogels for drug delivery systems of amoxicillin were reported by Singh et al. (Singh and Sharma, 2014b) The hydrogel was prepared via aqueous radical polymerization of GT (6 % (w/v)), acrylic acid (0.874 mol/L), ammonium persulfate (0.0263 mol/L) and *N,N'*-methylenebisacrylamide (0.0389 mol/L) as an initiator and cross-linker, respectively. The correlations between the synthetic reaction parameters and the structural criteria were determined. A variety of models for studying release kinetics were applied to monitor the release profile of drugs from polymeric networks.

6.4.4. KG for biomedical applications—A polyelectrolyte complex (PEC) was generated via the electrostatic interaction of carboxyl groups from KG with amines on chitosan, and the ensuing complex was loaded with diclofenac sodium and its release performance on various parameters, i.e. particle size, zeta potential, complex formation, rheological properties and drug loading efficiency, was analyzed (Naidu et al., 2009). The pH dependent drug release was demonstrated when a lower release of diclofenac sodium was observed in hydrochloric acid (0.1N; pH 1.2) compared to the release in a phosphate buffer (pH 6.8). Consequently, the KG/chitosan complex has a great prospect as a medium for the controlled delivery of drugs with the added advantage of reducing the dosing frequency, thereby lowering gastric toxicity.

MW-assisted grafting of KG onto poly (acrylamide) has been conducted and subsequently employed in the in vitro release of diclofenac sodium from the matrix tablets of KG-poly (acrylamide) (Malik and Ahuja, 2011). The study highlighted a more rapid release of the drug from a grafted copolymer conjugate compared to ungrafted KG.

The carboxymethylation of KG (Kumar and Ahuja, 2012) reduced its viscosity and improved both its mucoadhesive properties and ionic gelling behavior. Prepared sustained-release bead formulations based on carboxymethylated KG showed a release of metformin (a drug used to treat people with type 2 diabetes) by zero-order kinetics.

The fabrication of sponges by blending KG with gelatin (G) and impregnating with ciprofloxacin (CP) for antibacterial and wound dressing applications has been reported (Rathore et al., 2016). The ensuing porous sponges were characterized in terms of swelling percentage and porosity together with SEM data. In vitro biocompatibility, cell adhesion and proliferation tests were carried out using NIH 3T3 fibroblast and human keratinocyte cell lines indicated that the sponges are highly biocompatible.

Gold nanoparticles synthesized and stabilized by KG (KG/Au NPs) were assessed for their anti-proliferative properties in B16F10 melanoma cells as an in vitro experimental model (Kalaighana Selvi et al., 2017). The size of the nanoparticles was assessed by TEM and varied between 4.08 and 12.73 nm. The results demonstrated that the treatment with KG/Au NPs diminished cell proliferation. The qRT-PCR analysis revealed the genes (p53, caspase-3, caspase-9, PPAR α and PPAR β) responsible for apoptosis to be upregulated in B16F10 cells after treating them with GK/Au NPs. These studies highlighted the fact that GK/Au NPs show antiproliferative activity through the generation of apoptosis in a B16F10 melanoma cell line, signifying that GK/Au NPs have a potential for biomedical application.

6.4.5. GG interpenetrating (IPN) network—Natural polysaccharides have been used as colon-specific drug carriers due to their exceptional characteristics. Microbial fermentation in the large intestine could assist in the delivery of drugs by physical and diffusion blockade (Khan et al., 1999; Tuovinen et al., 2002). An interpenetrating network (IPN) system of GG cross-linked with poly (acrylic acid), and polyaniline has been fabricated via radical polymerization using *N,N'*-methylene-bis-acrylamide (MBA) (cross-linker) and ammonium persulfate (initiator) (K. Sharma et al., 2015a). Amoxicillin trihydrate and paracetamol were incorporated and their controlled drug release potential was evaluated in the colon, and various functional groups, i.e. –OH, –CH and –NH, in the hydrogel were found to be suitable for grafting of the drugs by chemical or physical interaction.

An IPN hydrogel prepared by grafting GG with poly (methyl acrylic acid–aniline) was examined and aimed at the sustained release of amoxicillin trihydrate in altered pH environments (acidic, natural and basic) and their thermal, structural and releasing kinetics were established (K. Sharma et al., 2015b). Effective colon-specific controlled release of drug delivery in the lower gastrointestinal tract could now be possible.

7. Conclusions and future prospects

Greener pathways to the synthesis and stabilization of metal/metal oxide NPs have been successfully implemented by many researchers worldwide. This methodology mainly deployed natural materials and green solvents, while keeping the process simple and economical. The major drawbacks of this method include the use of imprecise evaluation tools for the stability, aggregation behavior, size and shape of the NPs and the subsequent systematic description of the application of the NPs as a result of their physical and chemical characteristics.

Lately, tree gums (GA, GK, GT, KG and GG) have been intensively studied for the stabilization and greener synthesis of metal/metal oxide NPs. In addition, the green electrospinning process utilizing tree gums for the production of nanofibers and membranes is in the developmental stage and much more research in this field is expected in the near future. Tree gum matrixes and NPs functionalized by gums have been produced for the biosorption of environmental pollutants such as radioactive effluents, heavy metals, volatile organic compounds and dyes. The potential applications of tree gums and their functionalized nanocomposites developed as antibacterial agents are also showing remarkable promise.

NP-functionalized gums have been demonstrated to be a highly sensitive means of biosensing environmental pollutants in water and in related applications, e.g. as a biomarker for estimating the amount of glucose levels in blood plasma. This property could lead to the development of biosensing kits for environmental pollutants in drinking water as well as for the detection of biological fluids in human systems utilizing eco-friendly and biocompatible tree gum electrospun fibers.

Many bio-derived and renewable materials, such as cellulose, starch, chitosan and collagen, have been extensively employed in biomedical applications, e.g. in tissue engineering scaffolds, drug/gene delivery, and wound healing, due to their bio-compatibility, non-toxicity, biodegradability and accessibility of chemical functionalities in their structures for chemical modifications. Tree gums should now be incorporated into this group to serve as potential candidates for biomedical research and development.

Moreover, gum-based electrospun fibers show a promising future in replacing petroleum-based plastics, a phenomenon of concern today in our oceans. The development of bioplastic from gum-based electrospun fibers would be challenging and research towards their application in the fields of food packaging, carrier bags and antibacterial pads is essential for sustainable growth. In this context, tree gums present a promising renewable and highly economical bioresource for future generations, especially for under-developed countries, to utilize the local resources for higher value applications.

Electrospun fibers and membranes based on tree gums and their nanoparticle functionalized materials should garner much future attention in filtration/separation, adsorption, catalysis, imaging, greener corrosion inhibitors, nanofiltration (nanoparticles, pesticides, pharmaceutical waste etc.), air filtration, delivery of therapeutic drugs, wound healing, tissue engineering and controlled drug delivery etc. Furthermore, enhancement of physical and chemical properties via surface modification employing various greener technologies, such as plasma, γ -ray irradiation and laser treatments, will help generate economical, sustainable and bio-organic products and processes for the future.

The future use of tree gums also relies on the development of ultralight weight, high-strength, bio-based, biodegradable, porous, and tunable, two-dimensional (2D) membranes and three-dimensional (3D) sponges with facile and easy to implement synthetic schemes. The ensuing porous functionalized structures will form an integral part of applications for sustainable development under the umbrella of green chemistry and technology, specifically in fields of biomedicine (tissue engineering and drug delivery), heterogeneous catalysis (greener catalytic remediation), extraction of environmental contaminants of various types (heavy metals, nanoparticles, toxic organic solvents, pesticides, dyes) and/or use as a safer bioplastic (as food packaging and disposable materials). Quantification of the environmental benefits of these newer materials using the Life Cycle Analysis (LCA) method is also warranted.

In view of the current studies and trends, there is no doubt that the non-food applications of tree gums and their functionalized materials will play a significant role in many important areas, such as water treatment, renewable energy, biomedical research, the food industry and biotechnology (Peng et al., 2016).

Acknowledgements

This study was supported by the project LO1201, the financial support of the Ministry of Education, Youth and Sports in the framework of the targeted support of the “National Programme for Sustainability I” and the OPR&DI project “Centre for Nanomaterials, Advanced Technologies and Innovation—CZ.1.05/ 2.1.00/01.0005”. The authors would also like to acknowledge the assistance provided by the Research Infrastructure NanoEnvCz, supported by the Ministry of Education, Youth and Sports of the Czech Republic in the framework of Project No. LM2015073.

List of abbreviations

AFM	Atomic force microscopy
ATR	Attenuated total reflection
AgNO₃	Silver nitrate
BP	Bisphosphonate
COSY	correlation spectroscopy
CR	Congo red
<i>C. albicans</i>	<i>Candida albicans</i>
Cur	Curcumin
CP	Ciprofloxacin
DLS	Dynamic light scattering
DDSA	Dodecenylsuccinic anhydride
<i>E. coli</i>	<i>Escherichia coli</i>
EDXA	Electron diffraction X-ray analysis
GA	Gum arabic
GK	Gum karaya
GT	Gum Tragacanth
GG	Gum ghatti
GEM	Gemcitabine hydrochloride
HMBC	Heteronuclear multiple-bond correlation spectroscopy
HMQC	Heteronuclear single-quantum correlation spectroscopy
FE	Field emission
FCC	Face centered cubic crystal
FTIR	Fourier transform infrared
KG	Kondagogu gum
MB	Methylene blue
MW	Microwave
MWt	Molecular weight
MBC	Minimum bactericidal concentration

MIC	Minimum inhibitory concentration
MTT	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide
MP	Microparticles
MIPN	Imprinted polymeric nanogel
MG	Malachite green
GEM	Gemcitabine hydrochloride
HR-TEM	High resolution transmission electron microscopy
ICP-MS	Inductively coupled plasma mass spectrometry
IPN	Interpenetrating polymer network
NPs	Nanoparticles
NFs	Nanofibers
PVA	Poly(vinyl alcohol)
PVP	Polyvinyl pyrrolidone
PEO	Poly(ethylene oxide)
PCL	Poly caprolactone
PEDOT	Poly(3,4-ethylenedioxythiophene)
PLLA	Poly(L-lactic acid)
PLGA	Poly lactic glycolic acid
PEC	Polyelectrolytic complex
<i>Paeruginosa</i>	<i>Pseudomonas aeruginos</i>
QC	Quercetin
ROS	Reactive oxygen species
RF	Radio frequency
RhB	Rhodamine B
SEM	Scanning electron microscopy
<i>S. aureus</i>	<i>Staphylococcus aureus</i>
TEM	Transmission electron microscopy
TGA	Thermogravimetric analysis

TCH	Tetracyclic hydrochloride
TOCSY	Total correlation spectroscopy
UV	Ultra violet
Vis	Visible
XRD	X-ray diffraction
XPS	X-ray photon electron spectroscopy
ZOI	Zone of inhibition
ZVI	Zerovalent iron

References

- Abbott AP, Capper G, Davies DL, Rasheed RK, Tambyrajah V, 2003. Novel solvent properties of choline chloride/urea mixtures. *Chem. Commun.* 0, 70–71.
- Aberkane L, Jasniewski J, Gaiani C, Hussain R, Scher J, Sanchez C, 2012. Structuration mechanism of β -lactoglobulin - acacia gum assemblies in presence of quercetin. *Food Hydrocoll.* 29, 9–20.
- Adamson AW, Gast AP, 1997. *Physical chemistry of surfaces*, Sixth Edit ed. Wiley, New York, NY.
- Aderibigbe BA, Varaprasad K, Sadiku ER, Ray SS, Mbianda XY, Fotsing MC, Owonubi SJ, Agwuncha SC, 2015. Kinetic release studies of nitrogen-containing bisphosphonate from gum acacia crosslinked hydrogels. *Int. J. Biol. Macromol.* 73, 115–123.
- Agarwal S, Wendorff JH, Greiner A, 2008. Use of electrospinning technique for biomedical applications. *Polymer (Guildf)*. 49, 5603–5621.
- Ahmmad B, Leonard K, Shariful Islam M, Kurawaki J, Muruganandham M, Ohkubo T, Kuroda Y, 2013. Green synthesis of mesoporous hematite (α -Fe₂O₃) nanoparticles and their photocatalytic activity. *Adv. Powder Technol.* 24, 160–167.
- Akhtar MS, Panwar J, Yun Y-S, 2013. Biogenic Synthesis of Metallic Nanoparticles by Plant Extracts. *ACS Sustain. Chem. Eng.* 1, 591–602.
- Alam MS, Garg A, Pottot FH, Saifullah MK, Tareq AI, Manzoor O, Mohsin M, Javed MN, 2017. Gum ghatti mediated, one pot green synthesis of optimized gold nanoparticles: Investigation of process-variables impact using Box-Behnken based statistical design. *Int. J. Biol. Macromol.* 104, 758–767.
- Alborzi S, Lim LT, Kakuda Y, 2014 Release of folic acid from sodium alginate-pectin-poly(ethylene oxide) electrospun fibers under invitro conditions. *LWT - Food Sci. Technol.* 59, 383–388.
- Alborzi S, Lim LT, Kakuda Y, 2013 Encapsulation of folic acid and its stability in sodium alginate-pectin-poly(ethylene oxide) electrospun fibres. *J. Microencapsul.* 30, 64–71. [PubMed: 22703229]
- Amiri A, Shanbedi M, Eshghi H, Heris SZ, Baniadam M, 2012 Highly dispersed multiwalled carbon nanotubes decorated with Ag nanoparticles in water and experimental investigation of the thermophysical properties. *J. Phys. Chem. C* 116, 3369–3375.
- Anastas PT, Warner JC, 1998. *Green chemistry: theory and practice*. Oxford University Press, New York.
- Anderson DM, Wang WP, 1990 Composition of the gum from *Combretum paniculatum* and four other gums which are not permitted food additives. *Phytochemistry* 29, 1193–1195. [PubMed: 1366426]
- Anderson DMW, Bridgeman MME, 1985 The composition of the proteinaceous polysaccharides exuded by *astragalus microcephalus*, *A. Gummifer* and *A. Kurdicus*—The sources of turkish gum tragacanth. *Phytochemistry* 24, 2301–2304.
- Anderson DMW, Grant DAD, 1988 The chemical characterization of some *Astragalus* gum exudates. *Food Hydrocoll.* 2, 417–423.

- Anderson DMW, Howlett JF, McNab CGA, 1985a. The amino acid composition of the proteinaceous component of gum arabic (*Acacia Senegal*(L.) Willd.). Food Addit. Contam. 2, 159–164.
- Anderson DMW, Howlett JF, McNab CGA, 1985b. The amino acid composition of the proteinaceous component of gum karaya (*Sterculia* sp.). Food Addit. Contam. 2, 153–157.
- Anderson DMW, McDougall FJ, 1987 The amino acid composition and quantitative sugar-amino acid relationships in sequential Smith-degradation products from gum arabic (*Acacia Senegal*(L.) Willd.). Food Addit. Contam. 4, 125–132.
- Anderson DMW, McNab CGA, Anderson CG, Brown PM, Pringuer MA, 1983 Studies Of Uronic Acid Materials, Part 58: Gum Exudates From The Genus *Sterculia* (Gum Karaya). Int. Tree Crop. J. 2, 147–154.
- Anderson DMW, Stoddart JF, 1966 Studies on uronic acid materials. Carbohydr. Res. 2, 104–114.
- Anderson DMW, Weiping W, 1992 Gum Arabic (*Acacia Senegal*) From Uganda: Characteristic N.M.R. Spectra, Amino Acid Compositions, And Gum/Soil Cationic Relationships. Int. Tree Crop. J. 7, 167–179.
- Armendariz V, Herrera I, Peralta-videa JR, Jose-yacamán M, Troiani H, Santiago P, Gardea-Torresdey JL, 2004 Size controlled gold nanoparticle formation by *Avena sativa* biomass: use of plants in nanobiotechnology. J. Nanoparticle Res. 6, 377–382.
- Asghari-Varzaneh E, Shahedi M, Shekarchizadeh H, 2017 Iron microencapsulation in gum tragacanth using solvent evaporation method. Int. J. Biol. Macromol. 103, 640–647. [PubMed: 28528002]
- Atila D, Keskin D, Tezcaner A, 2015 Cellulose acetate based 3-dimensional electrospun scaffolds for skin tissue engineering applications. Carbohydr. Polym. 133, 251–261.
- Attallah OA, Al-Ghobashy MA, Nebesen M, Salem MY, 2016 Removal of cationic and anionic dyes from aqueous solution with magnetite/pectin and magnetite/silica/pectin hybrid nanocomposites: kinetic, isotherm and mechanism analysis. RSC Adv. 6, 11461–11480.
- Augustin MA, Hemar Y, 2009 Nano- and micro-structured assemblies for encapsulation of food ingredients. Chem. Soc. Rev. 38, 902–912. [PubMed: 19421570]
- Aydin YA, Aksoy ND, 2009 Adsorption of chromium on chitosan: Optimization, kinetics and thermodynamics. Chem. Eng. J. 151, 188–194.
- Bacelar AH, Silva-Correia J, Oliveira JM, Reis RL, 2016 Recent progress in gellan gum hydrogels provided by functionalization strategies. J. Mater. Chem. B 4, 6164–6174.
- Bahulkar SS, Munot NM, Surwase SS, 2015 Synthesis, characterization of thiolated karaya gum and evaluation of effect of pH on its mucoadhesive and sustained release properties. Carbohydr. Polym. 130, 183–190.
- Bajpai SK, Jadaun M, Tiwari S, 2016 Synthesis, characterization and antimicrobial applications of zinc oxide nanoparticles loaded gum acacia/poly(SA) hydrogels. Carbohydr. Polym. 153, 60–65.
- Bajpai SK, Kumari M, 2015 A green approach to prepare silver nanoparticles loaded gum acacia/poly(acrylate) hydrogels. Int. J. Biol. Macromol. 80, 177–188. [PubMed: 26123815]
- Balaghi S, Mohammadifar MA, Zargaraan A, Gavligi HA, Mohammadi M, 2011 Compositional analysis and rheological characterization of gum tragacanth exudates from six species of Iranian *Astragalus*. Food Hydrocoll. 25, 1775–1784.
- Bandyopadhyaya R, Nativ-Roth E, Regev O, Yerushalmi-Rozen R, 2002 Stabilization of Individual Carbon Nanotubes in Aqueous Solutions. Nano Lett. 2, 25–28.
- Banerjee SS, Chen D-H, 2007a. Fast removal of copper ions by gum arabic modified magnetic nano-adsorbent. J. Hazard. Mater. 147, 792–799.
- Banerjee SS, Chen DH, 2007b. Glucose-grafted gum arabic modified magnetic nanoparticles: Preparation and specific interaction with Concanavalin A. Chem. Mater. 19, 3667–3672.
- Bankura KP, Maity D, Mollick MMR, Mondal D, Bhowmick B, Bain MK, Chakraborty A, Sarkar J, Acharya K, Chattopadhyay D, 2012 Synthesis, characterization and antimicrobial activity of dextran stabilized silver nanoparticles in aqueous medium. Carbohydr. Polym. 89, 1159–1165.
- Baptista AC, Martins JI, Fortunato E, Martins R, Borges JP, Ferreira I, 2011 Thin and flexible bio-batteries made of electrospun cellulose-based membranes. Biosens. Bioelectron. 26, 2742–2745. [PubMed: 21055915]

- Barber PS, Griggs CS, Bonner JR, Rogers RD, 2013 Electrospinning of chitin nanofibers directly from an ionic liquid extract of shrimp shells. *Green Chem.* 15, 601.
- Baruwati B, Polshettiwar V, Varma RS, 2009 Glutathione promoted expeditious green synthesis of silver nanoparticles in water using microwaves. *Green Chem.* 11, 926.
- Baruwati B, Varma RS, 2009 High Value Products from Waste: Grape Pomace Extractâ€™A Three-in-One Package for the Synthesis of Metal Nanoparticles. *ChemSusChem* 2, 1041–1044. [PubMed: 19842157]
- Batalha IL, Hussain A, Roque ACA, 2010 Gum Arabic coated magnetic nanoparticles with affinity ligands specific for antibodies. *J. Mol. Recognit.* 23, 462–471. [PubMed: 20119950]
- Bera H, Boddupalli S, Nayak AK, 2015 Mucoadhesive-floating zinc-pectinate–sterculia gum interpenetrating polymer network beads encapsulating ziprasidone HCl. *Carbohydr. Polym.* 131, 108–118.
- Bhattarai N, Li Z, Edmondson D, Zhang M, 2006 Alginate-Based Nanofibrous Scaffolds: Structural, Mechanical, and Biological Properties. *Adv. Mater.* 18, 1463–1467.
- Bhattarai N, Zhang M, 2007 Controlled synthesis and structural stability of alginate-based nanofibers. *Nanotechnology* 18, 455601.
- Bie Y, Yang J, Nuli Y, Wang J, 2017 Natural karaya gum as an excellent binder for silicon-based anodes in high-performance lithium-ion batteries. *J. Mater. Chem. A* 5, 1919–1924.
- Bonino CA, Krebs MD, Saquing CD, Jeong SI, Shearer KL, Alsberg E, Khan SA, 2011 Electrospinning alginate-based nanofibers: From blends to crosslinked low molecular weight alginate-only systems. *Carbohydr. Polym.* 85, 111–119.
- Bosnea LA, Moschakis T, Biliaderis CG, 2017 Microencapsulated cells of *Lactobacillus paracasei* subsp. *paracasei* in biopolymer complex coacervates and their function in a yogurt matrix. *Food Funct.* 8, 554–562. [PubMed: 27935607]
- Boury B, Plumejeau S, 2015 Metal oxides and polysaccharides: an efficient hybrid association for materials chemistry. *Green Chem.* 17, 72–88.
- Brito ACF, Silva DA, de Paula RCM, Feitosa JPA, 2004 Sterculia striata exudate polysaccharide: characterization, rheological properties and comparison with Sterculia urens(karaya) polysaccharide. *Polym. Int.* 53, 1025–1032.
- Cao X, Wang X, Ding B, Yu J, Sun G, 2013 Novel spider-web-like nanoporous networks based on jute cellulose nanowhiskers. *Carbohydr. Polym.* 92, 2041–2047. [PubMed: 23399256]
- Castellani O, Al-Assaf S, Axelos M, Phillips GO, Anton M, 2010 Hydrocolloids with emulsifying capacity. Part 2 – Adsorption properties at the n-hexadecane–Water interface. *Food Hydrocoll.* 24, 121–130.
- Chabot V, Kim B, Sloper B, Tzoganakis C, Yu A, 2013 High yield production and purification of few layer graphene by Gum Arabic assisted physical sonication. *Sci. Rep.* 3, 1378. [PubMed: 23478744]
- Chanda N, Upendran A, Boote EJ, Zambre A, Axiak S, Selting K, Katti KV, Leevy WM, Afrasiabi Z, Vimal J, Singh J, Lattimer JC, Kannan R, 2014 Gold Nanoparticle Based X-Ray Contrast Agent for Tumor Imaging in Mice and Dog: A Potential NanoPlatform for Computer Tomography Theranostics. *J. Biomed. Nanotechnol.* 10, 383–392. [PubMed: 24730234]
- Chandran SP, Chaudhary M, Pasricha R, Ahmad A, Sastry M, 2006 Synthesis of Gold Nanotriangles and Silver Nanoparticles Using Aloe vera Plant Extract. *Biotechnol. Prog.* 22, 577–583. [PubMed: 16599579]
- Chang JJ, Lee YH, Wu MH, Yang MC, Chien CT, 2012 Electrospun anti-adhesion barrier made of chitosan alginate for reducing peritoneal adhesions. *Carbohydr. Polym.* 88, 1304–1312.
- Chang YC, Chen DH, 2005 Preparation and adsorption properties of monodisperse chitosan-bound Fe₃O₄ magnetic nanoparticles for removal of Cu(II) ions. *J. Colloid Interface Sci.* 283, 446–451.
- Chaudhary JP, Mahto A, Vadodariya N, Kholiya F, Maiti S, Natraj SK, Meena R, 2016 Fabrication of carbon and sulphur-doped nanocomposites with seaweed polymer carrageenan as efficient catalyst for rapid degradation of dye pollutants using solar concentrator. *RSC Adv.* 6, 61716.
- Chen D, Yang K, Wang H, Zhou J, Zhang H, 2015 Cr(VI) removal by combined redox reactions and adsorption using pectin-stabilized nanoscale zero-valent iron for simulated chromium contaminated water. *RSC Adv.* 5, 65068–65073.

- Cheng Y, Yin L, Lin S, Wiesner M, Bernhardt E, Liu J, 2011 Toxicity Reduction of Polymer-Stabilized Silver Nanoparticles by Sunlight. *J. Phys. Chem. C* 115, 4425–4432.
- Cinelli M, Coles SR, Nadagouda MN, Błaszczyszki J, Stowski R, Varma RS, Kirwan K, 2015 A green chemistry-based classification model for the synthesis of silver nanoparticles. *Green Chem.* 17, 2825–2839.
- Coccia F, Tonucci L, Bosco D, Bressan M, D'Alessandro N, 2012 One-pot synthesis of lignin-stabilised platinum and palladium nanoparticles and their catalytic behaviour in oxidation and reduction reactions. *Green Chem.* 14, 1073–1078.
- Colvin VL, 2003 The potential environmental impact of engineered nanomaterials. *Nat. Biotechnol.* 21, 1166–1170. [PubMed: 14520401]
- Committee On Toxicology, 2001. Arsenic in Drinking Water, Update. National Academies Press, Washington, D.C. <https://doi.org/10.17226/10194>.
- Cornelsen PA, Quintanilha RC, Vidotti M, Gorin PAJ, Simas-Tosin FF, Riegel-Vidotti IC, 2015 Native and structurally modified gum arabic: exploring the effect of the gum's microstructure in obtaining electroactive nanoparticles. *Carbohydr. Polym.* 119, 35–43.
- Correa SN, Naranjo AM, Herrera AP, 2016 Biosynthesis and characterization of gold nanoparticles using extracts of tamarindus indica L leaves. *J. Phys. Conf. Ser.* 687, 12082.
- Cui S, Yao B, Gao M, Sun X, Gou D, Hu J, Zhou Y, Liu Y, 2017 Effects of pectin structure and crosslinking method on the properties of crosslinked pectin nanofibers. *Carbohydr. Polym.* 157, 766–774. [PubMed: 27987989]
- Cui S, Yao B, Sun X, Hu J, Zhou Y, Liu Y, 2016 Reducing the content of carrier polymer in pectin nanofibers by electrospinning at low loading followed with selective washing. *Mater. Sci. Eng. C* 59, 885–893.
- Das D, Pal S, 2015 Modified biopolymer-dextrin based crosslinked hydrogels: application in controlled drug delivery. *RSC Adv.* 5, 25014–25050.
- Das R, Vecitis CD, Schulze A, Cao B, Ismail AF, Lu X, Chen J, Ramakrishna S, 2017 Recent advances in nanomaterials for water protection and monitoring. *Chem. Soc. Rev.* 46, 6946–7020. [PubMed: 28959815]
- Das T, Yeasmin S, Khatua S, Acharya K, Bandyopadhyay A, 2015 Influence of a blend of guar gum and poly(vinyl alcohol) on long term stability, and antibacterial and antioxidant efficacies of silver nanoparticles. *RSC Adv.* 5, 54059–54069.
- Dasari A, Guttenu V, 2016 Green synthesis, characterization, photocatalytic, fluorescence and antimicrobial activities of Cochlospermum gossypium capped Ag₂S nanoparticles. *J. Photochem. Photobiol. B Biol.* 157, 57–69.
- Dauthal P, Mukhopadhyay M, 2016 Noble Metal Nanoparticles: Plant-Mediated Synthesis, Mechanistic Aspects of Synthesis, and Applications. *Ind. Eng. Chem. Res.* 55, 9557–9577.
- Davidson RL, 1980. Handbook of water-soluble gums and resins. McGraw-Hill, London, United States.
- Davis TA, Llanes F, Volesky B, Mucci A, 2003 Metal selectivity of Sargassum spp. and their alginates in relation to their α -L-guluronic acid content and conformation. *Environ. Sci. Technol.* 37, 261–267. [PubMed: 12564896]
- Davis TA, Volesky B, Mucci A, 2003 A review of the biochemistry of heavy metal biosorption by brown algae. *Water Res.* 37, 4311–4330. [PubMed: 14511701]
- de Brito ACF, Sierakowski MR, Reicher F, Feitosa JPA, de Paula RCM, 2005 Dynamic rheological study of Sterculia striata and karaya polysaccharides in aqueous solution. *Food Hydrocoll.* 19, 861–867.
- De France KJ, Hoare T, Cranston ED, 2017 Review of Hydrogels and Aerogels Containing Nanocellulose. *Chem. Mater.* 29, 4609–4631.
- Desai K, Kit K, Li J, Michael Davidson P, Zivanovic S, Meyer H, 2009 Nanofibrous chitosan non-wovens for filtration applications. *Polymer (Guildf)*. 50, 3661–3669.
- Deshmukh AS, Setty CM, Badiger AM, Muralikrishna KSS, 2012 Gum ghatti: A promising polysaccharide for pharmaceutical applications. *Carbohydr. Polym.* 87, 980–986.

- Devendiran RM, kumar Chinnaiyan, S., Yadav NK, Moorthy GK, Ramanathan G, Singaravelu S, Sivagnanam UT, Perumal PT, 2016 Green synthesis of folic acid-conjugated gold nanoparticles with pectin as reducing/stabilizing agent for cancer theranostics. *RSC Adv.* 6, 29757–29768.
- Devi DK, Pratap SV, Haritha R, Sivudu KS, Radhika P, Sreedhar B, 2011 Gum acacia as a facile reducing, stabilizing, and templating agent for palladium nanoparticles. *J. Appl. Polym. Sci.* 121, 1765–1773.
- Devi LS, Joshi SR, 2012 Antimicrobial and synergistic effects of silver nanoparticles synthesized using soil fungi of high altitudes of eastern himalaya. *Mycobiology* 40, 27–34. [PubMed: 22783131]
- Dhar S, Murawala P, Shiras A, Pokharkar V, Prasad BLV, 2012 Gellan gum capped silver nanoparticle dispersions and hydrogels: cytotoxicity and in vitro diffusion studies. *Nanoscale* 4, 563–567. [PubMed: 22134682]
- Dufficy MK, Khan SA, Fedkiw PS, 2015 Galactomannan binding agents for silicon anodes in Li-ion batteries. *J. Mater. Chem. A* 3, 12023–12030.
- Dwivedi AD, Dubey SP, Sillanpää M, Kwon Y-NN, Lee C, Varma RS, 2015 Fate of engineered nanoparticles: Implications in the environment. *Coord. Chem. Rev.* 287, 64–78.
- El-Rafie MH, El-Naggar ME, Ramadan MA, Fouda MMG, Al-Deyab SS, Hebeish A, 2011 Environmental synthesis of silver nanoparticles using hydroxypropyl starch and their characterization. *Carbohydr. Polym.* 86, 630–635.
- Elemike EE, Onwudiwe DC, Ekennia AC, Ehiri RC, Nnaji NJ, 2017 Phytosynthesis of silver nanoparticles using aqueous leaf extracts of *Lippia citriodora*: Antimicrobial, larvicidal and photocatalytic evaluations. *Mater. Sci. Eng. C* 75, 980–989.
- Elsabee MZ, Naguib HF, Morsi RE, 2012 Chitosan based nanofibers, review. *Mater. Sci. Eng. C* 32, 1711–1726.
- Falcaro P, Ricco R, Yazdi A, Imaz I, Furukawa S, Maspoch D, Ameloot R, Evans JD, Doonan CJ, 2016 Application of metal and metal oxide nanoparticles at MOFs. *Coord. Chem. Rev.* 307, 237–254.
- Fan J, Shi Z, Ge Y, Wang J, Wang Y, Yin J, 2012 Gum arabic assisted exfoliation and fabrication of Ag–graphene-based hybrids. *J. Mater. Chem.* 22, 13764–13772.
- Fang J, Du S, Lebedkin S, Li Z, Kruk R, Kappes M, Hahn H, 2010 Gold Mesostructures with Tailored Surface Topography and Their Self-Assembly Arrays for Surface-Enhanced Raman Spectroscopy. *Nano Lett.* 10, 5006–5013. [PubMed: 21090587]
- Farooq M, Sagbas S, Sahiner M, Siddiq M, Turk M, Aktas N, Sahiner N, 2017 Synthesis, characterization and modification of Gum Arabic microgels for hemocompatibility and antimicrobial studies. *Carbohydr. Polym.* 156, 380–389.
- Fauconnier ML, Blecker C, Groyne J, Razafindralambo H, Vanzeveren E, Marlier M, Paquot M, 2000 Characterization of two Acacia gums and their fractions using a Langmuir film balance. *J. Agric. Food Chem.* 48, 2709–2712. [PubMed: 10898609]
- Ferris CJ, In het Panhuis M, 2009 Conducting bio-materials based on gellan gum hydrogels. *Soft Matter* 5, 3430–3437.
- Finotelli PV, Da Silva D, Sola-Penna M, Rossi AM, Farina M, Andrade LR, Takeuchi AY, Rocha-Leão MH, 2010 Microcapsules of alginate/chitosan containing magnetic nanoparticles for controlled release of insulin. *Colloids Surfaces B Biointerfaces* 81, 206–211.
- Flickinger MC, 2010. *Encyclopedia of industrial biotechnology: bioprocess, bioseparation, and cell technology.* Wiley, Hoboken, N.J 10.1002/9780470054581
- Forget A, Arya N, Randriantsilefisoa R, Miessmer F, Buck M, Ahmadi V, Jonas D, Blencowe A, Shastri VP, 2016 Nonwoven Carboxylated Agarose-Based Fiber Meshes with Antimicrobial Properties. *Biomacromolecules* 17, 4021–4026. [PubMed: 27936720]
- Freire MG, Teles ARR, Ferreira RAS, Carlos LD, Lopes-da-Silva JA, Coutinho JAP, 2011 Electrospun nanosized cellulose fibers using ionic liquids at room temperature. *Green Chem.* 13, 3173–3180.
- Frenot A, Chronakis IS, 2003 Polymer nanofibers assembled by electrospinning. *Curr. Opin. Colloid Interface Sci.* 8, 64–75.
- Fryxell GE, Cao G, 2007. *Environmental applications of nanomaterials: synthesis, sorbents and sensors.* Imperial College Press.

- Fu R, Li C, Yu C, Xie H, Shi S, Li Z, Wang Q, Lu L, 2016 A novel electrospun membrane based on moxifloxacin hydrochloride/poly(vinyl alcohol)/sodium alginate for antibacterial wound dressings in practical application. *Drug Deliv.* 23, 828–839. [PubMed: 24870202]
- Gashua IB, Williams PA, Baldwin TC, 2016 Molecular characteristics, association and interfacial properties of gum Arabic harvested from both *Acacia senegal* and *Acacia seyal*. *Food Hydrocoll.* 61, 514–522.
- Gavlighi HA, Meyer AS, Zaidel DNA, Mohammadifar MA, Mikkelsen JD, 2013a. Stabilization of emulsions by gum tragacanth (*Astragalus* spp.) correlates to the galacturonic acid content and methoxylation degree of the gum. *Food Hydrocoll.* 31, 5–14.
- Gavlighi HA, Mikkelsen H, Meyer JD, 2013b. Tragacanth Gum: Structural Composition, Natural Functionality and Enzymatic Conversion as Source of Potential Prebiotic Activity. Technical University of Denmark.
- Ghayempour S, Montazer M, Mahmoudi Rad M, 2016 Tragacanth gum biopolymer as reducing and stabilizing agent in biosynthesis of urchin-like ZnO nanorod arrays: A low cytotoxic photocatalyst with antibacterial and antifungal properties. *Carbohydr. Polym.* 136, 232–241.
- Gils PS, Ray D, Sahoo PK, 2010 Designing of silver nanoparticles in gum arabic based semi-IPN hydrogel. *Int. J. Biol. Macromol.* 46, 237–244. [PubMed: 20060413]
- Glicksman M, 1982. Food hydrocolloids, in: *Food Hydrocolloids*. CRC Press, Boca Raton, p. 240.
- Gok C, Aytas S, 2009 Biosorption of uranium(VI) from aqueous solution using calcium alginate beads. *J. Hazard. Mater.* 168, 369–375.
- Grassian VH, 2008. Nanoscience and nanotechnology: environmental and health impacts Hoboken, NJ, USA 10.1002/9780470396612
- Grein-Iankovski A, Riegel-Vidotti IC, Simas-Tosin FF, Narayanan S, Leheny RL, Sandy AR, 2016 Exploring the relationship between nanoscale dynamics and macroscopic rheology in natural polymer gums. *Soft Matter* 12, 9321–9329. [PubMed: 27805235]
- Greiner A, Wendorff JHH, 2007 Electrospinning: A Fascinating Method for the Preparation of Ultrathin Fibers. *Angew. Chemie Int. Ed.* 46, 5670–5703.
- Haider S, Park S-Y, 2009 Preparation of the electrospun chitosan nanofibers and their applications to the adsorption of Cu(II) and Pb(II) ions from an aqueous solution. *J. Memb. Sci.* 328, 90–96.
- Hajipour MJ, Fromm KM, Akbar Ashkarran A, Jimenez de Aberasturi D, de Larramendi IR, Rojo T, Serpooshan V, Parak WJ, Mahmoudi M, 2012 Antibacterial properties of nanoparticles. *Trends Biotechnol.* 30, 499–511. [PubMed: 22884769]
- Hall SR, 2009. Biotemplating: complex structures from natural materials. Imperial College Press.
- Hebbalalu D, Lalley J, Nadagouda MN, Varma RS, 2013 Greener Techniques for the Synthesis of Silver Nanoparticles Using Plant Extracts, Enzymes, Bacteria, Biodegradable Polymers, and Microwaves. *ACS Sustain. Chem. Eng.* 1, 703–712.
- Hemmati K, Masoumi A, Ghaemy M, 2016 Tragacanth gum-based nanogel as a superparamagnetic molecularly imprinted polymer for quercetin recognition and controlled release. *Carbohydr. Polym.* 136, 630–640. [PubMed: 26572395]
- Hoffman AS, 2002 Hydrogels for biomedical applications. *Adv. Drug Deliv. Rev.* 54, 3–12. [PubMed: 11755703]
- Homayoni H, Ravandi SAH, Valizadeh M, 2009 Electrospinning of chitosan nanofibers: Processing optimization. *Carbohydr. Polym.* 77, 656–661.
- Horst MF, Coral DF, Fernández van Raap MB, Alvarez M, Lassalle V, 2017 Hybrid nanomaterials based on gum Arabic and magnetite for hyperthermia treatments. *Mater. Sci. Eng. C* 74, 443–450.
- Hortigü MJ, Aranaz I, Gutiérrez MC, Ferrer ML, del Monte F, 2011 Chitosan Gelation Induced by the in Situ Formation of Gold Nanoparticles and Its Processing into Macroporous Scaffolds. *Biomacromolecules* 12, 179–186. [PubMed: 21128628]
- Huang J, Lin L, Sun D, Chen H, Yang D, Li Q, 2015 Bio-inspired synthesis of metal nanomaterials and applications. *Chem. Soc. Rev.* 44, 6330–6374. [PubMed: 26083903]
- Hungerford G, Toury M, McLoskey D, Donaldson N, Holmes-Smith AS, 2012 In situ formation of silver nanostructures within a polysaccharide film and application as a potential biocompatible fluorescence sensing medium. *Soft Matter* 8, 653–659.

- Ido T, Ogasawara T, Katayama T, Sasaki Y, Al-Assaf S, Phillips GO, 2008 Emulsification property of GATIFOLIA (gum ghatti) used for emulsions in food products. *Foods Food Ingredients J. Japan* 213, 365–372.
- Ignatova M, Manolova N, Rashkov I, Markova N, 2016 Quaternized chitosan/ κ -carrageenan/caffeic acid-coated poly(3-hydroxybutyrate) fibrous materials: Preparation, antibacterial and antioxidant activity. *Int. J. Pharm.* 513, 528–537.
- Iravani S, 2011 Green synthesis of metal nanoparticles using plants. *Green Chem.* 13, 2638–2650.
- Islam MS, Karim MR, 2010 Fabrication and characterization of poly(vinyl alcohol)/alginate blend nanofibers by electrospinning method. *Colloids Surfaces A Physicochem. Eng. Asp.* 366, 135–140.
- Islam MS, Yeum JH, Das AK, 2012 Effect of pullulan/poly(vinyl alcohol) blend system on the montmorillonite structure with property characterization of electrospun pullulan/poly(vinyl alcohol)/montmorillonite nanofibers. *J. Colloid Interface Sci.* 368, 273–281.
- Izawa H, Kadokawa J, 2010 Preparation and characterizations of functional ionic liquid-gel and hydrogel materials of xanthan gum. *J. Mater. Chem.* 20, 5235–5241.
- Jakóbk-Kolon A, Bok-Badura J, Karo K, Mitko K, Milewski A, 2017 Hybrid pectin-based biosorbents for zinc ions removal. *Carbohydr. Polym.* 169, 213–219.
- Janaki B, Sashidhar RB, 2000 Subchronic (90-day) toxicity study in rats fed gum kondagogu (*Cochlospermum gossypium*). *Food Chem. Toxicol.* 38, 523–534. [PubMed: 10828504]
- Janaki B, Sashidhar RB, 1998 Physico-chemical analysis of gum kondagogu (*Cochlospermum gossypium*): a potential food additive. *Food Chem.* 61, 231–236.
- Jang H, Kim Y-K, Huh H, Min D-H, 2014 Facile Synthesis and Intraparticle Self-Catalytic Oxidation of Dextran-Coated Hollow Au–Ag Nanoshell and Its Application for Chemo-Thermotherapy. *ACS Nano* 8, 467–475. [PubMed: 24383549]
- Jaouen V, Brayner R, Lantiat D, Steunou N, Coradin T, 2010 Insitu growth of gold colloids within alginate films. *Nanotechnology* 21, 185605. [PubMed: 20388968]
- Jayaraman K, Kotaki M, Zhang Y, Mo X, Ramakrishna S, Recent advances in polymer nanofibers. *J. Nanosci. Nanotechnol.* 4, 52–65.
- Jeong S, Choi SY, Park J, Seo J-H, Park J, Cho K, Joo S-W, Lee SY, 2011 Low-toxicity chitosan gold nanoparticles for small hairpin RNA delivery in human lung adenocarcinoma cells. *J. Mater. Chem.* 21, 13853–13859.
- Jha AK, Prasad K, Prasad K, Kulkarni AR, 2009 Plant system: Nature's nanofactory. *Colloids Surfaces B Biointerfaces* 73, 219–223.
- Ji J, Bar-On B, Wagner HD, 2012 Mechanics of electrospun collagen and hydroxyapatite/collagen nanofibers. *J. Mech. Behav. Biomed. Mater.* 13, 185–193. [PubMed: 22906988]
- Ji M, Chen X, Wai CM, Fulton JL, 1999 Synthesizing and Dispersing Silver Nanoparticles in a Water-in-Supercritical Carbon Dioxide Microemulsion. *J. Am. Chem. Soc.* 121, 2631–2632. [PubMed: 25258433]
- Juang R-S, Shiau R-C, 2000 Metal removal from aqueous solutions using chitosan-enhanced membrane filtration. *J. Memb. Sci.* 165, 159–167.
- Juby KA, Dwivedi C, Kumar M, Kota S, Misra HS, Bajaj PN, 2012 Silver nanoparticle-loaded PVA/gum acacia hydrogel: Synthesis, characterization and antibacterial study. *Carbohydr. Polym.* 89, 906–913. [PubMed: 24750879]
- Jungst T, Smolan W, Schacht K, Scheibel T, Groll J, 2016 Strategies and Molecular Design Criteria for 3D Printable Hydrogels. *Chem. Rev.* 116, 1496–1539. [PubMed: 26492834]
- Kaith BS, Sharma K, Kumar V, Kalia S, Swart HC, 2014 Fabrication and characterization of gum ghatti-polymethacrylic acid based electrically conductive hydrogels. *Synth. Met.* 187, 61–67.
- Kalaighana Selvi S, Mahesh Kumar J, Sashidhar RB, 2017 Anti-proliferative activity of Gum kondagogu (*Cochlospermum gossypium*) -gold nanoparticle constructs on B16F10 melanoma cells: An in vitro model. *Bioact. Carbohydrates Diet. Fibre* 11, 38–47.
- Kang J, Cui SW, Chen J, Phillips GO, Wu Y, Wang Q, 2011a. New studies on gum ghatti (*Anogeissus latifolia*) part I. Fractionation, chemical and physical characterization of the gum. *Food Hydrocoll.* 25, 1984–1990.

- Kang J, Cui SW, Phillips GO, Chen J, Guo Q, Wang Q, 2011b. New studies on gum ghatti (*Anogeissus latifolia*) part II. Structure characterization of an arabinogalactan from the gum by 1D, 2D NMR spectroscopy and methylation analysis. *Food Hydrocoll.* 25, 1991–1998.
- Kang J, Cui SW, Phillips GO, Chen J, Guo Q, Wang Q, 2011c. New studies on gum ghatti (*Anogeissus latifolia*) Part III: Structure characterization of a globular polysaccharide fraction by 1D, 2D NMR spectroscopy and methylation analysis. *Food Hydrocoll.* 25, 1999–2007.
- Kang J, Guo Q, Phillips GO, Cui SW, 2014 Understanding the structure–emulsification relationship of gum ghatti – A review of recent advances. *Food Hydrocoll.* 42, 187–195.
- Kang J, Guo Q, Wang Q, Phillips GO, Cui SW, 2015a. New studies on gum ghatti (*Anogeissus latifolia*) part 6: Physicochemical characteristics of the protein moiety of gum ghatti. *Food Hydrocoll.* 44, 237–243.
- Kang J, Guo Q, Wang Q, Phillips GO, Cui SW, 2015b. New studies on gum ghatti (*Anogeissus latifolia*) part 5: The conformational properties of gum ghatti. *Food Hydrocoll.* 43, 25–30.
- Kanmani P, Lim ST, 2013 Synthesis and characterization of pullulan-mediated silver nanoparticles and its antimicrobial activities. *Carbohydr. Polym.* 97, 421–428.
- Kannan R, Rahing V, Cutler C, Pandrapragada R, Katti KK, Kattumuri V, Robertson JD, Casteel SJ, Jurisson S, Smith C, Boote E, Katti KV, 2006 Nanocompatible chemistry toward fabrication of target-specific gold nanoparticles. *J. Am. Chem. Soc.* 128, 11342–11343. [PubMed: 16939243]
- Kannan R, Zambre A, Chanda N, Kulkarni R, Shukla R, Katti K, Upendran A, Cutler C, Boote E, Katti KV, 2012 Functionalized radioactive gold nanoparticles in tumor therapy. *Wiley Interdiscip. Rev. Nanomedicine Nanobiotechnology.* 4, 42–51. [PubMed: 21953803]
- Katayama T, Ido T, Sasaki Y, Ogasawara T, Al-Assaf S, Phillips G, 2008 Characterization of the adsorbed component of gum ghatti responsible for its oil–water interface advantages. *Foods Food Ingredients J. Japan* 213, 372–376.
- Kattumuri V, Katti KKV, Bhaskaran S, Boote EJJ, Casteel SWW, Fent GMM, Robertson DJJ, Chandrasekhar M, Kannan R, Katti KKV, 2007 Gum Arabic as a Phytochemical Construct for the Stabilization of Gold Nanoparticles: In Vivo Pharmacokinetics and X-ray-Contrast-Imaging Studies. *Small* 3, 333–341. [PubMed: 17262759]
- Katzbauer B, 1998 Properties and applications of xanthan gum. *Polym. Degrad. Stab.* 59, 81–84.
- Keller A, Pham J, Warren H, in het Panhuis M, 2017 Conducting hydrogels for edible electrodes. *J. Mater. Chem. B* 5, 5318–5328.
- Khadka DB, Haynie DT, 2012 Protein- and peptide-based electrospun nanofibers in medical biomaterials. *Nanomedicine Nanotechnology, Biol. Med.* 8, 1242–1262.
- Khan M, Khan M, Kuniyil M, Adil SF, Al-Warthan A, Alkhathlan HZ, Tremel W, Tahir MN, Siddiqui MRH, 2014 Biogenic synthesis of palladium nanoparticles using *Pulicaria glutinosa* extract and their catalytic activity towards the Suzuki coupling reaction. *Dalt. Trans.* 43, 9026–9031.
- Khan MZI, Prebeg Ž, Kurjakovi N, 1999 A pH-dependent colon targeted oral drug delivery system using methacrylic acid copolymers. I. Manipulation of drug release using Eudragit L100–55 and Eudragit S100 combinations. *J. Control. Release* 58, 215–222.
- Khin MM, Nair AS, Babu VJ, Murugan R, Ramakrishna S, 2012 A review on nanomaterials for environmental remediation. *Energy Environ. Sci.* 5, 8075–8109.
- Ki CS, Gang EH, Um IC, Park YH, 2007 Nanofibrous membrane of wool keratose/silk fibroin blend for heavy metal ion adsorption. *J. Memb. Sci.* 302, 20–26.
- Kim SH, Nam YS, Lee TS, Park WH, 2003 Silk fibroin nanofiber. Electrospinning, properties, and structure. *Polym. J.* 35, 185–190.
- Klimmek S, Stan HJ, Wilke A, Bunke G, Buchholz R, 2001 Comparative analysis of the biosorption of cadmium, lead, nickel, and zinc by algae. *Environ. Sci. Technol.* 35, 4283–4288. [PubMed: 11718343]
- Kodiyan A, Silva EA, Kim J, Aizenberg M, Mooney DJ, 2012 Surface Modification with Alginate-Derived Polymers for Stable, Protein-Repellent, Long-Circulating Gold Nanoparticles. *ACS Nano* 6, 4796–4805. [PubMed: 22650310]
- Kong H, Yang J, Zhang Y, Fang Y, Nishinari K, Phillips GO, 2014 Synthesis and antioxidant properties of gum arabic-stabilized selenium nanoparticles. *Int. J. Biol. Macromol.* 65, 155–162.

- Kong L, Ziegler GR, 2014 Rheological aspects in fabricating pullulan fibers by electro-wet-spinning. *Food Hydrocoll.* 38, 220–226.
- Konwarh R, Karak N, Misra M, 2013 Electrospun cellulose acetate nanofibers: The present status and gamut of biotechnological applications. *Biotechnol. Adv.* 31, 421–437. [PubMed: 23318668]
- Kora A, Beedu S, Jayaraman A, 2012 Size-controlled green synthesis of silver nanoparticles mediated by gum ghatti (*Anogeissus latifolia*) and its biological activity. *Org. Med. Chem. Lett.* 2, 17. [PubMed: 22571686]
- Kora AJ, Rastogi L, 2015 Green synthesis of palladium nanoparticles using gum ghatti (*Anogeissus latifolia*) and its application as an antioxidant and catalyst. *Arab. J. Chem.* In Press, DOI: 10.1016/j.arabjc.2015.06.024
- Kora AJ, Sashidhar RB, 2015 Antibacterial activity of biogenic silver nanoparticles synthesized with gum ghatti and gum olibanum: a comparative study. *J. Antibiot. (Tokyo).* 68, 88–97. [PubMed: 25138141]
- Kora AJ, Sashidhar RB, 2018 Biogenic silver nanoparticles synthesized with rhamnogalacturonan gum: Antibacterial activity, cytotoxicity and its mode of action. *Arab. J. Chem.* 11, 313–323.
- Kora AJ, Sashidhar RB, Arunachalam J, 2010 Gum kondagogu (*Cochlospermum gossypium*): A template for the green synthesis and stabilization of silver nanoparticles with antibacterial application. *Carbohydr. Polym.* 82, 670–679.
- Kou J, Varma RS, 2012a. Beet juice-induced green fabrication of plasmonic AgCl/Ag nanoparticles. *ChemSusChem* 5, 2435–2441. [PubMed: 22945662]
- Kou J, Varma RS, 2012b. Beet juice utilization: Expedient green synthesis of noble metal nanoparticles (Ag, Au, Pt, and Pd) using microwaves. *RSC Adv.* 2, 10283–10290.
- Kou J, Varma RS, 2013 Speedy fabrication of diameter-controlled Ag nanowires using glycerol under microwave irradiation conditions. *Chem. Commun.* 49, 692–694.
- Kratochvil D, Volesky B, 1998 Advances in the biosorption of heavy metals. *Trends Biotechnol.* 16, 291–300.
- Kriegel C, Arrechi A, Kit K, McClements DJ, Weiss J, 2008 Fabrication, Functionalization, and Application of Electrospun Biopolymer Nanofibers. *Crit. Rev. Food Sci. Nutr.* 48, 775–797. [PubMed: 18756399]
- Kulanthaivel S, Rathnam VSS, Agarwal T, Pradhan S, Pal K, Giri S, Maiti TK, Banerjee I, 2017 Gum tragacanth–alginate beads as proangiogenic–osteogenic cell encapsulation systems for bone tissue engineering. *J. Mater. Chem. B* 5, 4177–4189.
- Kumar A, Aerry S, Saxena A, De A, Mozumdar S, 2012 Copper nanoparticulates in Guar-gum: a recyclable catalytic system for the Huisgen [3 + 2]-cycloaddition of azides and alkynes without additives under ambient conditions. *Green Chem.* 14, 1298–1301.
- Kumar A, Ahuja M, 2012 Carboxymethyl gum kondagogu: Synthesis, characterization and evaluation as mucoadhesive polymer. *Carbohydr. Polym.* 90, 637–643. [PubMed: 24751087]
- Kumar N, Mittal H, Parashar V, Ray SS, Ngila JC, 2016 Efficient removal of rhodamine 6G dye from aqueous solution using nickel sulphide incorporated polyacrylamide grafted gum karaya bionanocomposite hydrogel. *RSC Adv.* 6, 21929–21939.
- Kumbhare V, Bhargava A, 1999 Studies on the nutritional composition of *Sterculia* species. *J. Food Sci. Technol.* 36, 542–544.
- Le Cerf D, Irinei F, Muller G, 1990 Solution properties of gum exudates from *Sterculia urens* (Karaya gum). *Carbohydr. Polym.* 13, 375–386.
- Lee KY, Jeong L, Kang YO, Lee SJ, Park WH, 2009 Electrospinning of polysaccharides for regenerative medicine. *Adv. Drug Deliv. Rev.* 61, 1020–1032. [PubMed: 19643155]
- Leslie SK, Cohen DJ, Sedlacek J, Pinsker EJ, Boyan BD, Schwartz Z, 2013 Controlled release of rat adipose-derived stem cells from alginate microbeads. *Biomaterials* 34, 8172–8184. [PubMed: 23906513]
- Li J, Mooney DJ, 2016 Designing hydrogels for controlled drug delivery. *Nat. Rev. Mater.* 1, 10.1038/natrevmats.2016.71
- Li L, Ni R, Shao Y, Mao S, 2014 Carrageenan and its applications in drug delivery. *Carbohydr. Polym.* 103, 1–11.

- Li M, Li H, Li X, Zhu H, Xu Z, Liu L, Ma J, Zhang M, 2017 A Bioinspired Alginate-Gum Arabic Hydrogel with Micro-/Nanoscale Structures for Controlled Drug Release in Chronic Wound Healing. *ACS Appl. Mater. Interfaces* 9, 22160–22175. [PubMed: 28640580]
- Li S, Yue X, Jing Y, Bai S, Dai Z, 2011 Fabrication of zonal thiol-functionalized silica nanofibers for removal of heavy metal ions from wastewater. *Colloids Surfaces A Physicochem. Eng. Asp.* 380, 229–233.
- Li X, Yang Q, Zhao Y, Long S, Zheng J, 2017 Soft Matter hydrogels with high toughness and self-healing. *Soft Matter* 13, 911–920. [PubMed: 28078338]
- Li X, Zhang H, Jin Q, Cai Z, 2017 Contribution of arabinogalactan protein to the stabilization of single-walled carbon nanotubes in aqueous solution of gum arabic. *Food Hydrocoll.* In Press, DOI: 10.1016/j.foodhyd.2017.08.013
- Li Y, Gan W, Zhou J, Lu Z, Yang C, Ge T, 2015 Hydrothermal synthesis of silver nanoparticles in Arabic gum aqueous solutions. *Trans. Nonferrous Met. Soc. China* 25, 2081–2086.
- Li Z, Ravaine V, Ravaine S, Garrigue P, Kuhn A, 2007 Raspberry-like Gold Microspheres: Preparation and Electrochemical Characterization. *Adv. Funct. Mater.* 17, 618–622.
- Liang D, Hsiao BS, Chu B, 2007 Functional electrospun nanofibrous scaffolds for biomedical applications. *Adv. Drug Deliv. Rev.* 59, 1392–412. [PubMed: 17884240]
- Lim S-F, Zheng Y-M, Zou S-W, Chen JP, 2009 Removal of copper by calcium alginate encapsulated magnetic sorbent. *Chem. Eng. J.* 152, 509–513.
- Lin HY, Chen HH, Chang SH, Ni TS, 2013 Pectin-chitosan-PVA nanofibrous scaffold made by electrospinning and its potential use as a skin tissue scaffold. *J. Biomater. Sci. Polym. Ed.* 24, 470–484. [PubMed: 23565688]
- Liu Q, Duan B, Xu X, Zhang L, 2017 Progress in rigid polysaccharide-based nanocomposites with therapeutic functions. *J. Mater. Chem. B* 5, 5690–5713.
- Liu Y, Zhao J-C, Zhang C-J, Guo Y, Cui L, Zhu P, Wang D-Y, 2015 Bio-based nickel alginate and copper alginate films with excellent flame retardancy: preparation, flammability and thermal degradation behavior. *RSC Adv.* 5, 64125–64137.
- Lokanathan AR, Uddin KMA, Rojas OJ, Laine J, 2014 Cellulose Nanocrystal-Mediated Synthesis of Silver Nanoparticles: Role of Sulfate Groups in Nucleation Phenomena. *Biomacromolecules* 15, 373–379. [PubMed: 24328321]
- Long Y, Ran X, Zhang L, Guo Q, Yang T, Gao J, Cheng H, Cheng T, Shi C, Su Y, 2013 A method for the preparation of silver nanoparticles using commercially available carboxymethyl chitosan and sunlight. *Mater. Lett.* 112, 101–104.
- Louie SM, Tilton RD, Lowry GV, 2016 Critical review: impacts of macromolecular coatings on critical physicochemical processes controlling environmental fate of nanomaterials. *Environ. Sci. Nano* 3, 283–310.
- López-Castejón ML, Bengoechea C, García-Morales M, Martínez I, 2016 Influence of tragacanth gum in egg white based bioplastics: Thermomechanical and water uptake properties. *Carbohydr. Polym.* 152, 62–69.
- López-Rubio A, Sanchez E, Wilkanowicz S, Sanz Y, Lagaron JM, 2012 Electrospinning as a useful technique for the encapsulation of living bifidobacteria in food hydrocolloids. *Food Hydrocoll.* 28, 159–167.
- Lu F, Astruc D, 2018 Nanomaterials for removal of toxic elements from water. *Coord. Chem. Rev.* 356, 147–164.
- Lubambo AF, de Freitas RA, Sierakowski M-RR, Lucyszyn N, Sasaki GL, Serafim BM, Saul CK, 2013 Electrospinning of commercial guar-gum: Effects of purification and filtration. *Carbohydr. Polym.* 93, 484–491.
- Lubambo AF, Ono L, Drago V, Mattoso N, Varalda J, Sierakowski MR, Sakakibara CN, Freitas RA, Saul CK, 2015 Tuning Fe₃O₄ nanoparticle dispersion through pH in PVA/guar gum/electrospun membranes. *Carbohydr. Polym.* 134, 775–783. [PubMed: 26428185]
- Lukman AI, Gong B, Marjo CE, Roessner U, Harris AT, 2011 Facile synthesis, stabilization, and anti-bacterial performance of discrete Ag nanoparticles using *Medicago sativa* seed exudates. *J. Colloid Interface Sci.* 353, 433–444. [PubMed: 20974473]

- Luque R, Ojeda M, Garcia A, Lastres C, Campos R, Pineda A, Romero AA, Yopez A, 2013 Evaluation of biomass-derived stabilising agents for colloidal silver nanoparticles via nanoparticle tracking analysis (NTA). *RSC Adv.* 3, 7119–7123.
- Luque R, Varma RS (Eds.), 2012. *Sustainable Preparation of Metal Nanoparticles*, RSC Green Chemistry. Royal Society of Chemistry, Cambridge 10.1039/9781849735469
- Ma R, Levard C, Marinakos SM, Cheng Y, Liu J, Michel FM, Brown GE, Lowry GV, 2012 Size-controlled dissolution of organic-coated silver nanoparticles. *Environ. Sci. Technol.* 46, 752–759. [PubMed: 22142034]
- Mahanta N, Valiyaveetil S, 2011 Surface modified electrospun poly(vinyl alcohol) membranes for extracting nanoparticles from water. *Nanoscale* 3, 4625–4631. [PubMed: 21904762]
- Mahendran T, Williams PA, Phillips GO, Al-Assaf S, Baldwin TC, 2008 New Insights into the Structural Characteristics of the Arabinogalactan–Protein (AGP) Fraction of Gum Arabic. *J. Agric. Food Chem.* 56, 9269–9276. [PubMed: 18783242]
- Malik S, Ahuja M, 2011 Gum kondagogu-g-poly (acrylamide): Microwave-assisted synthesis, characterisation and release behaviour. *Carbohydr. Polym.* 86, 177–184.
- Mallakpour S, Abdolmaleki A, Tabesh F, 2018 Ultrasonic-assisted manufacturing of new hydrogel nanocomposite biosorbent containing calcium carbonate nanoparticles and tragacanth gum for removal of heavy metal. *Ultrason. Sonochem.* 41, 572–581. [PubMed: 29137788]
- Mano JF, Silva GA, Azevedo HS, Malafaya PB, Sousa RA, Silva SS, Boesel LF, Oliveira JM, Santos TC, Marques AP, Neves NM, Reis RL, 2007 Natural origin biodegradable systems in tissue engineering and regenerative medicine: present status and some moving trends. *J. R. Soc. Interface* 4, 999–1030. [PubMed: 17412675]
- Masoumi A, Ghaemy M, 2014 Removal of metal ions from water using nanohydrogel tragacanth gum-polyamidoxime: Isotherm and kinetic study. *Carbohydr. Polym.* 108, 206–215.
- Matheickal JT, Yu Q, Woodburn GM, 1999 Biosorption of cadmium(II) from aqueous solutions by pre-treated biomass of marine alga *Durvillaea potatorum*. *Water Res.* 33, 335–342.
- Matlack AS, 2010. *Introduction to green chemistry*, Second Edi ed. CRC Press, Boca Raton, Fla.
- Matsumoto H, Tanioka A, 2011 Functionality in Electrospun Nanofibrous Membranes Based on Fiber's Size, Surface Area, and Molecular Orientation. *Membranes (Basel)*. 1, 249–264. [PubMed: 24957735]
- Matthews JA, Wnek GE, Simpson DG, Bowlin GL, 2002 Electrospinning of collagen nanofibers. *Biomacromolecules* 3, 232–238. [PubMed: 11888306]
- Mendes AC, Stephansen K, Chronakis IS, 2017a. Electrospinning of food proteins and polysaccharides. *Food Hydrocoll.* 68, 53–68.
- Mendes AC, Strohmenger T, Goycoolea F, Chronakis IS, 2017b. Electrostatic self-assembly of polysaccharides into nanofibers. *Colloids Surfaces A Physicochem. Eng. Asp.* 531, 182–188.
- Minato KI, Ohkawa K, Yamamoto H, 2006 Chain conformations of poly(γ -benzyl-L-glutamate) pre and post an electrospinning process. *Macromol. Biosci.* 6, 487–495. [PubMed: 16921536]
- Mishra A, Clark JH (Eds.), 2013. *Green Materials for Sustainable Water Remediation and Treatment*, RSC Green Chemistry. Royal Society of Chemistry, Cambridge 10.1039/9781849735001
- Mittal AK, Chisti Y, Banerjee UC, 2013 Synthesis of metallic nanoparticles using plant extracts. *Biotechnol. Adv.* 31, 346–356. [PubMed: 23318667]
- Mittal H, Jindal R, Kaith BS, Maity A, Ray SS, 2015 Flocculation and adsorption properties of biodegradable gum-ghatti-grafted poly(acrylamide-co-methacrylic acid) hydrogels. *Carbohydr. Polym.* 115, 617–628.
- Mittal H, Maity A, Ray SS, 2016 Gum karaya based hydrogel nanocomposites for the effective removal of cationic dyes from aqueous solutions. *Appl. Surf. Sci.* 364, 917–930.
- Mittal H, Maity A, Ray SS, 2015a. Synthesis of co-polymer-grafted gum karaya and silica hybrid organic–inorganic hydrogel nanocomposite for the highly effective removal of methylene blue. *Chem. Eng. J.* 279, 166–179.
- Mittal H, Maity A, Sinha Ray S, 2015b. The adsorption of Pb^{2+} and Cu^{2+} onto gum ghatti-grafted poly(acrylamide-co-acrylonitrile) biodegradable hydrogel: Isotherms and kinetic models *J. Phys. Chem. B* 119, 2026–2039.

- Mittal H, Mishra SB, 2014 Gum ghatti and Fe₃O₄ magnetic nanoparticles based nanocomposites for the effective adsorption of rhodamine B. *Carbohydr. Polym.* 101, 1255–1264. [PubMed: 24299899]
- Mohammadinejad R, Karimi S, Irvani S, Varma RS, 2016 Plant-derived nanostructures: types and applications. *Green Chem.* 18, 20–52.
- Mohan YM, Raju KM, Sambasivudu K, Singh S, Sreedhar B, 2007 Preparation of acacia-stabilized silver nanoparticles: A green approach. *J. Appl. Polym. Sci.* 106, 3375–3381.
- Montazer M, Keshvari A, Kahali P, 2016 Tragacanth gum /nano silver hydrogel on cotton fabric: In-situ synthesis and antibacterial properties. *Carbohydr. Polym.* 154, 257–266. [PubMed: 27577917]
- Monti OLA, Fourkas JT, Nesbitt DJ, 2004 Diffraction-Limited Photogeneration and Characterization of Silver Nanoparticles. *J. Phys. Chem. B* 108, 1604–1612.
- Mostafavi FS, Kadkhodae R, Emadzadeh B, Koocheki A, 2016 Preparation and characterization of tragacanth-locust bean gum edible blend films. *Carbohydr. Polym.* 139, 20–27.
- Mude N, Ingle A, Gade A, Rai M, 2009 Synthesis of Silver Nanoparticles Using Callus Extract of *Carica papaya* — A First Report. *J. Plant Biochem. Biotechnol.* 18, 83–86.
- Munarin F, Petrini P, Tanzi MC, Barbosa MA, Granja PL, 2012 Biofunctional chemically modified pectin for cell delivery. *Soft Matter* 8, 4731–4739.
- Murali R, Thanikaivelan P, Cheirmadurai K, 2016a. Melatonin in functionalized biomimetic constructs promotes rapid tissue regeneration in Wistar albino rats. *J. Mater. Chem. B* 4, 5850–5862.
- Murali R, Thanikaivelan P, Yan X, Lin Y, Xiao Z, Hou X, Dai J, Isner JM, Gurtner GC, Machens H-G, 2016b. Bionic, porous, functionalized hybrid scaffolds with vascular endothelial growth factor promote rapid wound healing in Wistar albino rats. *RSC Adv.* 6, 19252–19264.
- Nadagouda MN, Iyanna N, Lalley J, Han C, Dionysiou DD, Varma RS, 2014 Synthesis of Silver and Gold Nanoparticles Using Antioxidants from Blackberry, Blueberry, Pomegranate, and Turmeric Extracts. *ACS Sustain. Chem. Eng.* 2, 1717–1723.
- Nadagouda MN, Polshettiwar V, Varma RS, 2009 Self-assembly of palladium nanoparticles: synthesis of nanobelts, nanoplates and nanotrees using vitamin B1, and their application in carbon–carbon coupling reactions. *J. Mater. Chem.* 19, 2026–2031.
- Nadagouda MN, Varma RS, 2008 Green Synthesis of Ag and Pd Nanospheres, Nanowires, and Nanorods Using Vitamin B 2: Catalytic Polymerisation of Aniline and Pyrrole. *J. Nanomater.* 2008, 1–8. 10.1155/2008/782358
- Nadagouda MN, Varma RS, 2007 A Greener Synthesis of Core (Fe, Cu)-Shell (Au, Pt, Pd, and Ag) Nanocrystals Using Aqueous Vitamin C. *Cryst. Growth Des.* 7, 2582–2587.
- Nadagouda MN, Varma RS, 2006 Green and controlled synthesis of gold and platinum nanomaterials using vitamin B2: density-assisted self-assembly of nanospheres, wires and rods. *Green Chem.* 8, 516–518.
- Nadagouda MN, Varma RS, 2008 Green synthesis of silver and palladium nanoparticles at room temperature using coffee and tea extract. *Green Chem.* 10, 859–862.
- Naidu VGM, Madhusudhana K, Sashidhar RB, Ramakrishna S, Khar RK, Ahmed FJ, Diwan PV, 2009 Polyelectrolyte complexes of gum kondagogu and chitosan, as diclofenac carriers. *Carbohydr. Polym.* 76, 464–471.
- Nair AV, Raman M, Doble M, 2016 Cyclic β -(1→3) (1→6) glucan/carrageenan hydrogels for wound healing applications. *RSC Adv.* 6, 98545–98553.
- Navaladian S, Viswanathan B, Varadarajan TK, Viswanath RP, 2008 Microwave-assisted rapid synthesis of anisotropic Ag nanoparticles by solid state transformation. *Nanotechnology* 19, 45603.
- Neves SC, Gomes DB, Sousa A, Bidarra SJ, Petrini P, Moroni L, Barrias CC, Granja PL, 2015 Biofunctionalized pectin hydrogels as 3D cellular microenvironments. *J. Mater. Chem. B* 3, 2096–2108.
- Nguyen TTT, Chung OH, Park JS, 2011 Coaxial electrospun poly(lactic acid)/chitosan (core/shell) composite nanofibers and their antibacterial activity. *Carbohydr. Polym.* 86, 1799–1806.
- Nie H, He A, Zheng J, Xu S, Li J, Han CC, 2008 Effects of Chain Conformation and Entanglement on the Electrospinning of Pure Alginate. *Biomacromolecules* 9, 1362–1365. [PubMed: 18433165]

- Niknia N, Kadkhodae R, 2017 Gum tragacanth-polyvinyl alcohol cryogel and xerogel blends for oral delivery of silymarin: Structural characterization and mucoadhesive property. *Carbohydr. Polym.* 177, 315–323.
- Nishi KK, Jayakrishnan A, 2007 Self-gelling primaquine-gum Arabic conjugate: An injectable controlled delivery system for primaquine. *Biomacromolecules* 8, 84–90.
- Nista SVG, Bettini J, Mei LHI, 2015 Coaxial nanofibers of chitosan-alginate-PEO polycomplex obtained by electrospinning. *Carbohydr. Polym.* 127, 222–228.
- Nussinovitch A, 2010. Plant gum exudates of the world: sources, distribution, properties, and applications. CRC Press/Taylor & Francis, Boca Raton.
- Osman ME, Menzies AR, Martin BA, Williams PA, Phillips GO, Baldwin TC, 1995 Characterization of gum arabic fractions obtained by anion-exchange chromatography. *Phytochemistry* 38, 409–417.
- Osman ME, Menzies AR, Williams PA, Phillips GO, Baldwin TC, 1993a. The molecular characterisation of the polysaccharide gum from *Acacia senegal*. *Carbohydr. Res.* 246, 303–318.
- Osman ME, Williams PA, Menzies AR, Phillips GO, 1993b. Characterization of commercial samples of gum arabic. *J. Agric. Food Chem.* 41, 71–77.
- Padala SR, Williams PA, Phillips GO, 2009 Adsorption of Gum Arabic, Egg White Protein, and Their Mixtures at the Oil–Water Interface in Limonene Oil-in-Water Emulsions. *J. Agric. Food Chem.* 57, 4964–4973. [PubMed: 19422219]
- Padil VVT, erník M, 2015 Poly (vinyl alcohol)/gum karaya electrospun plasma treated membrane for the removal of nanoparticles (Au, Ag, Pt, CuO and Fe₃O₄) from aqueous solutions. *J. Hazard. Mater.* 287, 102–110.
- Padil VVT, Nguyen NHAA, Ro ek Z, Ševc A, erník M, 2015a. Synthesis, fabrication and antibacterial properties of a plasma modified electrospun membrane consisting of gum Kondagogu, dodecyl succinic anhydride and poly (vinyl alcohol). *Surf. Coatings Technol.* 271, 32–38.
- Padil VVT, Senan C, erník M, 2015b. Dodecylsuccinic anhydride derivatives of gum karaya (*Sterculia urens*): preparation, characterization, and their antibacterial properties. *J. Agric. Food Chem.* 63, 3757–3765. [PubMed: 25797306]
- Padil VVT, Senan C, Waclawek S, erník M, 2016 Electrospun fibers based on Arabic, karaya and kondagogu gums. *Int. J. Biol. Macromol.* 91, 299–309.
- Padil VVT, Stuchlík M, erník M, 2015c. Plasma modified nanofibres based on gum kondagogu and their use for collection of nanoparticulate silver, gold and platinum. *Carbohydr. Polym.* 121, 468–476.
- Padil Vinod VT, Waclawek S, Senan C, Kup ík J, Pešková K, erník M, Somashekarappa HM, 2017 Gum karaya (*Sterculia urens*) stabilized zero-valent iron nanoparticles: characterization and applications for the removal of chromium and volatile organic pollutants from water. *RSC Adv.* 7, 13997–14009.
- Pal P, Pandey JP, Sen G, 2017 Synthesis, characterization and flocculation studies of a novel graft copolymer towards destabilization of carbon nano-tubes from effluent. *Polymer (Guildf)*. 112, 159–168.
- Pal S, Patra AS, Ghorai S, Sarkar AK, Das R, Sarkar S, 2015 Modified guar gum/SiO₂: development and application of a novel hybrid nanocomposite as a flocculant for the treatment of wastewater. *Environ. Sci. Water Res. Technol.* 1, 84–95.
- Palaniraj A, Jayaraman V, 2011 Production, recovery and applications of xanthan gum by *Xanthomonas campestris*. *J. Food Eng.* 106, 1–12.
- Palma SICJ, Carvalho A, Silva J, Martins P, Marciello M, Fernandes AR, del Puerto Morales M, Roque ACA, 2015 Covalent coupling of gum arabic onto superparamagnetic iron oxide nanoparticles for MRI cell labeling: Physicochemical and in vitro characterization. *Contrast Media Mol. Imaging* 10, 320–328. [PubMed: 25766788]
- Pandey S, Goswami GK, Nanda KK, 2012 Green synthesis of biopolymer-silver nanoparticle nanocomposite: An optical sensor for ammonia detection. *Int. J. Biol. Macromol.* 51, 583–589. [PubMed: 22750580]

- Paul W, Sharma C, 2004 Chitosan and alginate wound dressings: a short review. *Trends Biomater Artif Organs* 18, 18–23.
- Pereao OK, Bode-Aluko C, Ndayambaje G, Fatoba O, Petrik LF, 2016 Electrospinning: Polymer Nanofibre Adsorbent Applications for Metal Ion Removal. *J. Polym. Environ.* 1–15. 10.1007/s10924-016-0896-y
- Petri DFS, 2015 Xanthan gum: A versatile biopolymer for biomedical and technological applications. *J. Appl. Polym. Sci.* 132, 42035.
- Peng S, Jin G, Li L, Li K, Srinivasan M, Ramakrishna S, 2016 Multi-functional electrospun nanofibres for advances in tissue regeneration, energy conversion & storage, and water treatment. *Chem. Soc. Rev.* 45, 1225–1241. [PubMed: 26727278]
- Philippe A, Schaumann GE, 2014 Interactions of Dissolved Organic Matter with Natural and Engineered Inorganic Colloids: A Review. *Environ. Sci. Technol.* 48, 8946–8962. [PubMed: 25082801]
- Philips GO, Williams PA, 2001 Tree exudates gums: Natural and versatile food additives and ingredients. *Food Ingredients Anal. Int.* 23, 26–28.
- Phillips GO, Williams PA, 2009. *Handbook of Hydrocolloids*. Woodhead Pub.
- Phillips GO, Williams PA, 2000. *Handbook of hydrocolloids*. CRC Press, Boca Raton, Fla.:
- Pinto VV, Ferreira MJ, Silva R, Santos HA, Silva F, Pereira CM, 2010 Long time effect on the stability of silver nanoparticles in aqueous medium: Effect of the synthesis and storage conditions. *Colloids Surfaces A Physicochem. Eng. Asp.* 364, 19–25.
- Pooja D, Panyaram S, Kulhari H, Reddy B, Rachamalla SS, Sistla R, 2015 Natural polysaccharide functionalized gold nanoparticles as biocompatible drug delivery carrier. *Int. J. Biol. Macromol.* 80, 48–56.
- Prado BM, Kim S, Özen BF, Mauer LJ, 2005 Differentiation of Carbohydrate Gums and Mixtures Using Fourier Transform Infrared Spectroscopy and Chemometrics. *J. Agric. Food Chem.* 53, 2823–2829. [PubMed: 15826025]
- Prajapati VD, Jani GK, Moradiya NG, Randeria NP, 2013 Pharmaceutical applications of various natural gums, mucilages and their modified forms. *Carbohydr. Polym.* 92, 1685–1699. [PubMed: 23399207]
- Prajapati VD, Jani GK, Moradiya NG, Randeria NP, Nagar BJ, Naikwadi NN, Variya BC, 2013 Galactomannan: A versatile biodegradable seed polysaccharide. *Int. J. Biol. Macromol.* 60, 83–92.
- Pramanik N, Mitra T, Khamrai M, Bhattacharyya A, Mukhopadhyay P, Gnanamani A, Basu RK, Kundu PP, 2015 Characterization and evaluation of curcumin loaded guar gum/polyhydroxyalkanoates blend films for wound healing applications. *RSC Adv.* 5, 63489–63501.
- Puskuri J, Katukam V, Sashidhar RB, 2017 Immunological evaluation of Gum kondagogu (*Cochlospermum gossypium*): A tree gum with potential applications in food and pharma industry. *Bioact. Carbohydrates Diet. Fibre* 11, 48–52.
- Qian Y, Qi M, Zheng L, King MW, Lv L, Ye F, 2016 Incorporation of rutin in electrospun pullulan/PVA nanofibers for novel UV-resistant properties. *Materials (Basel)*. 9, 504.
- Qiu H, Yan J, Lan G, Liu Y, Song X, Peng W, Cui Y, 2016 Removal of Cu 2+ from wastewater by modified xanthan gum (XG) with ethylenediamine (EDA). *RSC Adv.* 6, 83226–83233.
- Quintanilha RC, Orth ES, Grein-Iankovski A, Riegel-Vidotti IC, Vidotti M, 2014 The use of gum Arabic as “Green” stabilizer of poly(aniline) nanocomposites: A comprehensive study of spectroscopic, morphological and electrochemical properties. *J. Colloid Interface Sci.* 434, 18–27.
- Rafique A, Mahmood Zia K, Zuber M, Tabasum S, Rehman S, 2016 Chitosan functionalized poly(vinyl alcohol) for prospects biomedical and industrial applications: A review. *Int. J. Biol. Macromol.* 87, 141–154.
- Raguvaran R, Manuja BK, Chopra M, Thakur R, Anand T, Kalia A, Manuja A, 2017 Sodium alginate and gum acacia hydrogels of ZnO nanoparticles show wound healing effect on fibroblast cells. *Int. J. Biol. Macromol.* 96, 185–191.

- Raizaday A, Yadav HKS, Kumar SH, Kasina S, Navya M, Tashi C, 2015 Development of pH sensitive microparticles of Karaya gum: By response surface methodology. *Carbohydr. Polym.* 134, 353–363.
- Ramakrishna S, Fujihara K, Teo W-E, Lim T-C, Ma Z, 2005. An Introduction to Electrospinning and Nanofibers. World Scientific Publishing Company, Singapore 10.1142/5894
- Ramakrishna S, Jose R, Archana PS, Nair AS, Balamurugan R, Venugopal J, Teo WE, 2010 Science and engineering of electrospun nanofibers for advances in clean energy, water filtration, and regenerative medicine. *J. Mater. Sci.* 45, 6283–6312.
- Rana V, Rai P, Tiwary AK, Singh RS, Kennedy JF, Knill CJ, 2011 Modified gums: Approaches and applications in drug delivery. *Carbohydr. Polym.* 83, 1031–1047.
- Randall RC, Phillips GO, Williams PA, 1989 Fractionation and characterization of gum from *Acacia senegal*. *Food Hydrocoll.* 3, 65–75.
- Randall RC, Phillips GO, Williams PA, 1988 The role of the proteinaceous component on the emulsifying properties of gum arabic. *Food Hydrocoll.* 2, 131–140.
- Ranjbar-Mohammadi M, Bahrami SH, 2016 Electrospun curcumin loaded poly(ϵ -caprolactone)/gum tragacanth nanofibers for biomedical application. *Int. J. Biol. Macromol.* 84, 448–456.
- Ranjbar-Mohammadi M, Bahrami SH, 2015 Development of nanofibrous scaffolds containing gum tragacanth/poly (ϵ -caprolactone) for application as skin scaffolds. *Mater. Sci. Eng. C* 48, 71–79.
- Ranjbar-Mohammadi M, Bahrami SH, Joghataei MTT, 2013 Fabrication of novel nanofiber scaffolds from gum tragacanth/poly(vinyl alcohol) for wound dressing application: In vitro evaluation and antibacterial properties. *Mater. Sci. Eng. C* 33, 4935–4943.
- Ranjbar-Mohammadi M, Prabhakaran MP, Bahrami SH, Ramakrishna S, 2016a. Gum tragacanth/poly(L-lactic acid) nanofibrous scaffolds for application in regeneration of peripheral nerve damage. *Carbohydr. Polym.* 140, 104–112.
- Ranjbar-Mohammadi M, Rabbani S, Bahrami SH, Joghataei MT, Moayer F, 2016b. Antibacterial performance and in vivo diabetic wound healing of curcumin loaded gum tragacanth/poly(ϵ -caprolactone) electrospun nanofibers. *Mater. Sci. Eng. C* 69, 1183–1191.
- Ranjbar-Mohammadi M, Zamani M, Prabhakaran MPP, Bahrami SH, Ramakrishna S, 2016c. Electrospinning of PLGA/gum tragacanth nanofibers containing tetracycline hydrochloride for periodontal regeneration. *Mater. Sci. Eng. C* 58, 521–531.
- Rao K, Imran M, Jabri T, Ali I, Shafiullah Perveen, S., Ahmed S, Shah MR, 2017 Gum tragacanth stabilized green gold nanoparticles as cargos for Naringin loading: A morphological investigation through AFM. *Carbohydr. Polym.* 174, 243–252.
- Rao YN, Banerjee D, Datta A, Das SK, Guin R, Saha A, 2010 Gamma irradiation route to synthesis of highly re-dispersible natural polymer capped silver nanoparticles. *Radiat. Phys. Chem.* 79, 1240–1246.
- Rastogi L, Karunasagar D, Sashidhar RB, Giri A, 2017 Peroxidase-like activity of gum kondagogu reduced/stabilized palladium nanoparticles and its analytical application for colorimetric detection of glucose in biological samples. *Sensors Actuators B Chem.* 240, 1182–1188.
- Rastogi L, Kora AJ, Sashidhar RB, 2015 Antibacterial effects of gum kondagogu reduced/stabilized silver nanoparticles in combination with various antibiotics: a mechanistic approach. *Appl. Nanosci.* 5, 535–543.
- Rastogi L, Sashidhar RB, Karunasagar D, Arunachalam J, 2014 Gum kondagogu reduced/stabilized silver nanoparticles as direct colorimetric sensor for the sensitive detection of Hg²⁺ in aqueous system. *Talanta* 118, 111–117.
- Ratheesh G, Venugopal JR, Chinappan A, Ezhilarasu H, Sadiq A, Ramakrishna S, 2017 3D Fabrication of Polymeric Scaffolds for Regenerative Therapy. *ACS Biomater. Sci. Eng.* 3, 1175–1194.
- Rathore HS, Sarubala M, Ramanathan G, Singaravelu S, Raja MD, Gupta S, Sivagnanam UT, 2016 Fabrication of biomimetic porous novel sponge from gum kondagogu for wound dressing. *Mater. Lett.* 177, 108–111.
- Raveendran P, Fu J, Wallen SL, 2006 A simple and “green” method for the synthesis of Au, Ag, and Au–Ag alloy nanoparticles. *Green Chem.* 8, 34–38.
- Raveendran P, Fu J, Wallen SL, 2003 Completely “Green” Synthesis and Stabilization of Metal Nanoparticles. *J. Am. Chem. Soc.* 125, 13940–13941. [PubMed: 14611213]

- Reddy GB, Madhusudhan A, Ramakrishna D, Ayodhya D, Venkatesham M, Veerabhadram G, 2015 Green chemistry approach for the synthesis of gold nanoparticles with gum kondagogu: characterization, catalytic and antibacterial activity. *J. Nanostructure Chem.* 5, 185–193.
- Redgwell RJ, Schmitt C, Beaulieu M, Curti D, 2005 Hydrocolloids from coffee: Physicochemical and functional properties of an arabinogalactan-protein fraction from green beans. *Food Hydrocoll.* 19, 1005–1015.
- Reicha FM, Sarhan A, Abdel-Hamid MI, El-Sherbiny IM, 2012 Preparation of silver nanoparticles in the presence of chitosan by electrochemical method. *Carbohydr. Polym.* 89, 236–244.
- Reneker DH, Yarin AL, Zussman E, Xu H, 2007 Electrospinning of Nanofibers from Polymer Solutions and Melts. *Adv. Appl. Mech.* 41, 43–195.
- Rezaei A, Tavanai H, Nasirpour A, 2016 Fabrication of electrospun almond gum/PVA nanofibers as a thermostable delivery system for vanillin. *Int. J. Biol. Macromol.* 91, 536–543. [PubMed: 27267574]
- Rhein-Knudsen N, Ale MT, Meyer AS, 2015 Seaweed hydrocolloid production: An update on enzyme assisted extraction and modification technologies. *Mar. Drugs.* 13, 3340–3359. [PubMed: 26023840]
- Ribeiro de Barros H, Cardoso MB, Camargo de Oliveira C, Cavichiolo Franco CR, de Lima Belan D, Vidotti M, Riegel-Vidotti IC, 2016 Stability of gum arabic-gold nanoparticles in physiological simulated pHs and their selective effect on cell lines. *RSC Adv.* 6, 9411–9420.
- Rickerby DG, 2013 Sustainable Nanotechnology and the Environment: Advances and Achievements. ACS Symp. Ser., ACS Symposium Series. 10.1021/bk-2013-1124
- Riedo C, Scalarone D, Chiantore O, 2013 Multivariate analysis of pyrolysis-GC/MS data for identification of polysaccharide binding media. *Anal. Methods* 5, 4060–4067.
- Rocha I, Lucht E, Riegel-Vidotti IC, Vidotti M, Orth ES, 2014 Kinetic Approach to Elucidate Size Controllable Features in Nanocomposites of Gold Nanoparticles and Poly(3,4-ethylenedioxythiophene) in Aqueous Dispersion Stabilized by Gum Acacia. *J. Phys. Chem. C* 118, 25756–25764.
- Rockwell PL, Kiechel MA, Atchison JS, Toth LJ, Schauer CL, 2014 Various-sourced pectin and polyethylene oxide electrospun fibers. *Carbohydr. Polym.* 107, 110–118.
- Rodriguez E, Parsons JG, Peralta-Videa JR, Cruz-Jimenez G, Romero-Gonzalez J, Sanchez-Salcido BE, Saupe GB, Duarte-Gardea M, Gardea-Torresdey JL, 2007 Potential of *Chilopsis Linearis* for Gold Phytomining: Using Xas to Determine Gold Reduction and Nanoparticle Formation Within Plant Tissues. *Int. J. Phytoremediation* 9, 133–147. [PubMed: 18246721]
- Ryou M-H, Hong S, Winter M, Lee H, Choi JW, 2013 Improved cycle lives of LiMn₂O₄ cathodes in lithium ion batteries by an alginate biopolymer from seaweed. *J. Mater. Chem. A* 1, 15224–15229.
- Sadeghi S, Moghaddam AZ, Massinaei M, 2015 Novel tunable composites based on bentonite and modified tragacanth gum for removal of acid dyes from aqueous solutions. *RSC Adv.* 5, 55731–55745.
- Sadeghi S, Rad FA, Moghaddam AZ, 2014 A highly selective sorbent for removal of Cr(VI) from aqueous solutions based on Fe₃O₄/poly(methyl methacrylate) grafted Tragacanth gum nanocomposite: Optimization by experimental design. *Mater. Sci. Eng. C* 45, 136–145.
- Sahay R, Kumar PS, Sridhar R, Sundaramurthy J, Venugopal J, Mhaisalkar SG, Ramakrishna S, 2012 Electrospun composite nanofibers and their multifaceted applications. *J. Mater. Chem.* 22, 12953–12971.
- Sahraei R, Ghaemy M, 2017 Synthesis of modified gum tragacanth/graphene oxide composite hydrogel for heavy metal ions removal and preparation of silver nanocomposite for antibacterial activity. *Carbohydr. Polym.* 157, 823–833.
- Sahraei R, Sekhavat Pour Z, Ghaemy M, 2017 Novel magnetic bio-sorbent hydrogel beads based on modified gum tragacanth/graphene oxide: Removal of heavy metals and dyes from water. *J. Clean. Prod.* 142, 2973–2984.
- Samad YA, Asghar A, Hashaikh R, 2013 Electrospun cellulose/PEO fiber mats as a solid polymer electrolytes for Li ion batteries. *Renew. Energy* 56, 90–95.

- Sanchez C, Nigen M, Mejia Tamayo V, Doco T, Williams P, Amine C, Renard D, 2017 Acacia gum: History of the future. *Food Hydrocoll.* 10.1016/j.foodhyd.2017.04.008
- Sand A, Yadav M, Behari K, 2010 Graft copolymerization of 2-Acrylamidoglycolic acid on to xanthan gum and study of its physicochemical properties. *Carbohydr. Polym.* 81, 626–632.
- Saravanan P, Vinod VTP, Sreedhar B, Sashidhar RB, 2012 Gum kondagogu modified magnetic nano-adsorbent: An efficient protocol for removal of various toxic metal ions. *Mater. Sci. Eng. C* 32, 581–586.
- Sari-Chmaysssem N, Pessel F, Guégan JP, Taha S, Mawlawi H, Benvegnu T, 2016 Direct and one-pot conversion of polyguluronates and alginates into alkyl-L -guluronamide-based surfactant compositions. *Green Chem.* 18, 6573–6585.
- Sarika PR, James NR, Kumar PRA, Raj DK, Kumary TV, 2015 Gum arabic-curcumin conjugate micelles with enhanced loading for curcumin delivery to hepatocarcinoma cells. *Carbohydr. Polym.* 134, 167–174.
- Sarma TK, Chattopadhyay A, 2004 Starch-mediated shape-selective synthesis of Au nanoparticles with tunable longitudinal plasmon resonance. *Langmuir* 20, 3520–3524. [PubMed: 15875377]
- Sashidhar RB, Selvi SK, Vinod VTP, Kosuri T, Raju D, Karuna R, 2015 Bioprospecting of gum kondagogu (*Cochlospermum gossypium*) for bioremediation of uranium (VI) from aqueous solution and synthetic nuclear power reactor effluents. *J. Environ. Radioact.* 148, 33–41.
- Sathishkumar M, Sneha K, Yun Y, 2009 Palladium nanocrystal synthesis using *Curcuma longa* tuber extract. *Int. J. Mater. Sci.* 4, 521–527.
- Schiffman JD, Schauer CL, 2008 A Review: Electrospinning of Biopolymer Nanofibers and their Applications. *Polym. Rev.* 48, 317–352.
- Salehizadeh H, Yan N, Farnood R, 2018 Recent advances in polysaccharide bio-based flocculants, *Biotechnol. Adv.* 36, 92–119. [PubMed: 28993221]
- Seliktar D, 2012 Designing cell-compatible hydrogels for biomedical applications. *Science* (80-.). 336, 1124–1128.
- Sencadas V, Correia DM, Areias A, Botelho G, Fonseca AM, Neves IC, Gomez Ribelles JL, Lanceros Mendez S, 2012 Determination of the parameters affecting electrospun chitosan fiber size distribution and morphology. *Carbohydr. Polym.* 87, 1295–1301.
- Shah PS, Holmes JD, Doty RC, Johnston KP, Korgel BA, 2000 Steric stabilization of nanocrystals in supercritical CO₂ using fluorinated ligands. *J. Am. Chem. Soc.* 122, 4245–4246.
- Shalumon KT, Anulekha KH, Nair SV, Nair SV, Chennazhi KP, Jayakumar R, 2011 Sodium alginate/poly(vinyl alcohol)/nano ZnO composite nanofibers for antibacterial wound dressings. *Int. J. Biol. Macromol.* 49, 247–254. [PubMed: 21635916]
- Shankar SS, Ahmad A, Sastry M, 2003 Geranium Leaf Assisted Biosynthesis of Silver Nanoparticles. *Biotechnol. Prog.* 19, 1627–1631. [PubMed: 14656132]
- Shankar SS, Rai A, Ahmad A, Sastry M, 2004 Rapid synthesis of Au, Ag, and bimetallic Au core–Ag shell nanoparticles using *Neem* (*Azadirachta indica*) leaf broth. *J. Colloid Interface Sci.* 275, 496–502.
- Shankar SS, Rai A, Ankamwar B, Singh A, Ahmad A, Sastry M, 2004 Biological synthesis of triangular gold nanoprisms. *Nat. Mater.* 3, 482–488. [PubMed: 15208703]
- Sharma K, Kaith BS, Kumar V, Kalia S, Kumar V, Som S, Swart HC, 2014 Gum ghatti based novel electrically conductive biomaterials: A study of conductivity and surface morphology. *Express Polym. Lett.* 8, 267–281.
- Sharma K, Kaith BS, Kumar V, Kumar V, Som S, Kalia S, Swart HC, 2013 Synthesis and properties of poly(acrylamide-aniline)-grafted gum ghatti based nanospikes. *RSC Adv.* 3, 25830–25839.
- Sharma K, Kumar V, Kaith BS, Kumar V, Som S, Kalia S, Swart HC, 2014 A study of the biodegradation behaviour of poly(methacrylic acid/aniline)-grafted gum ghatti by a soil burial method. *RSC Adv.* 4, 25637–25649.
- Sharma K, Kumar V, Kaith BS, Kumar V, Som S, Pandey A, Kalia S, Swart HC, 2015a. Evaluation of a conducting interpenetrating network based on gum ghatti-g-poly(acrylic acid-aniline) as a colon-specific delivery system for amoxicillin trihydrate and paracetamol. *New J. Chem.* 39, 3021–3034.

- Sharma K, Kumar VV, Kaith BS, Som S, Kumar VV, Pandey A, Kalia S, Swart HC, 2015b. Synthesis of biodegradable Gum ghatti based poly(methacrylic acid-aniline) conducting IPN hydrogel for controlled release of amoxicillin trihydrate. *Ind. Eng. Chem. Res.* 54, 1982–1991.
- Sharma VK, Filip J, Zboril R, Varma RS, 2015 Natural inorganic nanoparticles – formation, fate, and toxicity in the environment. *Chem. Soc. Rev.* 44, 8410–8423. [PubMed: 26435358]
- Shekarforoush E, Faralli A, Ndoni S, Mendes AC, Chronakis IS, 2017 Electrospinning of Xanthan Polysaccharide. *Macromol. Mater. Eng.* 302, 1700067.
- Shenoy SL, Bates WD, Frisch HL, Wnek GE, 2005 Role of chain entanglements on fiber formation during electrospinning of polymer solutions: good solvent, non-specific polymer–polymer interaction limit. *Polymer (Guildf)*. 46, 3372–3384.
- Shukla SK, Shukla SK, Govender PP, Giri NG, 2016 Biodegradable polymeric nanostructures in therapeutic applications: opportunities and challenges. *RSC Adv.* 6, 94325–94351.
- Sill TJ, von Recum HA, 2008 Electrospinning: Applications in drug delivery and tissue engineering. *Biomaterials* 29, 1989–2006. [PubMed: 18281090]
- Silva SS, Mano JF, Reis RL, 2017 Ionic liquids in the processing and chemical modification of chitin and chitosan for biomedical applications. *Green Chem.* 19, 1208–1220.
- Simeonidis K, Mourdikoudis S, Kaprara E, Mittrakas M, Polavarapu L, 2016 Inorganic engineered nanoparticles in drinking water treatment: a critical review. *Environ. Sci. Water Res. Technol.* 2, 43–70.
- Singh A, Chaudhari M, Sastry M, 2006 Construction of conductive multilayer films of biogenic triangular gold nanoparticles and their application in chemical vapour sensing. *Nanotechnology* 17, 2399–2405.
- Singh B, Pal L, 2008 Development of sterculia gum based wound dressings for use in drug delivery. *Eur. Polym. J.* 44, 3222–3230.
- Singh B, Sharma N, 2008 Development of novel hydrogels by functionalization of sterculia gum for use in anti-ulcer drug delivery. *Carbohydr. Polym.* 74, 489–497.
- Singh B, Sharma S, Dhiman A, 2013 Design of antibiotic containing hydrogel wound dressings: Biomedical properties and histological study of wound healing. *Int. J. Pharm.* 457, 82–91.
- Singh B, Sharma V, 2017 Crosslinking of poly(vinylpyrrolidone)/acrylic acid with tragacanth gum for hydrogels formation for use in drug delivery applications. *Carbohydr. Polym.* 157, 185–195.
- Singh B, Sharma V, 2014a. Correlation study of structural parameters of bioadhesive polymers in designing a tunable drug delivery system. *Langmuir* 30, 8580–8591. [PubMed: 24963826]
- Singh B, Sharma V, 2014b. Influence of polymer network parameters of tragacanth gum-based pH responsive hydrogels on drug delivery. *Carbohydr. Polym.* 101, 928–940.
- Singh BN, Panda NN, Pramanik K, 2016 A novel electrospinning approach to fabricate high strength aqueous silk fibroin nanofibers. *Int. J. Biol. Macromol.* 87, 201–207.
- Singh DK, Verma DK, Singh Y, Hasan SH, 2017 Preparation of CuO nanoparticles using Tamarindus indica pulp extract for removal of As(III): Optimization of adsorption process by ANN-GA. *J. Environ. Chem. Eng.* 5, 1302–1318.
- Singh V, Kumari P, Pandey S, Narayan T, 2009 Removal of chromium (VI) using poly(methylacrylate) functionalized guar gum. *Bioresour. Technol.* 100, 1977–1982. [PubMed: 19056258]
- Sokolsky-Papkov M, Domb AJ, Golenser J, 2006 Impact of aldehyde content on amphotericin B - Dextran imine conjugate toxicity. *Biomacromolecules* 7, 1529–1535. [PubMed: 16677035]
- Song JE, Phenrat T, Marinakos S, Xiao Y, Liu J, Wiesner MR, Tilton RD, Lowry GV, 2011 Hydrophobic interactions increase attachment of gum arabic- and PVP-coated Ag nanoparticles to hydrophobic surfaces. *Environ. Sci. Technol.* 45, 5988–5995. [PubMed: 21692483]
- Song JY, Jang H-K, Kim BS, 2009 Biological synthesis of gold nanoparticles using Magnolia kobus and Diopyros kaki leaf extracts. *Process Biochem.* 44, 1133–1138.
- Sousa AMM, Souza HKS, Ukmalis J, Liu SC, Gonçalves MP, Liu L, 2015a. Electrospinning of agar/PVA aqueous solutions and its relation with rheological properties. *Carbohydr. Polym.* 115, 348–355.

- Sousa AMM, Souza HKS, Uknalis J, Liu SC, Gonçalves MP, Liu LS, 2015b. Improving agar electrospinnability with choline-based deep eutectic solvents. *Int. J. Biol. Macromol.* 80, 139–148. [PubMed: 26116384]
- Sridhar R, Lakshminarayanan R, Madhaiyan K, Amutha Barathi V, Lim KHC, Ramakrishna S, 2015 Electrospayed nanoparticles and electrospun nanofibers based on natural materials: applications in tissue regeneration, drug delivery and pharmaceuticals. *Chem Soc Rev.* 44, 790–814. [PubMed: 25408245]
- Stephen AM, Phillips GO, Williams PA, 2006. Food polysaccharides and their applications. CRC/ Taylor & Francis.
- Stevens LR, Gilmore KJ, Wallace GG, in het Panhuis M, 2016 Tissue engineering with gellan gum. *Biomater. Sci.* 4, 1276–1290. [PubMed: 27426524]
- Stone SA, Gosavi P, Athauda TJ, Ozer RR, 2013 In situ citric acid crosslinking of alginate/polyvinyl alcohol electrospun nanofibers. *Mater. Lett.* 112, 32–35.
- Tagad CK, Rajdeo KS, Kulkarni A, More P, Aiyer RC, Sabharwal S, 2014 Green synthesis of polysaccharide stabilized gold nanoparticles: chemo catalytic and room temperature operable vapor sensing application. *RSC Adv.* 4, 24014–24019.
- Takei T, Sato M, Ijima H, Kawakami K, 2010 In Situ Gellable Oxidized Citrus Pectin for Localized Delivery of Anticancer Drugs and Prevention of Homotypic Cancer Cell Aggregation. *Biomacromolecules* 11, 3525–3530. [PubMed: 21028797]
- Teo WE, Ramakrishna S, 2006 A review on electrospinning design and nanofibre assemblies. *Nanotechnology* 17, R89–R106. [PubMed: 19661572]
- Thakkar KN, Mhatre SS, Parikh RY, 2010 Biological synthesis of metallic nanoparticles. *Nanomedicine Nanotechnology, Biol. Med.* 6, 257–262.
- Thavasi V, Singh G, Ramakrishna S, 2008 Electrospun nanofibers in energy and environmental applications. *Energy Environ. Sci.* 1, 205–221.
- Thekkae Padil VV, ernik M, 2013 Green synthesis of copper oxide nanoparticles using gum karaya as a biotemplate and their antibacterial application. *Int. J. Nanomedicine* 8, 889–898. [PubMed: 23467397]
- Thomas V, Yallapu MM, Sreedhar B, Bajpai SK, 2007 A versatile strategy to fabricate hydrogel–silver nanocomposites and investigation of their antimicrobial activity. *J. Colloid Interface Sci.* 315, 389–395.
- Thompson CJ, Chase GG, Yarin AL, Reneker DH, 2007 Effects of parameters on nanofiber diameter determined from electrospinning model. *Polymer (Guildf).* 48, 6913–6922.
- Tian Y, Wu M, Liu R, Li Y, Wang D, Tan J, Wu R, Huang Y, 2011 Electrospun membrane of cellulose acetate for heavy metal ion adsorption in water treatment. *Carbohydr. Polym.* 83, 743–748.
- Tischer CA, Gorin PAJ, Iacomini M, 2002 The free reducing oligosaccharides of gum arabic: aids for structural assignments in the polysaccharide. *Carbohydr. Polym.* 47, 151–158.
- Tischer CA, Iacomini M, Gorin PAJ, 2002a. Structure of the arabinogalactan from gum tragacanth (*Astragalus gummifer*). *Carbohydr. Res.* 337, 1647–1655. [PubMed: 12423966]
- Tischer CA, Iacomini M, Wagner R, Gorin PA., 2002b. New structural features of the polysaccharide from gum ghatti (*Anogeissus latifolia*). *Carbohydr. Res.* 337, 2205–2210. [PubMed: 12433484]
- Torres-Giner S, Ocio MJ, Lagaron JM, 2008 Development of Active Antimicrobial Fiber-Based Chitosan Polysaccharide Nanostructures using Electrospinning. *Eng. Life Sci.* 8, 303–314.
- Toskas G, Hund R-D, Laourine E, Cherif C, Smyrniotopoulos V, Roussis V, 2011 Nanofibers based on polysaccharides from the green seaweed *Ulva Rigida*. *Carbohydr. Polym.* 84, 1093–1102.
- Tsai RY, Kuo TY, Hung SC, Lin CM, Hsien TY, Wang DM, Hsieh HJ, 2015 Use of gum arabic to improve the fabrication of chitosan-gelatin-based nanofibers for tissue engineering. *Carbohydr. Polym.* 115, 525–532.
- Tsui MTK, Cheung KC, Tam NFY, Wong MH, 2006 A comparative study on metal sorption by brown seaweed. *Chemosphere* 65, 51–57.
- Tuovinen LM, Peltonen SH, Suortti TM, Crowther NJ, Elomaa MA, Järvinen KP, 2002 Enzymatic degradation of and bovine serum albumin release from starch-acetate films. *Biomacromolecules* 3, 284–290. [PubMed: 11888313]

- Vaghela C, Kulkarni M, Karve M, Aiyer R, Haram S, 2014 Agarose–guar gum assisted synthesis of processable polyaniline composite: morphology and electro-responsive characteristics. *RSC Adv.* 4, 59716–59725.
- Varma AJ, Deshpande SV, Kennedy JF, 2004 Metal complexation by chitosan and its derivatives: A review. *Carbohydr. Polym.* 55, 77–93.
- Varma RS, 2016 Greener and sustainable trends in synthesis of organics and nanomaterials. *ACS Sustain. Chem. Eng.* 4, 5866–5878.
- Varma RS, 2014 Nano-catalysts with magnetic core: sustainable options for greener synthesis. *Sustain. Chem. Process.* 2, 1–8.
- Vashist A, Vashist A, Gupta YK, Ahmad S, 2014 Recent advances in hydrogel based drug delivery systems for the human body. *J. Mater. Chem. B* 2, 147–166.
- Vashisth P, Nikhil K, Roy P, Pruthi PA, Singh RP, Pruthi V, 2016 A novel gellan-PVA nanofibrous scaffold for skin tissue regeneration: Fabrication and characterization. *Carbohydr. Polym.* 136, 851–859.
- Vashisth P, Pruthi PA, Singh RP, Pruthi V, 2014 Process optimization for fabrication of gellan based electrospun nanofibers. *Carbohydr. Polym.* 109, 16–21.
- Vashisth P, Raghuwanshi N, Srivastava AK, Singh H, Nagar H, Pruthi V, 2017 Ofloxacin loaded gellan/PVA nanofibers - Synthesis, characterization and evaluation of their gastroretentive/mucoadhesive drug delivery potential. *Mater. Sci. Eng. C* 71, 611–619.
- Vegi GMN, Sistla R, Srinivasan P, Beedu SR, Khar RK, Diwan PV, 2009 Emulsifying properties of gum kondagogu (*Cochlospermum gossypium*), a natural biopolymer. *J. Sci. Food Agric.* 89, 1271–1276.
- Ventura MG, Paninho AI, Nunes AVM, Fonseca IM, Branco LC, 2015 Biocompatible locust bean gum mesoporous matrices prepared by ionic liquids and a scCO₂ sustainable system. *RSC Adv.* 5, 107700–107706.
- Venugopal J, Ramakrishna S, 2005 Applications of polymer nanofibers in biomedicine and biotechnology. *Appl. Biochem. Biotechnol.* 125, 147–158. [PubMed: 15917579]
- Verbeken D, Dierckx S, Dewettinck K, 2003 Exudate gums: occurrence, production, and applications. *Appl. Microbiol. Biotechnol.* 63, 10–21.
- Vigneshwaran N, Nachane RP, Balasubramanya RH, Varadarajan PV, 2006 A novel one-pot “green” synthesis of stable silver nanoparticles using soluble starch. *Carbohydr. Res.* 341, 2012–2018. [PubMed: 16716274]
- Vigneswaran S, Unesco, 2009. Water and wastewater treatment technologies; Vol. 1. EOLSS Publ.
- Vinod VTP, Saravanan P, Sreedhar B, Devi DK, Sashidhar RB, 2011a. A facile synthesis and characterization of Ag, Au and Pt nanoparticles using a natural hydrocolloid gum kondagogu (*Cochlospermum gossypium*). *Colloids Surfaces B Biointerfaces* 83, 291–298.
- Vinod VTP, Sashidhar RB, Sarma VUM, Vijaya Saradhi UVR, 2008a. Compositional Analysis and Rheological Properties of Gum Kondagogu (*Cochlospermum gossypium*): A Tree Gum from India. *J. Agric. Food Chem.* 56, 2199–2207. [PubMed: 18318494]
- Vinod VTP, Sashidhar RB, Sivaprasad N, Sarma VUM, Satyanarayana N, Kumaresan R, Rao TN, Raviprasad P, 2011b. Bioremediation of mercury (II) from aqueous solution by gum karaya (*Sterculia urens*): A natural hydrocolloid. *Desalination* 272, 270–277.
- Vinod VTP, Sashidhar RB, Sreedhar B, Rama Rao B, Nageswara Rao T, Abraham JT, 2009 Interaction of Pb²⁺ and Cd²⁺ with gum kondagogu (*Cochlospermum gossypium*): A natural carbohydrate polymer with biosorbent properties. *Carbohydr. Polym.* 78, 894–901.
- Vinod VTP, Sashidhar RB, Sukumar AA, 2010a. Competitive adsorption of toxic heavy metal contaminants by gum kondagogu (*Cochlospermum gossypium*): A natural hydrocolloid. *Colloids Surfaces B Biointerfaces* 75, 490–495.
- Vinod VTP, Sashidhar RB, Suresh KI, Rama Rao B, Vijaya Saradhi UVR, Prabhakar Rao T, 2008b Morphological, physico-chemical and structural characterization of gum kondagogu (*Cochlospermum gossypium*): A tree gum from India. *Food Hydrocoll.* 22, 899–915.
- Vinod VTP, Sashidhar RBB, Sarma VUMUM, Raju SS, 2010 Comparative amino acid and fatty acid compositions of edible gums kondagogu (*Cochlospermum gossypium*) and karaya (*Sterculia urens*). *Food Chem.* 123, 57–62.

- Vinod VTP, Sashidhar RBB, Sreedhar B, 2010b. Biosorption of nickel and total chromium from aqueous solution by gum kondagogu (*Cochlospermum gossypium*): A carbohydrate biopolymer. *J. Hazard. Mater.* 178, 851–860.
- Virkutyte J, Varma RS, 2011 Green synthesis of metal nanoparticles: Biodegradable polymers and enzymes in stabilization and surface functionalization. *Chem. Sci.* 2, 837–846.
- Viswanathan G, Murugesan S, Pushparaj V, Nalamasu O, Ajayan PM, Linhardt RJ, 2006 Preparation of biopolymer fibers by electrospinning from room temperature ionic liquids. *Biomacromolecules* 7, 415–418. [PubMed: 16471910]
- Volesky B, 2007 Biosorption and me. *Water Res.* 41, 4017–4029. [PubMed: 17632204]
- Wacławek S, Lutze HV, Grübel K, Padil VVT, erník M, Dionysiou DD, 2017 Chemistry of persulfates in water and wastewater treatment: A review. *Chem. Eng. J.* 330, 44–62.
- Wang AJ, Liao QC, Feng JJ, Zhang PP, Li AQ, Wang JJ, 2012 Apple pectin-mediated green synthesis of hollow double-caged peanut-like ZnO hierarchical superstructures and photocatalytic applications. *CrystEngComm* 14, 256–263.
- Wang H-S, Fu G-D, Li X-S, 2009 Functional Polymeric Nanofibers from Electrospinning. *Recent Pat. Nanotechnol.* 3, 21–31. [PubMed: 19149752]
- Wang H, Halas NJ, 2008 Mesoscopic Au “Meatball” Particles. *Adv. Mater.* 20, 820–825.
- Wang H, Zhang Y, Shao H, Hu X, 2005 Electrospun ultra-fine silk fibroin fibers from aqueous solutions. *J. Mater. Sci.* 40, 5359–5363.
- Wang J, Pan K, He Q, Cao B, 2013 Polyacrylonitrile/polypyrrole core/shell nanofiber mat for the removal of hexavalent chromium from aqueous solution. *J. Hazard. Mater.* 244–245, 121–129.
- Wang L, Imura M, Yamauchi Y, 2012a. Tailored synthesis of various Au nanoarchitectures with branched shapes. *CrystEngComm* 14, 7594–7599.
- Wang L, Liu C-H, Nemoto Y, Fukata N, Wu KC-W, Yamauchi Y, 2012b. Rapid synthesis of biocompatible gold nanoflowers with tailored surface textures with the assistance of amino acid molecules. *RSC Adv.* 2, 4608–4611.
- Webb K, Hlady V, Tresco PA, 1998 Relative importance of surface wettability and charged functional groups on NIH 3T3 fibroblast attachment, spreading, and cytoskeletal organization. *J. Biomed. Mater. Res.* 41, 422–430.
- Wei J, Wang J, Su S, Wang S, Qiu J, Zhang Z, Christopher G, Ning F, Cong W, 2015 3D printing of an extremely tough hydrogel. *RSC Adv.* 5, 81324–81329.
- Weiping W, 2000. Tragacanth and karaya., in: *Handbook of Hydrocolloids*. Woodhead Publishing Ltd, pp. 231–246.
- Wen P, Wen Y, Zong MH, Linhardt RJ, Wu H, 2017 Encapsulation of Bioactive Compound in Electrospun Fibers and Its Potential Application. *J. Agric. Food Chem.* 65, 9161–9179. [PubMed: 28949530]
- Whistler RL, BeMiller JN, 1993. *Industrial gums: polysaccharides and their derivatives*. Academic Press.
- Williams PA, Kean T, Thanou M, 2011. *Renewable Resources for Functional Polymers and Biomaterials*, RSC Polymer Chemistry Series. Royal Society of Chemistry, Cambridge 10.1039/9781849733519
- Woehl MA, Ono L, Riegel Vidotti IC, Wypych F, Schreiner WH, Sierakowski MR, 2014 Bioactive nanocomposites of bacterial cellulose and natural hydrocolloids. *J. Mater. Chem. B* 2, 7034–7044.
- Wongsasulak S, Patapeejumruswong M, Weiss J, Supaphol P, Yoovidhya T, 2010 Electrospinning of food-grade nanofibers from cellulose acetate and egg albumen blends. *J. Food Eng.* 98, 370–376.
- Wu C-CC, Chen D-HH, 2012 Spontaneous synthesis of gold nanoparticles on gum arabic-modified iron oxide nanoparticles as a magnetically recoverable nanocatalyst. *Nanoscale Res. Lett.* 7, 317. [PubMed: 22713480]
- Xhanari K, Finšgar M, Knez Hrni M, Maver U, Knez Ž, Seiti B, 2017 Green corrosion inhibitors for aluminium and its alloys: a review. *RSC Adv.* 7, 27299–27330.

- Xu L, Sitinamaluwa H, Li H, Qiu J, Wang Y, Yan C, Li H, Yuan S, Zhang S, 2017 Low cost and green preparation process for α -Fe₂O₃@gum arabic electrode for high performance sodium ion batteries. *J. Mater. Chem. A* 5, 2102–2109.
- Xue Z, Zhang W, Yan M, Liu J, Wang B, Xia Y, 2017 Pyrolysis products and thermal degradation mechanism of intrinsically flame-retardant carrageenan fiber. *RSC Adv.* 7, 25253–25264. 10.1039/C7RA01076A
- Yan G, Viraraghavan T, 2001 Heavy metal removal in a biosorption column by immobilized *M. rouxii* biomass. *Bioresour. Technol.* 78, 243–249.
- Yan H, Yang L, Yang Z, Yang H, Li A, Cheng R, 2012 Preparation of chitosan/poly(acrylic acid) magnetic composite microspheres and applications in the removal of copper(II) ions from aqueous solutions. *J. Hazard. Mater.* 229–230, 371–80.
- Yang H, Gao PF, Wu WB, Yang XX, Zeng QL, Li C, Huang CZ, 2014 Antibacterials loaded electrospun composite nanofibers: release profile and sustained antibacterial efficacy. *Polym. Chem.* 5, 1965–1975.
- Yang J, Pan J, 2012 Hydrothermal synthesis of silver nanoparticles by sodium alginate and their applications in surface-enhanced Raman scattering and catalysis. *Acta Mater.* 60, 4753–4758.
- Yoon K, Hsiao BS, Chu B, 2008 Functional nanofibers for environmental applications. *J. Mater. Chem.* 18, 5326–5334.
- Yu JH, Fridrikh SV, Rutledge GC, 2006 The role of elasticity in the formation of electrospun fibers. *Polymer (Guildf)*. 47, 4789–4797.
- Zarekhalili Z, Bahrami SH, Ranjbar-Mohammadi M, Milan PB, 2017 Fabrication and characterization of PVA/Gum tragacanth/PCL hybrid nanofibrous scaffolds for skin substitutes. *Int. J. Biol. Macromol.* 94, 679–690.
- Zhang D, Chen L, Zang C, Chen Y, Lin H, 2013 Antibacterial cotton fabric grafted with silver nanoparticles and its excellent laundering durability. *Carbohydr. Polym.* 92, 2088–2094. [PubMed: 23399262]
- Zhang Q, De Oliveira Vigier K, Royer S, Jérôme F, 2012 Deep eutectic solvents: syntheses, properties and applications. *Chem. Soc. Rev.* 41, 7108–7146. [PubMed: 22806597]
- Zhao R, Li X, Sun B, Zhang Y, Zhang D, Tang Z, Chen X, Wang C, 2014 Electrospun chitosan/sericin composite nanofibers with antibacterial property as potential wound dressings. *Int. J. Biol. Macromol.* 68, 92–97.
- Zhao X, Xia Y, Li Q, Ma X, Quan F, Geng C, Han Z, 2014 Microwave-assisted synthesis of silver nanoparticles using sodium alginate and their antibacterial activity. *Colloids Surfaces A Physicochem. Eng. Asp.* 444, 180–188.
- Zheng K, Setyawati MI, Leong DT, Xie J, 2018 Antimicrobial silver nanomaterials. *Coord. Chem. Rev.* 357, 1–17.
- Zhou K, Kang M, He X, Hong Z, Huang Z, Wei M, 2017 A multi-functional gum arabic binder for NiFe₂O₄ nanotube anodes enabling excellent Li/Na-ion storage performance. *J. Mater. Chem. A* 5, 18138–18147.
- Zhou Y, Yang H, Liu X, Mao J, Gu S, Xu W, 2013 Electrospinning of carboxyethyl chitosan/poly(vinyl alcohol)/silk fibroin nanoparticles for wound dressings. *Int. J. Biol. Macromol.* 53, 88–92.
- Zia KM, Tabasum S, Nasif M, Sultan N, Aslam N, Noreen A, Zuber M, 2017 A review on synthesis, properties and applications of natural polymer based carrageenan blends and composites. *Int. J. Biol. Macromol.* 96, 282–301.

Research Highlights

- The most relevant industrial tree gums and their physical and chemical properties, structural assignments and non-food applications are discussed.
- Greener synthesis and production of NPs (nanoparticles) and NFs (nanofibers) using tree gums are illustrated.
- The interactions of metal species, dyes and NPs with gum structures are summarized.
- Antibacterial and biomedical applications of gums with NPs, NFs and hydrogels are reviewed.

Fig. 1:
Potential applications of NPs and NFs derived from processes based on tree gums.

Fig. 2:
The morphological and sugar constituents of GA, GK, GT, KG and GG.

Fig. 3:
Schematic representation of the production of NPs using gum solutions and their characterization.

Fig. 4: Schematic representation of (a) Au NP formation with distinct shapes (cauliflower, raspberry, urchin, and confeito, respectively) via sonication, employing GA as a capping agent and catechol and ascorbic acid (reductants). Reproduced with the permission of ref (Wang et al., 2012), Copyright © 2012, The Royal Society of Chemistry and (b) striking color variation of the PEDOT-Au NPs prepared using GA as a stabilizer. Reprinted with the permission of ref (Rocha et al., 2014), Copyright © 2014, American Chemical Society.

Fig. 5: GA stabilized (a) Se NPs (TEM image); (b) HRTEM images of SeNPs; (c) and (d) aggregated Se NPs without GA as a stabilizer; (e) GA- Ag NPs formed by radiolysis; and (f) Pd NPs capped GA by thermal processes, and inset picture, selected area of electron diffraction pattern. Reprinted with the permission (a, b, c, & d) of ref. (Kong et al., 2014) and (e) ref. (Rao et al., 2010), Copyright © 2014, Academic Press Inc. Elsevier Science and (f) ref. (Devi et al., 2011), John Wiley & Sons.

Fig. 6: Representative TEM images of NPs created and stabilized by KG (a) Ag NPs; (b) Pt NPs; (c) Au NPs via hydrothermal synthesis and (d) CuO synthesized by GK (e) ZVI protected by a GK structure; (f) HRTEM images of ZVI (zerovalent iron) NPs produced by GK; (g) depiction of steric stabilization mechanism for ZVI NPs and (h) the core of ZVI surrounded by a GK network structure (Vinod et al., 2011). Reproduced with permission Copyright © 2011, Academic Press Inc. Elsevier Science and reproduced from ref. (Vinod et al., 2017) with the permission of RSC.

Fig. 7: Morphological characterizations of electrospun fibers of PVA-GA (left), PVA-GK (center) and PVA-KG (right) with varying PVA-gum proportions (50:50 to 100:0). Reproduced with the permission of ref. (Padil et al., 2016)

Fig. 8:
Schematic presentation of toxic metal adsorption onto gum structures (right) and gum electrospun membranes (left).

Fig. 9:
Application of electrospun membranes for the extraction of NPs from water.

Table 1:
Comparison of sources, functional properties and commercial applications of various gum hydrocolloids

Gum Hydrocolloids	Source	Functional properties (Food applications)	Non-food applications of gum derivatives and composites
Guar gum	Seed of guar beans	Thickener, stabilizer, emulsifier and firming agent (Prado et al., 2005; Vipul D. Prajapati et al., 2013)	<ul style="list-style-type: none"> - electrochemical and biosensor (Vaghela et al., 2014) - NP stabilizing agent/antibacterial and antioxidant (Das et al., 2015) - wound healing (Pramanik et al., 2015) - nano-catalysis (Kumar et al., 2012) - hybrid nano-composite for water purification (Pal et al., 2015)
Locust bean gum	Carob tree seeds	Thixotropic, binder, stabilizer, gelling agent, lubricator (Prado et al., 2005; Vipul D. Prajapati et al., 2013)	<ul style="list-style-type: none"> - mesoporous gel matrices (Ventura et al., 2015) - wound healing (Murali et al., 2016b) - Au NPs synthesis and ethanol sensing (Tagad et al., 2014) - binders for lithium-ion batteries (Duffrey et al., 2015)
Pectin	plant cell wall (citrus, apple and sugar beet)	Thickener, stabilizer, gelling agent, emulsifier (Williams et al., 2011)	<ul style="list-style-type: none"> - cell delivery (Munarin et al., 2012) - tissue engineering and regenerative medicine (Neves et al., 2015) - Cr (VI) removal from contaminated water (Chen et al., 2015) - removal of cationic and anionic dyes (Attallah et al., 2016) - photocatalytic applications (A. J. Wang et al., 2012)
Agar	Red seaweeds (<i>Gelidium</i> species)	Thickener, stabilizer, gelling agent (Williams et al., 2011)	<ul style="list-style-type: none"> - growth media for culturing bacteria and pharmaceuticals (Rhein-Knudsen et al., 2015) - electrospun composite fibers for controlled drug release (Yang et al., 2014) - hydrogels with self-healing properties and high toughness (Xuefeng Li et al., 2017)
Alginate	Brown seaweeds (<i>Macrocystis</i> , <i>Ascophyllum</i> , <i>Laminaria</i> and <i>Ecklonia</i> species)	Thickening agent, stabilizer (Williams et al., 2011)	<ul style="list-style-type: none"> - wound dressings, encapsulate and/or release cells and medicine (Finotelli et al., 2010; Leslie et al., 2013; Paul and Sharma, 2004) - metal adsorption (Thomas A. Davis et al., 2003) - 3D printing (Wei et al., 2015) - bio-based materials with excellent fire retardancy (Liu et al., 2015) - improved lifecycle of LiMn2O4 cathodes in lithium ion batteries (Ryou et al., 2013) - bio-based surfactants (Sari-Chmayssem et al., 2016)
Carrageenan	Red seaweeds (<i>Gracilaria</i> , <i>Gigartina</i> and <i>Eucheuma</i> species)	Thickener, gelling agent, stabilizer, emulsifier (Williams et al., 2011)	<ul style="list-style-type: none"> - drug delivery, microcapsules and microspheres (Li et al., 2014) - binders (Williams et al., 2011; Zia et al., 2017) - nanocomposite for photodegradation of dyes (Chaudhary et al., 2016) - flame-retardant (Xue et al., 2017) - hydrogel for wound healing (Nair et al., 2016)
Xanthan gum	Xanthomonas campestris bacterium	Thickener, stabilizer, emulsifier and forming agent (Palaniraj and Jayaraman, 2011; Williams et al., 2011)	<ul style="list-style-type: none"> - functional ionic liquid-gel and hydrogel (Izawa and Kadokawa, 2010) - metal ion removal from wastewater (Qiu et al., 2016) - agricultural chemicals (Flickinger, 2010) - water based paints (Flickinger, 2010) - textile and carpet printing (Flickinger, 2010) - adhesives (Flickinger, 2010) - paper industry (Flickinger, 2010) - ceramic glazes (Flickinger, 2010) - enhanced oil recovery (Katzbauer, 1998) - carriers for drugs and proteins and as scaffolds for cells (Petri, 2015)
Gellan gum	<i>Pseudomonas elodea</i>	Emulsifier, stabilizer, and thickener (Williams et al., 2011)	<ul style="list-style-type: none"> - regenerative medicine and tissue engineering (Bacelar et al., 2016; Stevens et al., 2016) - conducting bio-materials (Ferris and in het Panhuis, 2009) - conducting hydrogels for edible electrodes (Keller et al., 2017)

Gum Hydrocolloids	Source	Functional properties (Food applications)	Non-food applications of gum derivatives and composites
Gum arabic (GA)	<i>Acacia senegal</i> and <i>Acacia seyal</i>	Emulsifier, stabilizer, and thickener (Sanchez et al., 2017; Williams et al., 2011)	<ul style="list-style-type: none"> - silver nanoparticle dispersions and hydrogels (Dhar et al., 2012) - biosensing (Hungerford et al., 2012) - stabilization of single walled carbon nanotubes (Bandyopadhyaya et al., 2002; X. Li et al., 2017) - encapsulating matrix (Augustin and Hemar, 2009; Bosnea et al., 2017) - stabilizing agent for NPs (Ribeiro de Barros et al., 2016) - branched Au architectures with well-defined shapes (Wang et al., 2012a) - biocompatible gold nanoflowers (Wang et al., 2012b) - multi-functional binder for the fabrication of NiFe₂O₄ nanotube electrodes (Zhou et al., 2017) - binder in water-based electrode fabrication processes (Xu et al., 2017) - green corrosion inhibitors (Xhanari et al., 2017) - exfoliation and fabrication of Ag-graphene-based hybrids (Fan et al., 2012) - high yield production and purification of graphene layer (Chabot et al., 2013)
Gum Ghatti (GG)	<i>Anogeissus latifolia</i>	Thickener, stabilizer, emulsifier (Deshmukh et al., 2012; Williams et al., 2011)	<ul style="list-style-type: none"> - electrically conductive biomaterials (Sharma et al., 2014) - interpenetrating network (IPN) hydrogel (Sharma et al., 2015b) - electrically conductive hydrogel (Kashma Sharma et al., 2014) - colon-specific drug delivery systems based cross-linked hydrogels (Sharma et al., 2015a) - remediation of industrial wastewater polluted by metal ions (Hemant Mittal et al., 2015b)
Gum karaya (GK)	<i>Sterculia</i> species (<i>urens</i> , <i>villosa</i> , <i>setigera</i>)	Emulsifier, stabilizer and thickening agent (Nussinovitch, 2010; Williams et al., 2011)	<ul style="list-style-type: none"> - binder for silicon-based anodes in lithium-ion batteries (Bie et al., 2017) - nanocomposite hydrogels for the removal of cationic dyes (Kumar et al., 2016) - metal ions removal (Jakóbk-Kolon et al., 2017) - wound dressing (Singh and Pal, 2008)
Tragacanth gum (GT)	<i>Astragalus</i> species, microcephalus, <i>gummifer kurdicus</i>)	Acid stable (Nussinovitch, 2010; Williams et al., 2011) Bifunctional emulsifier (Nussinovitch, 2010) Creamy texture pseudo plastic (Nussinovitch, 2010) Film former (Nussinovitch, 2010) Adhesive (Nussinovitch, 2010; Williams et al., 2011) Thickener (Nussinovitch, 2010; Williams et al., 2011) suspending agent (Nussinovitch, 2010; Williams et al., 2011)	<ul style="list-style-type: none"> - tunable drug delivery system (Singh and Sharma, 2014a) - cryogel and xerogel blends (Niknia and Kadkhodae, 2017) - hydrogels in drug delivery applications (Singh and Sharma, 2017) - microencapsulation (Asgari-Varzaneh et al., 2017) - hydrogel nanocomposite for removal of heavy metal (Mallakpour et al., 2018) - bioplastics (López-Castejón et al., 2016) - edible blend films and coatings (Mostafavi et al., 2016)
Kondagogu Gum (KG)	<i>Sterculia</i> species (<i>Cochlospermum</i> <i>gossypium</i>)	Emulsifier, thickening agent and stabilizer (Nussinovitch, 2010; Puskuri et al., 2017)	<ul style="list-style-type: none"> - biosensor (Rastogi et al., 2017) - food and medical industries (Puskuri et al., 2017) - wound dressing (Rathore et al., 2016) - bio-sorbent for environmental contaminants (Rastogi et al., 2014; Saravanan et al., 2012) - photocatalytic, fluorescence and antimicrobial activities (Dasari and Guttena, 2016)

Table 2:

Analytical data of important tree gums

Parameter	GA	GT	GK	GG	KG	References
Moisture (g%)	12.5–16.0	9.9 – 12.7	17	14	15.2	(Anderson and Weiping, 1992; Balaghi et al., 2011; Davidson, 1980; Gavligi et al., 2013a, 2013b; Glicksman, 1982; Janaki and Sashidhar, 1998; Kang et al., 2015a; Katayama et al., 2008; Mahendran et al., 2008; Phillips and Williams, 2000; Tischer et al., 2002a; Verbeke et al., 2003; Vinod et al., 2010; Vinod et al., 2008a, 2008b)
Total ash (g%)	4.1	2.9 – 3.2	7	6	7.3	(Anderson and Weiping, 1992; Balaghi et al., 2011; Brito et al., 2004; Davidson, 1980; de Brito et al., 2005; Gavligi et al., 2013a, 2013b; Glicksman, 1982; Hall, 2009; Janaki and Sashidhar, 1998; Kang et al., 2012a; Katayama et al., 2008; Le Cerf et al., 1990; Mahendran et al., 2008; Phillips and Williams, 2000; Stephen et al., 2006; Cesar A Tischer et al., 2002a; Verbeke et al., 2003; Vinod et al., 2010; Vinod et al., 2008a, 2008b; Whistler and BeMiller, 1993)
Nitrogen (g%)	0.22–0.39	0.46 – 0.58	0.08 – 0.68	Not defined	Not defined	(Anderson et al., 1985a, 1983; Balaghi et al., 2011; Brito et al., 2004; de Brito et al., 2005; Gavligi et al., 2013a, 2013b; Hall, 2009; Le Cerf et al., 1990; Mahendran et al., 2008; Phillips and Williams, 2000; Stephen et al., 2006; Tischer et al., 2002a; Verbeke et al., 2003; Whistler and BeMiller, 1993)
Protein (g%)	1.5 – 2.6	2.84 – 3.65	0.3	Not defined	6.3	(Anderson et al., 1985a, 1983; Balaghi et al., 2011; Brito et al., 2004; de Brito et al., 2005; Gavligi et al., 2013a, 2013b; Hall, 2009; Janaki and Sashidhar, 1998; Le Cerf et al., 1990; Mahendran et al., 2008; Phillips and Williams, 2000; Stephen et al., 2006; Tischer et al., 2002a; Verbeke et al., 2003; Vinod et al., 2010; Vinod et al., 2008a, 2008b; Whistler and BeMiller, 1993)
Acetyl content (g%)	Not defined	Not defined	8	Not defined	12	(Bruto et al., 2004; de Brito et al., 2005; Hall, 2009; Janaki and Sashidhar, 1998; Le Cerf et al., 1990; Stephen et al., 2006; Verbeke et al., 2003; Vinod et al., 2010; Vinod et al., 2008a, 2008b; Whistler and BeMiller, 1993)
Molecular mass (Da)	1.0×10^5	1.6×10^6	$2 - 5 \times 10^6$	8.9×10^7	1.1×10^6	(Balaghi et al., 2011; Castellani et al., 2010; Deshmukh et al., 2012; Gavligi et al., 2013a, 2013b; Ido et al., 2008; Katayama et al., 2008; Mahendran et al., 2008; Osman et al., 1995, 1993a, 1993b; Padala et al., 2009; Padil et al., 2016, 2015a, 2015b; Phillips and Williams, 2000; Randall et al., 1988; C.A. Tischer et al., 2002; Tischer et al., 2002a; Verbeke et al., 2003; Vinod et al., 2008a, 2008b)
Viscosity (dL/g)	13.2	25.9	27.9	Not defined	32.6	(Anderson et al., 1985a, 1983; Balaghi et al., 2011; Brito et al., 2004; de Brito et al., 2005; Gavligi et al., 2013a, 2013b; Hall, 2009; Janaki and Sashidhar, 1998; Le Cerf et al., 1990; Mahendran et al., 2008; Phillips and Williams, 2000; Stephen et al., 2006; Tischer et al., 2002a; Verbeke et al., 2003; Vinod et al., 2010; Vinod et al., 2008a, 2008b; Whistler and BeMiller, 1993)
pH	5.0±0.3	5.2±0.3	4.8±0.1	4.8±0.1	4.9 – 5.0	(Anderson et al., 1985a, 1983; Balaghi et al., 2011; Brito et al., 2004; de Brito et al., 2005; Gavligi et al., 2013a, 2013b; Janaki and Sashidhar, 1998; Le Cerf et al., 1990; Mahendran et al., 2008; Phillips and Williams, 2000; Stephen et al., 2006; Tischer et al., 2002a; Vinod et al., 2008b; Whistler and BeMiller, 1993)
Sugar composition (mol %)						
Galactose	39 – 42	14 – 23	13 – 26	29	18.90	(Anderson and Weiping, 1992; Janaki and Sashidhar, 1998; Mahendran et al., 2008; Phillips and Williams, 2000; Verbeke et al., 2003; Vinod et al., 2010; Vinod et al., 2008a)
Arabinose	24 – 27	37 – 63	49	48	2.5	(Anderson and Weiping, 1992; Janaki and Sashidhar, 1998; Mahendran et al., 2008; Phillips and Williams, 2000; Verbeke et al., 2003; Vinod et al., 2010; Vinod et al., 2008a)

Parameter	GA	GT	GK	GG	KG	References
Rhamnose	12 –16	4.0	15 – 30	6.0	12.8	(Anderson and Weiping, 1992; Janaki and Sashidhar, 1998; Mahendran et al., 2008; Phillips and Williams, 2000; Verbeken et al., 2003; Vinod et al., 2010; Vinod et al., 2008a)
Mannose	Not defined	Not defined	10.0	Not defined	8.3	(Janaki and Sashidhar, 1998; Vinod et al., 2010; Vinod et al., 2008a, 2008b)
Glucose	Not defined	Not defined	Not defined	Not defined	7.84	(Janaki and Sashidhar, 1998; Vinod et al., 2010; Vinod et al., 2008a, 2008b)
Glucuronic acid	15 – 16	3 – 12	110.0	10.0	16.2	(Anderson et al., 1985a, 1983; Balaghi et al., 2011; Brito et al., 2004; de Brito et al., 2005; Gavlight et al., 2013a, 2013b; Hall, 2009; Janaki and Sashidhar, 1998; Le Cerf et al., 1990; Mahendran et al., 2008; Phillips and Williams, 2000; Stephen et al., 2006; Tischer et al., 2002a; Verbeken et al., 2003; Vinod et al., 2010; Vinod et al., 2008a, 2008b; Whistler and BeMiller, 1993)
Galacturonic acid	Not defined	3 – 11	15– 28	Not defined	10.5	(Janaki and Sashidhar, 1998; Vinod et al., 2010; Vinod et al., 2008a, 2008b)

Table 3: Electrospinning of commercial polysaccharides and their comparison with tree gum hydrocolloids

Commercial polysaccharides	Gum hydrocolloids with other carriers (polymers/solvents) for electrospinning	Emerging applications	References
Guar gum	Water	Not defined	(Lubambo et al., 2013)
	PVA/water	Biomedical	(Lubambo et al., 2015)
Alginate	PVA/water	Antimicrobial wound dressings and tissue engineering	(Fu et al., 2016)
	Chitosan/ glycerol /acetic acid/ water	Tissue antiadhesion barrier	(Chang et al., 2012)
	Glycerol	Not defined	(Nie et al., 2008)
	Polyethylene oxide (PEO)/ Triton	Not defined	(Bonino et al., 2011)
	Poly(vinyl alcohol) (PVA)/ water	Not defined	(Islam and Karim, 2010)
	PVA / citric acid	Not defined	(Stone et al., 2013)
	Sodium alginate/PVA/nano ZnO	Antibacterial wound dressings	(Shalumon et al., 2011)
Pullulan	Chitosan/PEO/ water/ 5% ethanol	Not defined	(Nista et al., 2015)
	Cellulose acetate/ DMF/ DMSO	skin or bone tissue engineering scaffolds	(Atila et al., 2015)
	Whey protein / phosphate-buffer	Encapsulation of Bifidobacterium strains for functional foods	(López-Rubio et al., 2012)
	DMSO	Not defined	(Kong and Ziegler, 2014)
	PVA/water	Distribution of bioactive compounds	(Islam et al., 2012; Qian et al., 2016)
Almond gum	PVA/water	Thermostable delivery system for vanillin	(Rezaei et al., 2016)
Pectin	PEO/water	Biomedical, electrochemical devices, and drug delivery systems	(Cui et al., 2016; Rockwell et al., 2014)
	Chitosan/PVA/	skin tissue scaffolds	(Lin et al., 2013)

Commercial polysaccharides	Gum hydrocolloids with other carriers (polymers/solvents) for electrospinning	Emerging applications	References
	Acetic acid/ water		
	Alginate/PEO/NaOH solution	Enhanced encapsulation of folic acid for functional foods	(Alborzi et al., 2013, 2014)
	PEO/ water/ 1 wt% Triton X-100/ 5 wt% DMSO	Not defined	(Cui et al., 2017)
Agar	Polyacrylonitrile (PAN)	Controlled drug release	(Yang et al., 2014)
	PVA/ water	Not defined	(Sousa et al., 2015a, 2015b)
Carrageenan	Chitosan /caffeic acid-coated poly(3-hydroxybutyrate)	Antibacterial and antioxidant activity	(Ignatova et al., 2016)
Xanthan	Chitosan/ water	Drug delivery carriers	(Mendes et al., 2017b)
	Formic acid	Not defined	(Shekarforoush et al., 2017)
Gellan gum	PVA/water	Skin tissue regeneration	(Vashisth et al., 2014)
	PVA/Water/ Ofloxacin	Gastroretentive/mucoadhesive drug delivery	(Vashisth et al., 2017, 2016)
Gum Arabic	PVA/ water		(Padil et al., 2016)
	Chitosan/gelatin/water	Tissue engineering	(Tsai et al., 2015)
Gum Tragacanth	Curcumin /poly(e-caprolactone)/ acetic acid	Biomedical	(Ranjbar-Mohammadi and Bahrami, 2016)
	Poly lactic glycolic acid (PLGA) / tetracycline hydrochloride (TCH)	Controlled drug release	(Ranjbar-Mohammadi et al., 2016c)
	PVA / water	Wound dressing	(Ranjbar-Mohammadi et al., 2013)
	Poly(e-caprolactone) (PCL)/ poly(vinyl alcohol) (PVA)	Scaffolds for skin substitutes	(Zarekhalili et al., 2017)
Gum Karaya	PVA/Water	Removal of NPs contamination from water	(Padil et al., 2016; Padil and ernik, 2015)
Gum Kondagogu	PVA/Water	Removal NPs from water	(Padil et al., 2016, 2015c)

Commercial polysaccharides	Gum hydrocolloids with other carriers (polymers/solvents) for electrospinning	Emerging applications	References
	DDSA / PVA/ water	Antibacterial membrane	(Padil et al., 2015a)

Table 4:
Summary of the literature pertaining to NPs synthesis mediated by several gum hydrocolloids

Tree gums	Category and composition of NPs	Method of preparation	Characterizations of NPs	References
GA	Ag NPs; GA (0.5 wt%); AgNO ₃ (0.5 wt%)	Room temperature synthesis	~ 5 nm in size; face centered cubic structures with crystalline,	(Mohan et al., 2007)
GA	Ag; GA (0.01 wt%; 2.0 mL); AgNO ₃ (0.1 wt%; 0.2 mL)	γ - ray irradiation route	3 nm; spherical shape; face centered cubic crystallinity	(Rao et al., 2010)
GA	Ag NPs; 5% GA (5%); PVA (3%) and AgNO ₃ (1.0 mM)	γ radiation-induced crosslinking	10–40 nm	(Juby et al., 2012)
GA	Au NPs; GA (12 mg, 6 mL); NaAuCl ₄ (0.1 M, 0.1 mL); phosphor amino acid (0.1 M, 20 μ L)	Stirring	15–20 nm, spherical shape	(Kattumuri et al., 2007)
GA	Se NPs; GA (1 mg/mL); 0.6 M selenious acid; stirring for 6 h; addition of 4.5 ml of 0.1 M ascorbic acid.	Stirred for 0.5 h	~34.9 nm, spherical shape	(Kong et al., 2014)
GA	Ag NPs; GA (0.3 g/L, 270 mL); AgNO ₃ (2 mM); NaBH ₄ (0.08M, 15 mL)	Vigorous stirring	6 nm; spherical in shape and monodispersed.	(Cheng et al., 2011)
GA	¹⁹⁸ AuNPs; GA and P(CH ₂ NHCH(CH ₃)COOH) ₃ (THPAL)	Spontaneous reaction	Radio labelled Au NPs	(Kannan et al., 2006)
GA	GA (0.01 g; 5 mL); ascorbic acid (0.1M, 5mL); KAuBr ₄ (5mM, 5 mL)	Sonicated for 5 s at R.T	520nm; flower shape	(L. Wang et al., 2012b)
GA	ZnO NPs; GA (1g); Na acrylate (10.63 mM); N.Ni – methylene bis-acrylamide (486.47 mM); K persulfate (370.3 μ M) and Zn(II), 1 g)	Sonothermal	40– 60 nm; polar structures	(Webb et al., 1998)
GK	Ag NPs;	Oxidation-reduction reaction	7–10 nm, spherical	(Padil and ernik, 2015)
GK	Au NPs; GK (1 wt%); HAuCl ₄ (5 $\times$ 10 ⁻³ M, 100 μ L); shaking at 75°C for 1 h.	Stirring	7.8 $\pm$ 1.8 nm, spherical, stable for 6 months	(Padil and ernik, 2015)
GK	Au NPs; GK (15 mg, 1.0 mL); HAuCl ₄ (10 mM, 100 μ L);	Stirred for 1h at 90 °C	20–25 nm, spherical	(Pooja et al., 2015)
GK	Pt NPs; GK (1 wt%); Pt (5 $\times$ 10 ⁻³ M, 100 μ L)	Autoclaving at 103 kPa for 15 min	5.0 $\pm$ 1.2 nm, spherical	(Padil and ernik, 2015)
GK	CuO NPs; GK (1.0 mg, 1.0 mL); CuCl ₂ ·2H ₂ O (1mM)	Thermal	10.5 $\pm$ 2.4 nm, spherical	(Padil and ernik, 2015; Thekkae Padil and ernik, 2013)
GK	Fe ₃ O ₄ NPs; Fe ²⁺ and Fe ³⁺ ions and NH ₄ OH solution.	Co-precipitation	18.5 $\pm$ 3.5nm, spherical	(Padil and ernik, 2015)
KG	Ag NPs; KG (100 mg, 10 mL); AgNO ₃ (100 μ L, 10mM)	Shaking at 45°C for 1 h.	5.5 $\pm$ 2.5nm.spherical, face centered cubic, stable >6 months	(Vinod et al., 2011a)

Tree gums	Category and composition of NPs	Method of preparation	Characterizations of NPs	References
KG	Ag NPs; KG (0.5%); AgNO ₃ (1 mM)	Autoclaving at 121 °C at 15 psi for 1 h.	3 nm, spherical, highly stable	(Rastogi et al., 2014)
KG	Ag NPs; Ag NPs; KG (0.5%); AgNO ₃ (1 mM)	Autoclaving at 121 °C at 15 psi for 1 h.	3 nm, spherical, highly stable	(Kora et al., 2010)
KG	Au NPs; KG (100 mg, 10 mL); HAuCl ₄ (100 µL, 10mM)	Shaking at 75 °C for 1 h.	7.8±2.3 nm, spherical, stable >6 months	(Vinod et al., 2011a)
KG	Au NPs; KG (0.5%, 3 mL); HAuCl ₄ (1.0 mM, 1.0mL)	Autoclaving at 15 psi, 120 °C for 10 min	12 ± 2 nm, nano-crystalline	(Reddy et al., 2015)
KG	Pd NPs; KG (0.5%); PdCl ₂ (1.0 mM)	Autoclaving at 121 °C and 15 psi for 30 min.	6.5 ± 2.3 nm, crystallized in face centered cubic symmetry.	(Rastogi et al., 2017)
KG	Pt NPs; GK (100mg, 10 mL); H ₂ PtCl ₆ (100 µL, 10mM)	Autoclaving at 15 psi for 15 min.	2.4±0.7 nm, crystalline, stable for more than 6 months	(Vinod et al., 2011a)
KG	Fe ₃ O ₄ NPs; KG (25 mg, 50 mL); Fe Cl ₂ and FeCl ₃ (Fe ²⁺ /Fe ³⁺ ratio 2:1)	Co-precipitation under hydrothermal conditions.	8– 15 nm; spherical size	(Saravanan et al., 2012)
GT	ZnO NPs	Low-temperature plus ultrasonic	55–80 nm, highly crystalline nature and single phase	(Ghayempour et al., 2016)
GG	Ag NPs; AgNO ₃ (1.0 mM); GG (0.5%)	Autoclaving at 121 °C and 15 psi for 60 min.	5.7 ± 0.2 nm, spherical NPs	(Kora et al., 2012; Kora and Sashidhar, 2015)
GG	Pd NPs; GG (0.5%); PdCl ₂ (1.0 mM)	Autoclaving at 121 °C and 103 kPa for 30 min.	4.8± 1.6 nm, spherical shape	(Kora and Rastogi, 2015)
GG	Au NPs; GG (1% w/v; 4 mL); HAuCl ₄ (100 mM, 30.7 µL/mL)	Stirring and heated at 60 °C	112.5 nm; spherical shape	(Alam et al., 2017)

Table 5:

Natural gums and fibers for environmental bioremediation (heavy metals, organic dyes, radioactive materials and NPs)

Gum-based Adsorbents (nanocomposite, hydrogels/NPs/fibers and membranes)	Type of contaminants	Adsorption capacity (mg/g), kinetic and adsorption models	Adsorption/removal mechanisms	References
GA/Fe ₃ O ₄	Cu ²⁺	38.5; Langmuir isotherm and pseudo-2 nd order kinetics	Complexation	(Banerjee and Chen, 2007a)
GK/PVA NF	Ag, Au and Pt NPs	119 (Ag); 196 (Au) and 236 (Pt)	Functional group interactions	(Padil et al., 2015c)
GT/graphene oxide composite	Pd ²⁺ , Cd ²⁺ and Ag ⁺	142.50 (Pb ²⁺), 112.50 (Cd ²⁺) and 132.12(Ag ⁺) pseudo-1 st order kinetics, and Langmuir model.	Chemical reaction and mass transfer	(Sahraei and Ghaemy, 2017)
GT/Polyamidoxime nanohydrogel	Co ²⁺ , Zn ²⁺ , Cd ²⁺ and Cr ³⁺	100.0 (Co ²⁺), 76.92 (Zn ²⁺), 71.42 (Cr ³⁺) and 66.67 (Cd ²⁺); Temkin isotherm and pseudo-2 nd order kinetics.	Metal- amidoxime/ GT chelating	(Masoumi and Ghaemy, 2014)
GT/ Fe ₃ O ₄ /poly(methyl methacrylate) NP	Cr ⁶⁺	7.64; Langmuir isotherm and pseudo-2 nd order kinetics	Chemisorption	(Sadeghi et al., 2014)
GK	Hg ²⁺	62.5; Langmuir model and pseudo-2 nd order kinetics	Micro-precipitation and ion-exchange process	(Vinod et al., 2011b)
GK/PAA/SiC NPs	Malachite green and rhodamine B	757.57 (MG) and 497.51(RhB); Langmuir model and pseudo 2 nd order kinetics	Physical adsorption controlled by diffusion	(Mittal et al., 2016)
GK/PAA-acrylamide/ SiO ₂ nanocomposite	Methylene blue	1408.67; pseudo-2 nd order kinetics, and Langmuir model	Physical adsorption plus electrostatic interactions	(Hemant Mittal et al., 2015a)
GK/PVA NF	Ag, Au, Pt, CuO and Fe ₃ O ₄ NPs	25.5 (Ag); 45.8 (Au); 51.5 (Pt); 7.5 (CuO); 5.2 (Fe ₃ O ₄)	Physisorption, interactions, complexation,	(Padil and ernik, 2015)
GK/PVA NF (plasma treated)	Au, Ag, Pt, CuO and Fe ₃ O ₄ NPs	116 (Ag), 261.1 (Au), 289.8 (Pt), 66.3 (CuO) and 49.9 (Fe ₃ O ₄); Langmuir model and pseudo-2 nd order kinetics	Physisorption, interactions, complexation	(Padil and ernik, 2015)
KG	Pb ²⁺ , Cd ²⁺ , Ni ²⁺ , Cr ³⁺ , Cr ⁶⁺ , Fe ²⁺ , Co ²⁺ , Cu ²⁺ , Zn ²⁺ , As ³⁺ , Se ²⁺ , Hg ²⁺	Langmuir isotherm model and pseudo-2 nd order kinetics	Physisorption, micro-precipitation and ion-exchange processes	(Vinod et al., 2010a, 2010b; Vinod et al., 2009)
KG-nanocomposite	U ⁶⁺	487; Langmuir isotherm model and pseudo-2 nd order kinetics	Precipitation, ion exchange, complexation	(Sashidhar et al., 2015)
KG/Fe ₃ O ₄ nanocomposite	Cd ²⁺ , Cu ²⁺ , Pb ²⁺ , Ni ²⁺ , Zn ²⁺ , Hg ²⁺	106.8 (Cd ²⁺), 56.6 (Pb ²⁺), 85.9 (Cu ²⁺), 49 (Ni ²⁺), 37 (Zn ²⁺) and 35 (Hg ²⁺), Langmuir models	Interaction, physisorption	(Saravanan et al., 2012)
KG/PVA NF	Ag, Au and Pt NPs	143.4 (Ag); 173.5 (Au) and 270.4 9 (Pt); Pseudo-2 nd order kinetics	Functional group interaction	

Gum-based Adsorbents (nanocomposite, hydrogels/NPs/fibers and membranes)	Type of contaminants	Adsorption capacity (mg/g), kinetic and adsorption models	Adsorption/removal mechanisms	References
GK- ZVI NPs	Cr ³⁺ , Cr ⁶⁺ and volatile organic compounds (<i>cis</i> -1,2-dichloroethene, perchloroethene and trichloroethene)	Complete degradation of Cr (Con. 10 ppm) and VOCs Pseudo-2 nd order kinetics	Functional group interaction	(Farooq et al., 2017)
GG/Pd NPs	G-250, methylene blue, methyl orange, and 4-nitrophenol	150 µM (G-250), 62.5 µM (methylene blue), 30 µM (methyl orange) and 100 µM (4-nitrophenol)	Catalytic reduction	(Kora and Rastogi, 2015)
GG/PAA-co-acryl- amide /Fe ₃ O ₄ NPs	Rhodamine B	654.87; Langmuir model and pseudo-2 nd order kinetics	Electrostatic attraction, and binding sites	(Mittal and Mishra, 2014)

Table 6:

Metal/metal oxide NPs synthesized by gum fibers and their electrospun functional membranes for antibacterial efficiencies.

Composition of NPs	Type of bacteria tested	Size and concentration of NPs	Antibacterial susceptibility of bacterial strains towards NPs (ZOI^a/MIC^b /MBC ^c)	References
PVA/GA/Ag NP	<i>E. coli</i>	10–40 nm; GA (5%), PVA (3%), AgNO ₃ (1mM)	Not defined	(Juby et al., 2012)
GA/DETA microgels	<i>E. coli</i> , <i>S. aureus</i>	5–100 μ m	5 mg/mL (<i>E. coli</i>), 10 mg/mL (<i>S. aureus</i>)	(Farooq et al., 2017)
GA /poly(sodium acrylate)/Ag NPs hydrogel	<i>E. coli</i>	20–30 nm; GA (1 g); Na-acrylate (10.63 mmol), AgNO ₃ (0.117 mmol)	Not defined	(Bajpai and Kumari, 2015)
GA /poly (acrylate) hydrogel/ ZnO NPs	<i>E. coli</i>	40–60 nm; ZnO (2%), GA (1.0g)	32 $\pm$ 0.07 mm	(Bajpai et al., 2016)
GT/ ZnO nanorod	<i>E. coli</i> , <i>S. aureus</i> , <i>C. albicans</i>	55–80 nm; Zn(NO ₃) ₂ ·6H ₂ O (0.1M), GT (1%)	3.3 $\pm$ 0.1 mm (<i>E. coli</i>), 3.2 $\pm$ 0.1 mm (<i>S. aureus</i>), 3.0 $\pm$ 0.1 mm (<i>C. albicans</i>)	(Ghayempour et al., 2016)
GT/nano silver hydro citric acid and sodium hypophosphite hydrogel on cotton fabric	<i>E. coli</i> , <i>S. aureus</i>	77.55 nm; TG (0.8%), AgNO ₃ (0.335%)	Reduction number of colonies 98.0% (<i>E. coli</i>) and 99.69% (<i>S. aureus</i>)	(Montazer et al., 2016)
GT/PVA NF	<i>S. aureus</i> , <i>P. aeruginosa</i>	40% (GT), 60% (PVA)	good antimicrobial properties against (<i>P. aeruginosa</i>)	(Ranjbar-Mohammadi et al., 2013)
GK/Dodecyl succinic anhydride (DDSA) composite	<i>E. coli</i> , <i>P. Aeruginosa</i> , and <i>S. aureus</i>	GK/DDSA (10%)	Gram-negative <i>E. coli</i> (14.2 $\pm$ 0.8 mm); <i>P. aeruginosa</i> and Gram-positive <i>S. aureus</i> (15.0 $\pm$ 0.8 mm), respectively for 10 wt.% concentration of DDSA/DGK	(Padil et al., 2015b)
GK/CuO NPs		4.8 $\pm$ 1.6 nm; CuCl ₂ · 2H ₂ O (1 mM) and GK (10 mg/mL)	<i>S. aureus</i> (25923) 14.5 $\pm$ 0.8 mm; <i>E. coli</i> (25922), 16.2 $\pm$ 0.8 mm.	(Thekkae Padil and ernik, 2013)
KG / Ag NPs	Gram-negative (<i>Escherichia coli</i> (ATCC 25922), <i>E. coli</i> (ATCC 35218), <i>Pseudomonas aeruginosa</i> (ATCC 27853) and Gram-positive (<i>Staphylococcus aureus</i> (ATCC 25923))	4.5 $\pm$ 3.1 nm; 0.5% KG (0.5%) and AgNO ₃ (1 mM)	The minimum inhibitory concentration (MIC) for <i>S. aureus</i> (10 μ g/mL); <i>P. aeruginosa</i> (5 μ g/mL) and <i>E. coli</i> (2.0 μ g/mL). The minimum bactericidal concentration (MBC) of silver NPs against test bacterial strains for both <i>S. aureus</i> and <i>P. aeruginosa</i> (12 μ g/mL) each and <i>E. coli</i> (2 μ g/mL)	(Kora and Rastogi, 2015)
KG-Ag NPs	<i>S. aureus</i> (ATCC 25923; ATCC 49834); <i>E. coli</i> (ATCC 25922) and <i>P. aeruginosa</i> (ATCC 27853)	5.8 $\pm$ 2.4 nm; GK-Ag NPs (1 μ g/mL)	<i>E. coli</i> (25922) 3.0 μ g/mL; <i>P. aeruginosa</i> (27853) 5.0 μ g/mL; <i>S. aureus</i> (25923) 5.0 μ g/mL; <i>S. aureus</i> (49834) 5.0 μ g/mL	(Rastogi et al., 2015)
KG / gelatin sponge ciprofloxacin	<i>S. aureus</i> and <i>E. coli</i>	GK (1% w/v) and gelatin (3% w/v)	<i>S. aureus</i> (20 mm) and <i>E. coli</i> (25 mm)	(Rathore et al., 2016)
KG/ Ag NPs	<i>S. aureus</i> (ATCC 25923); and <i>Escherichia coli</i> (ATCC 25922), <i>E. coli</i>	KG (0.5%) and AgNO ₃ (1.0 mM)	<i>S. aureus</i> (ATCC; 25923), 11 mm; <i>E. coli</i> (ATCC 25922), 8.0 mm; <i>E. coli</i> (ATCC 35218), 8.4 mm; and <i>P. aeruginosa</i> (ATCC 27853),	(Kora et al., 2010)

Composition of NPs	Type of bacteria tested	Size and concentration of NPs	Antibacterial susceptibility of bacterial strains towards NPs (ZOI ^a /MIC ^b /MBC ^c)	References
Dodecyl succinic anhydride (DDSA)/decetylated KG fibers and membranes	(ATCC 35218) and <i>Pseudomonas aeruginosa</i> (ATCC 27853) Gram-negative <i>Escherichia coli</i> (CCM 3954) and <i>Pseudomonas aeruginosa</i> (CCM 3955) and Gram-positive <i>Staphylococcus aureus</i> (CCM 3953)	(PVA, 10 wt%) and DDSA/DGK (10 wt %)	8.7 mm <i>E. coli</i> (8.0±0.1 mm, 6.0±0.5 mm); <i>P. aeruginosa</i> (7.0±0.1, 4.5±0.6); <i>S. aureus</i> (9.0±0.1, 7.0±0.8)	(Padil et al., 2015a)
GG/ Ag NPs	<i>Staphylococcus aureus</i> (ATCC 25923); and <i>Escherichia coli</i> (ATCC 25922), <i>E. coli</i> (ATCC 35218), and <i>Pseudomonas aeruginosa</i> (ATCC 27853)	5.7 ± 0.2 nm 0.1% GG and 1 mM AgNO ₃ 5 µg of silver NPs	<i>S. aureus</i> , 25923 (12.25 mm); <i>E. coli</i> 25922 (9 mm); <i>E. coli</i> 35218 (8 mm); <i>P. aeruginosa</i> 27853 (11 mm)	(Kora and Sashidhar, 2015)

^aZone of inhibition (ZOI)^bminimum inhibitory concentration (MIC)^cminimum bactericidal concentration (MBC)