Chapter 4
Polymers for Coagulation and Flocculation in Water Treatment

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Abstract The desires to improve on the operational efficiency of coagulation/flocculation (CF), a unit process in water and wastewater treatment, and to obviate the other challenges synonymous with the use of inorganic coagulants (i.e. aluminium- and iron-based alum) impelled the search for alternative coagulants that can ameliorate the identified shortcomings. Amongst the array of synthetic and natural origin materials that have been screened as alternatives to the conventional inorganic alum, polymeric coagulants have shown better promise. The inherent structural features of polymeric coagulants enhanced the CF process operation and economy. This treatise is an exposition on the variables that define the choice of polymeric coagulant as an alternative to the conventional inorganic coagulants. The theoretical bases for the choice of the different polymeric coagulants were discussed. Using the identified active coagulating species in the different polymeric coagulant as a premise, the underlying CF mechanisms in the use of this genre of coagulants were expounded. The research gap in the use of polymeric coagulant as substitute to the conventional inorganic coagulant was also highlighted.

4.1 Introduction

Coagulation/flocculation (CF) is a two-stage process that involves the destabilization and agglomeration of dispersed, dissolved, colloidal and suspended particles in the dispersion medium. In the conventional municipal wastewater treatment plants, the coagulation stage, where the coagulants are mixed into the water to be treated, is preceded by screening and other pre-treatment methods (Fig. 4.1).

Ordinarily, large suspended particles in an aqua system would settle without any form of treatment, if the system is stagnant and left undisturbed. In the case that the conditions required for the settling of these dispersed particulate matters are not

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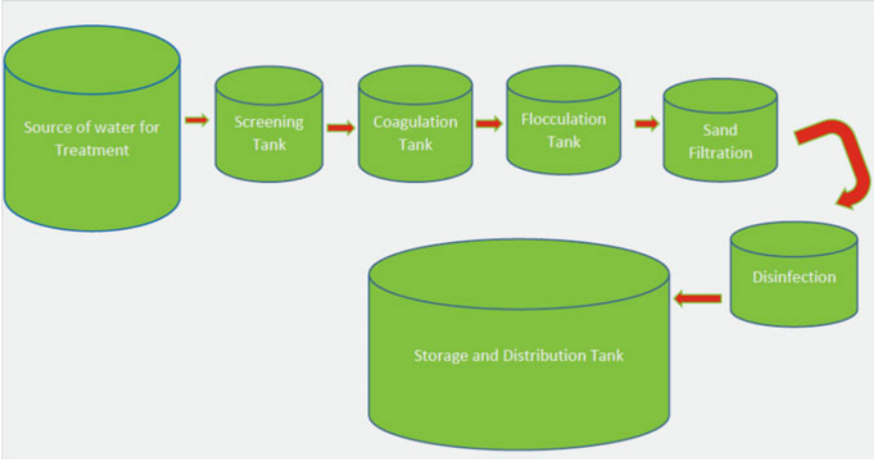

Fig. 4.1 Schematic representation of a typical conventional water treatment plants showing the different unit operations

met, the settling becomes unattainable. The settling of the dispersed particulates also becomes tasking if colloidal particles formed the large chunk of the dispersed phase in the aqua matrix. Consequently, water clarification using sedimentation alone is an unfeasible approach and a new functional approach, known as coagulation/flocculation, that enhanced the settling rate of the dispersed fractions of the aqueous system was developed. In the CF process, the stable dispersed particles are transformed to unstable and insoluble agglomerates, which are denser than water and then settle easily.

The process of CF involves series of chemical and mechanical operations that entails the addition and mixing of coagulant with the water matrix. These processes occur in two distinct stages that are termed as coagulation and flocculation. The first stage is the coagulation stage that involves rapid mixing of the coagulant with the water to be treated, which leads to the formation of micro-flocs, while the second stage (i.e. the flocculation stage) is the slow agitation stage that involves the aggregation of the micro-flocs to form the well-defined macro-flocs.

4.2 Polymeric Materials

Polymeric materials are made up of molecules which have long sequences of one or more species of atoms or groups of atoms linked to each other, usually by covalent bonds. The polymeric materials are also referred to as “macromolecules” and they are formed by the covalent linkage of small molecules, known as monomer, through a process known as polymerization. The long-chain skeletal framework of polymers sets them apart from other materials and gives rise to their characteristic properties.

The skeletal framework of polymers occurs in linear, branched and network forms. While linear skeletal structure can be represented by a chain with two ends, branched polymers have side chains, or branches, of significant length which are bonded to the main chain at branch points (also known as junction points), and are characterized in terms of the number and size of the branches. Network polymers have three-dimensional structures in which each chain is connected to all others by a sequence of junction points and other chains. Such polymers are said to be cross-linked and are characterized by their cross-linked density or the degree of cross-linking, which is related directly to the number of junction point per unit volume. Nonlinear polymers (i.e. branched and network polymers) are formed either by polymerization or prepared by linking together (i.e. cross-linking) of pre-existing polymer chains. Variations in skeletal structure give rise to major differences in properties.

4.3 Polymers in Coagulation–Flocculation

From the perspective of the chemical composition, the common coagulants used in CF operations can be broadly classified as organic and inorganic based. The inorganic-based coagulants include alum (aluminium sulphate), sodium aluminate, ferric sulphate, ferrous sulphate, ferric chloride, etc. The organic-based coagulants are mainly polymeric materials and can be further classified as synthetic- and natural-based coagulants. Synthetic chemical coagulants are based on organic polymers (or polyelectrolytes) while the natural-based organic coagulant is derived from both plants and animals.

In water and wastewater treatment operations, organic polyelectrolytes are used either for the CF operation or for sludge dewatering. Relative to the use of the inorganic coagulants in water treatment, the use of polymeric coagulants significantly reduced the coagulant dose requirements, the sludge volume, the ionic load cum the residual aluminium concentrations in the treated water and the process economy (i.e. cost savings of up to 25–30%) [33, 47]. The use of polymeric coagulants also enhanced the rate of floc settling and improved the floc textures in low-temperature coagulation or in soft coloured waters [14]. Since larger and stronger flocs are obtained from the use of organic polyelectrolytes, the capacity of a treatment facility and the rate of solid and water phase separation is substantially increased. In addition, the dosage of other ancillary chemicals required for water treatment is reduced and the coagulant is applicable in the treatment of broader range of water and wastewater.

Despite the numerous advantages of organic polyelectrolytes in CF operations, the use is also bedecked with challenges. Some of the derivatives of synthetic polymers are found to be non-biodegradable and the intermediate products of their degradation are hazardous to human health as their monomer is neurotoxic and carcinogenic [48]. Consequent upon the challenges synonymous with the use of synthetic polymeric materials in CF operations, the option of deriving polymeric coagulants from natural-based materials is now being explored. It was posited [51] that the polymeric coagulants derived from plants and animals are promising alternatives to the conventional coagulants because they are highly biodegradable, non-toxic and non-corrosive. They produced less voluminous sludge and do not alter the pH of the treated water. Furthermore, since the plants are locally grown, the natural plant-based coagulants are more cost-effective than imported chemicals [49].

4.3.1 Synthetic Polymeric Coagulants

The classification of the synthetic organic polymers used in water and wastewater treatment operations is based on the ionic charge present, e.g. cationic, anionic and non-ionic polyelectrolytes. Cationic polyelectrolytes formed the largest number of polymeric coagulants that have been used in CF operations. Bolto [3] provided a review of the varieties of cationic polymers used as coagulants in water and wastewater treatment operations. Most often, the cationic polyelectrolytes used possess quaternary ammonium groups that have a formal positive charge, irrespective of the pH value, and are referred to as strong polyelectrolytes [2]. Polymeric coagulants whose cationic properties are expressed only in acidic medium and considered weak polyelectrolyte are also used. Examples of cationic polyelectrolytes that have been used in CF operations include poly (diallyldimethyl ammonium chloride), epichlorohydrin/dimethylamine polymers, cationic polyacrylamides, etc.

Amongst the naturally occurring cationic polymers, chitosan is the most commonly used in CF operations. It is a partially deacetylated chitin and consists of a 1:4 random copolymers of *N*-acetyl-α-D-glucosamine and α-D-glucosamine. A review on the applications of chitosan in water industries was provided by Pariser and Lombardi [44]. Another natural cationic coagulant that is gaining popularity is the aqueous extract of the seed of *Moringa oleifera*, whose active coagulating ingredient has been identified as a cationic, low molecular mass peptide, whose isoelectric point of charge is above 10 [17, 18, 32]. Research reports [38, 50]; Jahn et al. [20, 30–32] have shown the performance efficiency of this seed extract in CF operations.

Relative to the synthetic polymers, polysaccharides are fairly shear stable and are biodegradable, but exhibit lower coagulation and flocculation efficiencies which always necessitate the use of higher dosage for optimal performance. Pal et al. [43] posited that in order to develop coagulants with better features than that of both the synthetic and natural polymeric coagulants, the best features of natural polymers can be combined with that of synthetic polymers via chemical modification. Naturally occurring non-ionic polymers have been transformed to cationic polymers through chemical modifications of the surface functional groups. A prominent example is the conversion of starch, a polymer composed of α-D-glucose units, to a cationic derivative by the reaction of the primary OH group with different cationic moieties. Incorporation of synthetic polymers via graft copolymerization reaction of synthetic polymers onto amylopectin, guar gum, glycogen and starch produced polymeric coagulants that are more effective than the original starting polymers because of the dangling polymer chains [2]. Kraft lignin, a coagulant with cationic character, has also been produced via the surface modification of lignin [27].

The commonly used anionic polymeric coagulant in water and wastewater treatment usually contains weakly acidic carboxylic acid groups; thus, the charge density is pH dependent [2]. A common example is anionic polyacrylamide. The anionic natural polymers are the sulphated polysaccharides or their derivatives, which include heparin, dextran sulphate, mannan sulphate, alginates, carrageenans, Gellan, gum Arabic and xanthan and chondroitin sulphate. These anionic polysaccharides found application more in medicine than in the water industries [59]. Few natural anionic polymers that have been tested in CF operations include tannins and modified natural polymer lignin sulphonate [28, 46].

Non-ionic polyacrylamide is a good example of the synthetic non-ionic polyelectrolytes while examples of natural non-ionic polysaccharides include amylose, amylopectin, cellulose, guar gum, etc. Natural, non-ionic polysaccharides that have been used in the water industries include starches, galactomannans, cellulose derivatives, microbial polysaccharides, gelatins and glues. Consequent upon the non-ionic nature of these polysaccharides, they are often used as coagulant aid instead of being used as the primary coagulant.

4.3.2 Natural Polymeric Coagulants

Aside the few natural polymeric coagulants, whose characteristics are well known, array of bio-based polymeric coagulants has also been derived from a range of biomaterials. It includes the fruit seeds of plant species, bone shell extracts, plant bark resins and extracts of the exoskeleton of shellfish (Fig. 4.2).

Choy et al. [7] provided a detailed review of the research report on twenty-one (21) types of plant-based coagulants derived from fruit waste and other biomaterials. The performance efficiencies of these green bio-based coagulants, the merits and demerits were enunciated. In another treatise, a review of fourteen (14) plant-based natural coagulants derived from common vegetables and legumes was provided [6]. The challenges of the different research efforts that focused on the use of bio-based coagulants were analysed as a prelude to further research efforts. Progress on the use of natural polymeric materials for water and wastewater purifications has also been chronicled by Oladoja [35]. Perspective on the promise and limitations of these bio-based polymeric coagulants were presented in this treatise. A synopsis of selected materials from which natural polymeric coagulants have been derived is presented in Table 4.1 [37].

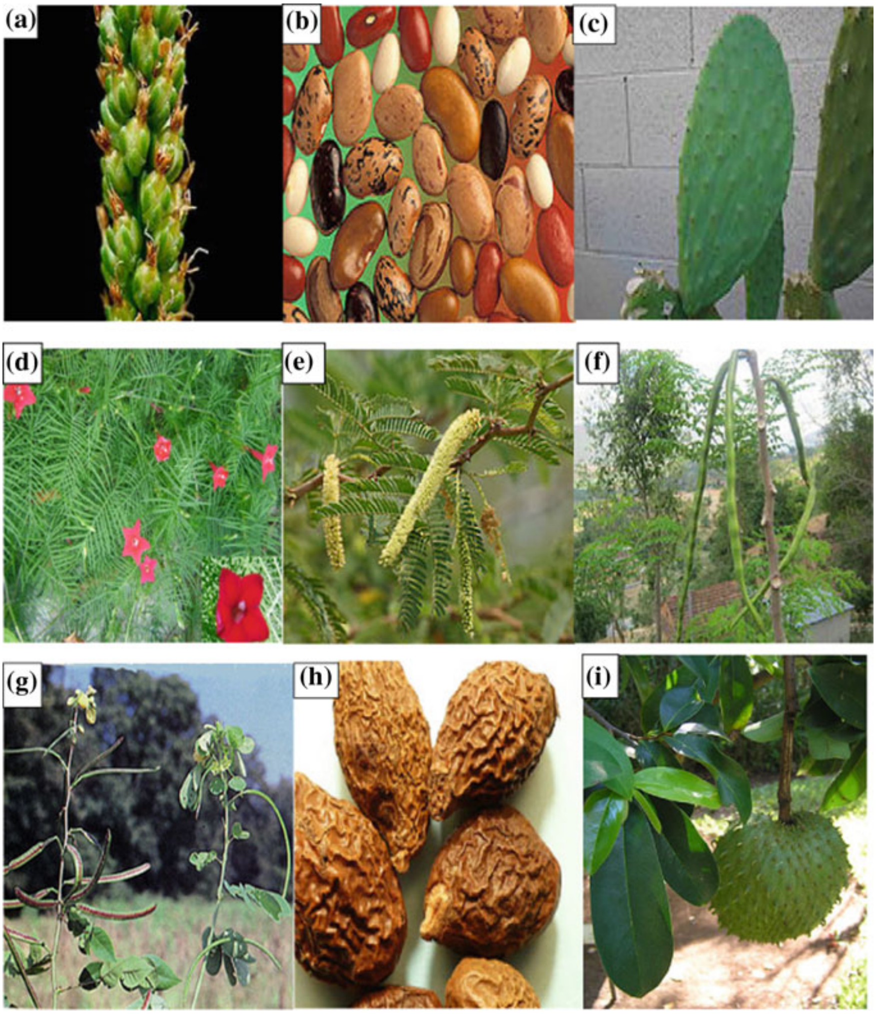

Fig. 4.2 Photographic images of biomaterials from which natural polymeric coagulant have been derived (Plantago major fruit (**a**), Bean seeds of *Phaseolus vulgaris* (**b**), *Opuntia* Species (**c**), *Ipomoea quamocalit* (**d**), *Prosopis juliflora* (**e**), *Moringa Oleifera* Pod (**f**), Cassia obtusifolia plant (**g**), *Sterculia lychnophora* (**h**), Annona muricata (**i**))

4.4 The Underlying Mechanisms of the Process of CF

Premised on the classifications posited by Crittenden et al. [8], CF of the dispersed phase in an aqua system can be achieved via any or combination of the following operational mechanisms:

Table 4.1 Selected biomaterials studied as natural polymeric coagulants [37]

S/N	Scientific names	Common names	Family name	Country of origin	References
1	*Coccinia indica*	Ivy gourd, scarlet gourd, small gourd, kowai fruit, scarlet-fruited gourd	Cucurbitaceae	Central Africa, India and Asia	Lim [24], Shaheen et al. [52]
2	*Hibiscus esculentus*	Okra, lady's finger, gumbo, gobo	Malvaceae	Old World tropics (West Africa)	Small [54]
3	*Luffa cylindrica*	Smooth luffa, egyptian luffa, vegetable sponge, sponge guard	Cucurbitaceae	Old World tropics; probably Asia	Lim [24], Small [54]
4	*Arachis hypogaea*	Peanut, groundnut, monkey nut, pinder, goober	Fabaceae	South America	Lim [24], Boshou and Corley [4], Fageria et al. [13]
5	*Cicer arietinum*	Dal seeds, chick pea, bengal gram, garbanzo bean	Fabaceae	Mediterranean region	Lim [24], Ahmad et al. [1]
6	*Dolichos biflorus*	Horsegram, kulthi	*Fabaceae*	Old World tropics	Brink [5]
7	*Glycine max*	Soybean, soya bean	Fabaceae	Eastern Asia	Frederic [15]
8	*Guar gum*	Guar bean, cluster bean, guaran	Fabaceae	India	Peter et al. [45]
9	*Lablab purpureus*	Hyacinth bean, bonavist bean, chink, country bean, dolichos bean	Fabaceae	Old World tropics	Small [55]
10	*Phaseolus angularis*	Azuki bean, adsuki bean, red bean	Fabaceae	Unknown exact origin	Jansen [21]
11	*Phaseolus mungo*	Urad bean, black gram, black lentil, black matpe, urd bean	Fabaceae	India	Lim [24]
12	*Pisum sativum*	Green pea, pea, field pea, garden pea, stringless snow pea	Fabaceae	Southwestern Asia	Lim [24]

(continued)

Table 4.1 (continued)

S/N	Scientific names	Common names	Family name	Country of origin	References
13	*Vigna unguiculata*	Cow pea, black-eyed pea, southern pea, cowgram	Fabaceae	Southern Africa	Lim [24]
14	*Phaseolus vulgaris*	Common bean	Fabaceae	Central or South America	Fageria et al. [13]
15	*Cereus repandus*	Cadushi, giant club cactus, hedge cactus, peruvian apple cactus	Cactaceae	South America	Diaz et al. [9]
16	*Stenocereus griseus*	Pitaya agria, sour pitaya	Cactaceae	America	Fuentes et al. [16]
17	*Opuntia ficus-indica*	Prickly pears, tuna, nopal	Cactaceae	Americas	Zhang et al. [61] Miller et al. [29] Mane et al. [25] Shilpa et al. [53]
18	*Oryza sativa*	Rice	Poaceae	China	Thakre and Bhole [58]

(a) *Double-layer compression*

This mode of coagulation mechanism is initiated when a highly charged ionic species is used as the coagulant. This ionic coagulant tinkers with the overall ionic activity of the system and the electric double layer that encapsulates the dispersed particles is compressed and the repulsive energy barrier that keeps the particles apart is suppressed (Fig. 4.3a). In this case, molecular attraction is promoted and the formation of micro- and macro-flocs is enhanced.

(b) *Charge neutralization*

In this case, the oppositely charged ionic species derived from the coagulant is adsorbed onto the surface of the dispersed particulate matters. The negatively charged dispersed particles are neutralized by the positively charged coagulants and molecular attraction ensued (Fig. 4.3b).

(c) *Adsorption and bridging*

This mode of coagulation mechanism is common with polymeric coagulants. The skeletal framework of the polymeric coagulant induced the bridging of the dispersed particles, thereby bringing them together (Fig. 4.3c). Owing to the nature of the skeletal framework of polymeric coagulants, they are capable of extending

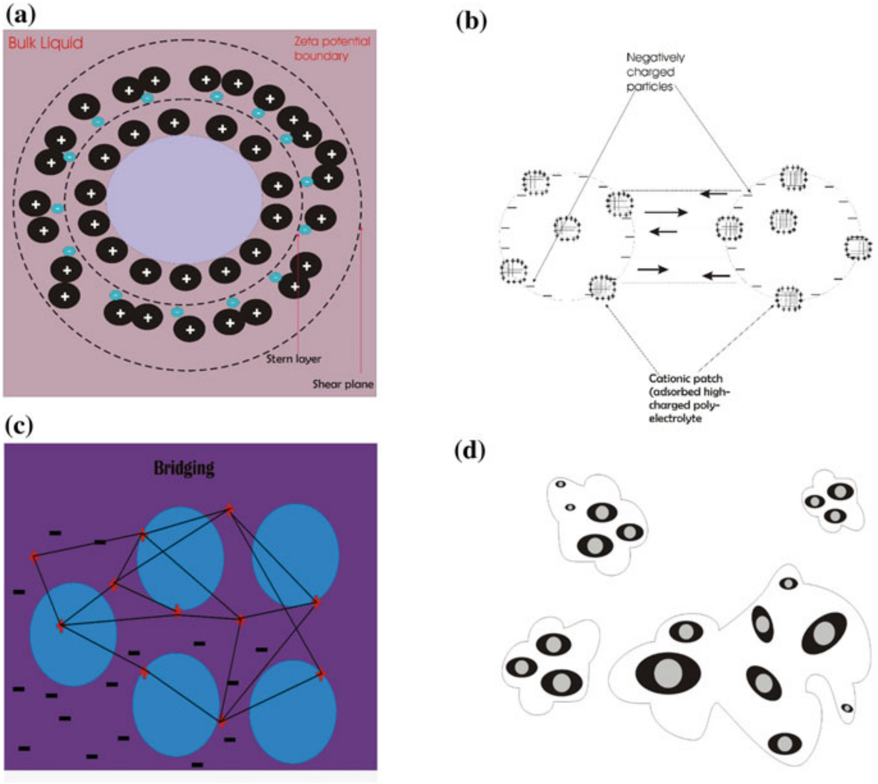

Fig. 4.3 **a** Schematic representation of double-layer compression mechanism, **b** schematic representation of charge neutralization mechanism, **c** schematic representation of adsorption and bridging mechanism, **d** schematic representation of sweep coagulation mechanism

into the solution to capture and bind multiple dispersed particles together to form denser and settleable flocs.

(d) *Sweep coagulation*

This mode of coagulation mechanism occurs through the enmeshment of the dispersed particulate matters into the matrix of the insoluble metal hydroxide formed from the hydrolysis of the metal coagulant (Fig. 4.3d). Relative to the charge neutralization mode of coagulation mechanism, sweep coagulation provides an improved coagulation and greater pollutant removal [12].

An overview of the underlying principles of the different coagulation mechanisms showed that the nature of coagulant influences the adopted operational coagulation mechanism. Alum coagulants (i.e. aluminium or ferric) can only operate via any or combination of sweep coagulation, charge neutralization and double-layer compression, but cannot operate using the adsorption and bridging mechanism. On the other hand, polymeric coagulants cannot operate using sweep coagulation, but it can operate with adsorption and bridging, double-layer compression or charge neutralization. Amongst the underlying operational mechanisms synonymous with polymeric coagulants, adsorption and bridging mechanism are the most preferred, but the occurrence of additional operational mechanism that includes double-layer compression or charge neutralization is only possible when the skeletal framework of the polymeric coagulant is highly charged.

4.5 A Peep into the Peculiarities of Polymeric Coagulants and the Operational CF Mechanism(S)

In CF operations using polymeric coagulants, the skeletal frameworks provide large number of active sites for particle adsorption and charge neutralization. It has been posited that the two most important features that defined polymeric coagulant as a good coagulant/flocculant are the large molecular weight and, in the case of polyelectrolytes, the charge density [2]. The large molecular weight ensures a broader distribution of the polymer chain, thereby promoting the bridging of the dispersed matters in the aqua matrix while the high charge density promotes the additional effects of charge neutralization. The high charge density effects underlie the preference and prominence of cationic polyelectrolytes to the other genre of polyelectrolyte coagulants in CF operations.

Generally, the active coagulating ingredients in natural bio-based coagulants are polymeric in nature but the molecular compositions and the skeletal framework are diverse. Thus, the variations in the molecular compositions and the skeletal framework are expected to influence the coagulation efficiencies and the underlying mechanisms of coagulation in different polymeric coagulants. The treatise [37] that provided mechanistic insights into the coagulation abilities of polysaccharide-based coagulants lend credence to the effects of the nature of the active coagulating ingredients on the CF abilities of polymeric coagulants.

The coagulation ability of chitosan, a linear copolymer of D-glucosamine and N-acetyl-D-glucosamine, was attributed to the high cationic charge density and ability to specifically bond to solid particles [37]. Owing to the high content of amine group on the polymer framework, it is positively charged at the pH value of natural water; thus, it effectively destabilizes and coagulates negatively charged suspended and colloidal matters and then flocculates them.

The seed gums obtained from diverse fruit seed (e.g. *Trigonella foenum-graecum*, *Cyamopsis tetragonoba*, *Ceratonia siliqua*, *Solanum lycopersicum*, *Coffea arabica*, *Convolvulaceae, Asteraceae, Arecaceae* etc.) have been studied as green bio-based polymeric coagulants. Thus far, the coagulating abilities of seed gums were attributed to either the presence of galactomannans or uronic acids. Since these two active coagulating ingredients are polymeric, the underlying coagulation mechanism by seed gums was ascribed to the bridging and adsorption mechanism, which is the coagulation mechanism specific to polymeric coagulants.

Galactomannans is a water soluble, macromolecular, hydrocolloid, having galactose and mannose in 1:2 molar ratio (Fig. 4.4a) while uronic acid (Fig. 4.4b) is a class of sugar acid with both carbonyl and carboxylic acid functional groups.

Different wastes from fruits, e.g. *Carica papaya*, *Feronia limonia*, *Mangifera indica*, *Persea americana*, *Phoenix dactylifera*, *Prunus armeniaca*, *Tamarindus indica*, have been screened as possible sources of natural polymeric coagulants and the coagulating abilities observed were attributed to the presence of long polymeric chain of unidentified natural polymers (i.e. proteins and polysaccharides) in the fruit wastes.

Mucilages derived from array of plants (e.g. *Opuntia ficus-indica* cactus, *Hibiscus esculentus*, *Plantago species*, *Malva sylvestris*) have been evaluated in CF operations. Mucilage, an hydrocolloid, is a complex polymer of carbohydrate with highly branched structure [26] that contains varying proportions of L-arabinose, D-galactose, L-rhamnose, and D-xylose, as well as galacturonic acid in different proportions. Premised on the chemical compositions of mucilage, the polysaccharide fraction was considered to be the active coagulating ingredient. This general assumption on the nature of the active ingredient present in mucilage was allayed by the findings of Miller et al. [29] who posited that there are fractional components of the *Opuntia* spp., outside those reported, that contributes to the coagulation activity.

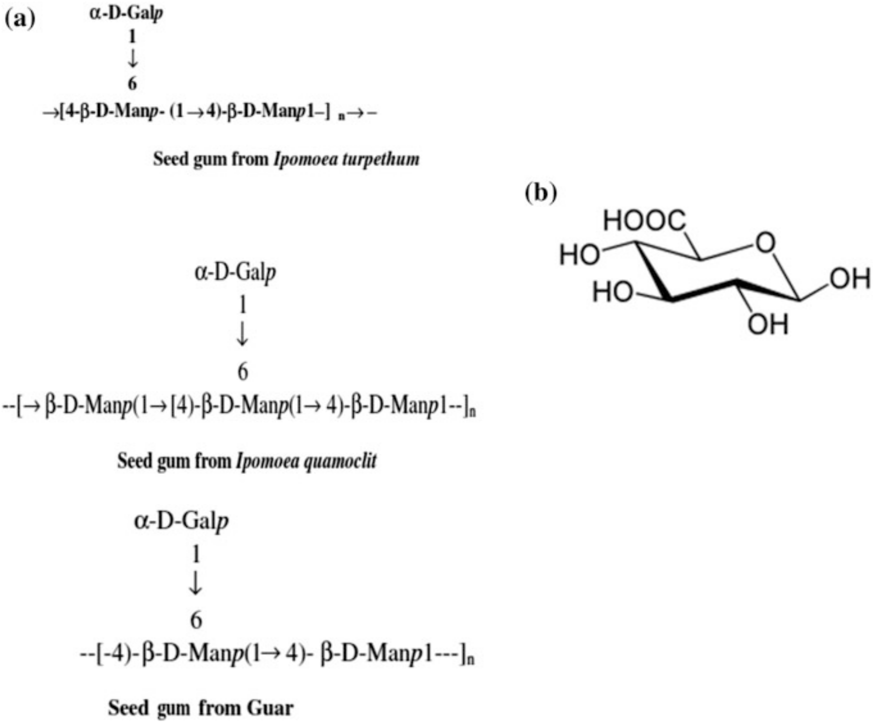

Fig. 4.4 **a** Illustration of the chemical structures of different galactomannans, **b** chemical structure of uronic acid (glucuronic acid)

The coagulating abilities of different fruit seeds (Nirmali, maize, mesquite bean, *Cactus latifaria*, *Cassia angustifolia,* leguminose, *Aesculus hyppocastanum, Quercus robur*, *Quercus cerris*, *Quercus rubra, Castanea sativa, Moringa Oleifera,* etc.*)* have been evaluated in CF operations. Premised on the position that the active coagulating species in *Moringa Oleifera* is a cationic protein, researchers have often concluded that the active coagulating species in other fruit seed coagulants are also proteins.

Tannins, a water-soluble polyphenolic compound, have been investigated as either the primary coagulant or coagulant aid in water treatment (Özacar and Sengil [40], [22, 36, 39, 41]. Polyphenols are characterized by the presence of manifold of phenol in the structural units. The anionic nature of tannin is caused by the phenolic groups, which is a good hydrogen donor. Consequent upon the anionic nature of tannins, they are used as natural anionic polyelectrolyte in CF operations.

The use of starch and starch-rich materials either as coagulant or coagulant aid [10], [34, 57] has been reported. Starch is a mixture of two polymers of anhydroglucose units (i.e. amylose and amylopectin) [60]. Albeit, there are reports on the coagulating ability of starch but Oladoja [35] disagreed with this assertion on the premise that the poor cationic charge density of starch precludes it from being a primary coagulant and that the process that was assumed to be coagulation–flocculation was just an adsorption process.

Polysaccharides that have coagulating properties have been extracted from bacteria (e.g. *Alcaligenes cupidus* KT-201, *A. latus* B-16, *Bacillus* sp. DP-152, *Bacillus firmus*, *Arthrobacter* sp. Raats, *Enterobacter cloacae* WD7, *Streptomyces* sp. Gansen and *Cellulomonas* sp. Okoh, *Bacillus* sp. Gilbert and *Pseudoalteromonas* sp. SM9913). The determination of the chemical composition and the surface charge of these polysaccharides showed that they are acidic and the component acid is posited to be one or more of the acidic groups of pyruvate, succinate, uronate, acetate or sulphate [42, 56].

Another natural polymer, alginates, which occur as structural component in marine brown algae (*phaeophyceae*) and as capsular polysaccharides in soil bacteria have been evaluated as a green polymeric coagulant in CF operations. Alginic acid is a linear copolymer with homopolymeric blocks of (1-4)-linked β-D-mannuronate and its C-5 epimer α-L-guluronate residues. Alginates react with polyvalent metal cations, especially calcium ions to produce strong gels or insoluble polymers [11], King [23]. The mechanism of coagulation is postulated to be guided by either charge neutralization cum particle bridging or sweep coagulation during the formation of calcium alginate gel, which is especially more effective at high calcium concentrations [19].

4.6 Research Gap

An overview of the different polymeric coagulants that have been screened for water and wastewater treatment showed the abundance of efforts that have been expended in this regard. Despite the retinue of laboratory reports that showed the comparable efficacy of the polymeric coagulants with the conventional inorganic coagulants, the use of the conventional inorganic coagulants, whose operational efficiency is laced with array of inadequacies are still in vogue.

Amongst the two classes of polymeric coagulants (i.e. synthetic- and natural-based coagulants), the use of synthetic coagulants is gradually becoming more acceptable in the water industries but the inherent challenges synonymous with the use are also a debilitating factor, despite the high operational efficiency that has been reported for its use. Considering the fact that the natural polymeric coagulants are highly biodegradable, non-toxic, non-corrosive, produces less voluminous sludge and does not alter the pH of the water under treatment, they have been found to be the promising alternative to the conventional inorganic coagulants. Despite the favourable features of the natural polymeric coagulants, the use has been restricted to few indigenous people in the under-resourced regions of the world.

In a comprehensive review [35] on headway on natural polymeric coagulants in water and wastewater treatment operations, detailed viewpoints on the research gap that accounted for the poor transition of laboratory findings to field trials and real-life applications in this field of research were chronicled. The synopses of these viewpoints, which gave an insight into the research gap that is militating against the real-life applications of natural polymeric coagulants in water and wastewater treatment, are presented below:

(a) The need to develop efficacious scientific strategies to isolate the active coagulating ingredient from the crude extracts to prevent the unusual overload of the treated water with organic matters.
(b) Development of proven scientific approach for the proper identification of the active coagulating component.
(c) Improper identification of the active coagulating species often leads to conflicting coagulation mechanisms proposed for coagulant derived from the same source
(d) Information on the overall quality characteristics of the treated water, which is pertinent to the evaluation of the overall safety of the treated water are rarely provided in reports from bench-scale studies.
(e) In most cases, the proposed coagulation mechanism by authors is based on speculations and data obtained from unrelated literature and not on any rigorous scientific expedition.
(f) The development of effective advocacy strategies for the dissemination of research findings to the appropriate governmental and non-governmental agencies, who served as an interface between the end-users and the researchers, is required.

4.7 Summary

The shortcomings identified with the use of the conventional inorganic coagulant were the impetus for the development of polymeric-based coagulant in water and wastewater treatment. The inherent skeletal framework of the polymeric coagulant that positioned them as efficacious coagulant is the large molecular weight and, in the case of polyelectrolytes, the charge density. Premised on the skeletal framework of polymeric coagulants, they cannot operate via the CF mechanism that bothered on sweep coagulation, but it can operate with mechanism that is governed by adsorption and bridging, double-layer compression or charge neutralization. Bridging the identified research gaps in this field of research would enhance the chances of getting research efforts in this field transposed from bench-scale to real-life applications.

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