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Review

An insight into the emerging exopolysaccharide gellan gum as a novel polymer

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ABSTRACT

The microbial exopolysaccharides are water-soluble polymers secreted by microorganisms during fermentation. The biopolymer gellan gum is a relatively recent addition to the family of microbial polysaccharides that is gaining much importance in food, pharmaceutical and chemical industries due to its novel properties. It is commercially produced by C.P. Kelco in Japan and the USA. This article presents a critical review of the available information on the gum synthesized by *Sphingomonas paucimobilis* with special emphasis on its fermentative production. Factors affecting the fermentative production of gellan gum and problems associated with mass transfer have been addressed. Classification and trade names of gellan gum has been specified. Characteristics of gellan gum with respect to its structure, physicochemical properties are discussed. An attempt has also been made to review the current and potential applications of gellan gum in food, pharmaceutical and other industries.

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1. Introduction

Throughout the world, there is a growing belief that natural foods are an integral part of a healthy life style. With increasing use of processed and simulated foods, health-conscious consumer needs reduced fat and enhanced fiber foods of all types, so that the food producers have sourced an increasing proportion of the raw materials from nature itself. This objective can be achieved using natural type of materials that have low calorific values, although foods containing such materials need to match the quality of the original product and without adverse dietary effects. It has been remarkably noted that most of the polysaccharides used in the food industry, which have low calorie (except for starch), can interact with water to form new textures and perform specific functions (gelling and thickening agents, emulsion stabilizers, water absorption, fat replacer, *etc.*). Therefore, many nutritional scientists are now greatly interested in the physiological effects of such polysaccharides as health-functional materials.

Recently, with increase in the global environmental problems, greater efforts have been made to develop the effective usage of traditional polysaccharides, because these polysaccharides are environmentally degradable and bioabsorbable.

Especially, the new microbial polysaccharides are of growing commercial importance and are produced on a large scale by industrial fermentation. The microbial polysaccharides can be produced on demand and with consistent quality, so that availability and variability are not a matter of concern (Sanderson, 1990). With the recent development of novel drug delivery systems, it is observed that amongst the various exopolysaccharides, one of the most deserving polymers is gellan gum (Dawalbaje, Dhuppe, & Mitkare, 2012). Gellan gum is one of the widely used fermentation materials, which offers a solution to many problems encountered in the current gelling agents, because it can form a transparent gel in the presence of multivalent cations, which is resistant to heat and acid (Sanderson, 1990; Sworn, 2000). Since gellan gum can provide a wide-range of gel textures by careful control of added salts, these gels can give the same texture as other polysaccharide gels or create new textures. Therefore, gellan gum is one of the most intensively studied polysaccharides and an appropriate model in order to study thermo-reversible sol–gel transition.

Microbial exopolysaccharides have found a wide range of applications in the food, pharmaceutical and other industries due to their unique structure and physical properties. Some of these applications include their utility as emulsifiers, stabilizers, binders, gelling agents, coagulants, lubricants, film formers and thickening agents (Francois, Andre, & Pierre, 1986). Among the biopolymers which are either currently commercial products or which have been the subject of extensive studies are Xanthan from *Xanthomonus camprestris*, Gellan gum from *Sphingomonas paucimobilis* and *Azotobacter chroococcum* (Sutherland, 1994). Gellan gum is one of the industrially useful exopolysaccharide due to its functional properties. It is a Sphingan group heteropolysaccharide secreted by members of bacterial genus *Sphingomonas* (Pollock, 2002).

1.1. History

Gellan gum is the generic name for extracellular polysaccharide produced by bacterium *Pseudomonas elodea*. It was previously referred to by codenames S-60 and PS-60. The gellan gum producing microorganism was isolated from the elodea plant tissue (Kaneleo & Kang, 1979). Further studies revealed that the bacterium was a new strain of species *Pseudomonas*, hence termed as *P. elodea* (Miles, Morris, & O'Neil, 1984). In 1994, it was discovered that gellan gum producing bacterium was *S. paucimobilis*, and classified in α-4 subclass of the proteobacteria (Takeuchi, Sawada, Oyaizu, & Yokota, 1994). In 1992, the USFDA approved gellan gum to be used as a food additive (Pszczola, 1993). Specifications for gellan gum were prepared at 46th Joint Expert Committee on Food Additives (JECFA) in 1996. These are summarized in Table 1.

Table 1
Specifications of gellan gum.

Property	Value
Definition	Gellan gum is high molecular weight polysaccharide produced by a pure culture fermentation of carbohydrates by *Pseudomonas elodea*, purified by recovery with isopropyl alcohol, dried and milled
Molecular mass	Approximately 5,00,000
Description	Off-white powder
Functional uses	Thickening agent, gelling agent, stabilizer, *etc.*
Solubility	Soluble in water, forming viscous solution, insoluble in ethanol
Loss on drying	Not more than 15% (105 °C, 2.5 h)
Lead	Not more than 2 mg/kg
Nitrogen	Not more than 3%
Gel test with calcium ion	Add 1 g of sample, 0.5 g sodium chloride, heat to 80 °C for 1 min. Allow solution to cool to R.T. A firm gel is produced
Gel test with sodium ion	To 1% solution of sample, add 0.5 g sodium chloride, heat to 80 °C and stir for 1 min. Allow solution to cool to R.T. A firm gel is formed.
Isopropyl alcohol	Not more than 750 mg/kg
Microbial criteria	
1. Total plate count	Not more than 10,000 colonies/gm
2. *E. coli*	Negative by test
3. Salmonella	Negative by test
4. Yeasts and molds	Not more than 400 colonies/gm

Table 2
Different strains producing gellan gum.

Strain	Gellan gum yield (g/L)	References
Sphingomonas paucimobilis ATC 31461	35.70	Bajaj and Saudagar (2006)
Sphingomonas paucimobilis E2 (DSM 6314)	8.73	Kim and Lee (1999)
Sphingomonas paucimobilis NK 2000	7.33	Nampoothiri and Singhania (2003)
Sphingom *Sphingomonas paucimobilis* GS1	6.60	Ashtaputre and Shah (1995)

1.2. Strains producing gellan gum

Sphingomonas is a group of gram negative, rod shaped, chemoheterotrophic, strictly aerobic bacteria containing glycosphingolipids (GSLs) in their cell envelopes, and produce yellow pigmented colonies (Yabuuchi and Yano, 1990). The bacterium used for the industrial production of gellan gum is *S. paucimobilis* ATCC 31461 (Kang & Colegrove, 1982; Kang & Veeder, 1982). Different strains producing gellan gum are listed in Table 2.

1.3. Composition of different types of gellan gum

The polysaccharide gellan gum contains a repeating unit composed of β-D-glucose (D-Glc), L-rhamnose (L-Rha) and D-glucuronic acid (D-GlcA). The approximate composition is glucose 60%, rhamnose 20% and glucuronic acid 20%. In addition to these, it contains considerable amounts of non-polysaccharide material such as cell protein and ash, which can be removed by filtration or centrifugation (Jansson, Lindberg, & Sanford, 1983; O'Neil, Silvendran, & Morris, 1983). Structure of gellan gum along with native and deacetylated gellan gum is represented in Figs. 1 and 2 (Manjanna, Pramodkumar, & Shivkumar, 2010). Chemical composition of different types of gellan gum is illustrated in Table 3.

1.4. Conformational transition to double helix – a prerequisite for gel formation

It is found that gellan gum undergoes a thermally reversible coil to double helix transition and junction zones of gellan gum are formed by aggregation of double helical gellan gum molecules. This conformational transition temperature of gellan gum has been reported to be around 30 °C (Milas, Shi, & Rinaudo, 1990). However, the temperatures at which the coil to double helix transition and subsequent aggregation of helices of gellan gum occur in aqueous solutions are influenced strongly not only by the polymer concentration but also by the presence of cations (Miyoshi, Takaya, & Nishinari, 1994). An experiment was carried out to study the effects of sodium cation on the conformational properties of gellan gum in aqueous solutions using highly purified Li-type gellan gum, Na-gellan gum and K-type gellan gum samples by measuring the osmotic pressure, intrinsic viscosity and circular dichroism. It was concluded in the study that the conformational transition temperature increases with increasing polymer concentration but was independent of chemical species of countercations. Also the transition temperature for K-gellan was found to be higher than that for Li and Na-gellan (Etsayu, 2002).

2. Fermentative production of gellan gum

The growth media suitable for the production of different exopolysaccharides by microorganisms vary widely, which reflects the differing role of each polysaccharide in nature. It is essential to consider the effect on polymer biosynthesis rates, yields and composition of varying growth media during fermentative production of these polysaccharides (Margaritis and Pace, 1985).

2.1. Factors affecting production of gellan gum

2.1.1. Media components

Media used for the production of gellan gum consists of carbon source, nitrogen source and inorganic salts. An adequate secretion of exopolysaccharides is observed when the bacteria are supplied with an abundant carbon source and a minimal of nitrogen source (Pollock, 2002). Sometimes complex medium ingredients supplying vitamin can also enhance the cell growth and production (Giavasis, Harvey, & Mc Neil, 2000; Margaritis and Pace, 1985; Martin & Sa-Correia, 1993; Survase, Saudagar, & Singhal, 2007). Effect of various media components on gellan gum production are as follows:

2.1.1.1. Effect of carbon source on gellan gum production. Carbon source is found to be the vital component of the media required for the production of exopolysaccharides as it affects the production yields, composition, structure and properties of bacterial polysaccharide (Fialho et al., 1999). According to Kang and Colegrove (1982) and Kang and Veeder (1982), carbohydrates such as glucose, fructose, maltose, sucrose and mannitol can be used either alone or in combination as carbon source. The amount of carbon source usually varies between 2–4% by mass. Lobas, Schumpe and Deckwer (1992) used glucose as carbon source for the production of gellan gum with approximate yields of 8–10 g/L. Fialho et al. (1999) compared gellan gum production using glucose, lactose and sweet cheese whey as carbon source and yields obtained were 14.5, 10.2 and 7.9 g/L respectively. Banik, Santhiagu, and Upadyay (2007) developed a molasses based medium for the production of gellan gum by *S. paucimobilis* ATCC 31461. They applied Plackett Burman design criterion to study effect of various nutrient supplements on gellan gum production using molasses. Among the

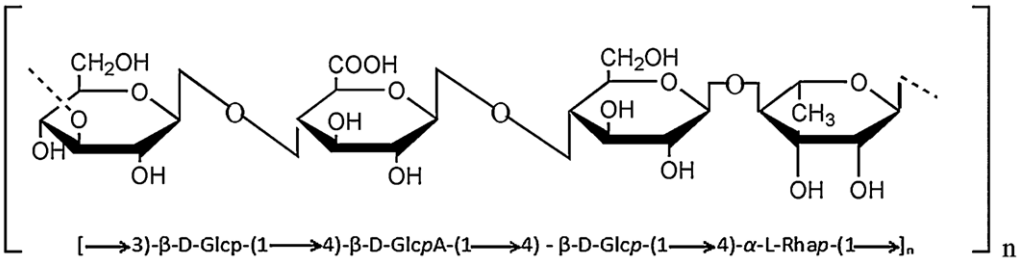

Fig. 1. Chemical structure of gellan gum.

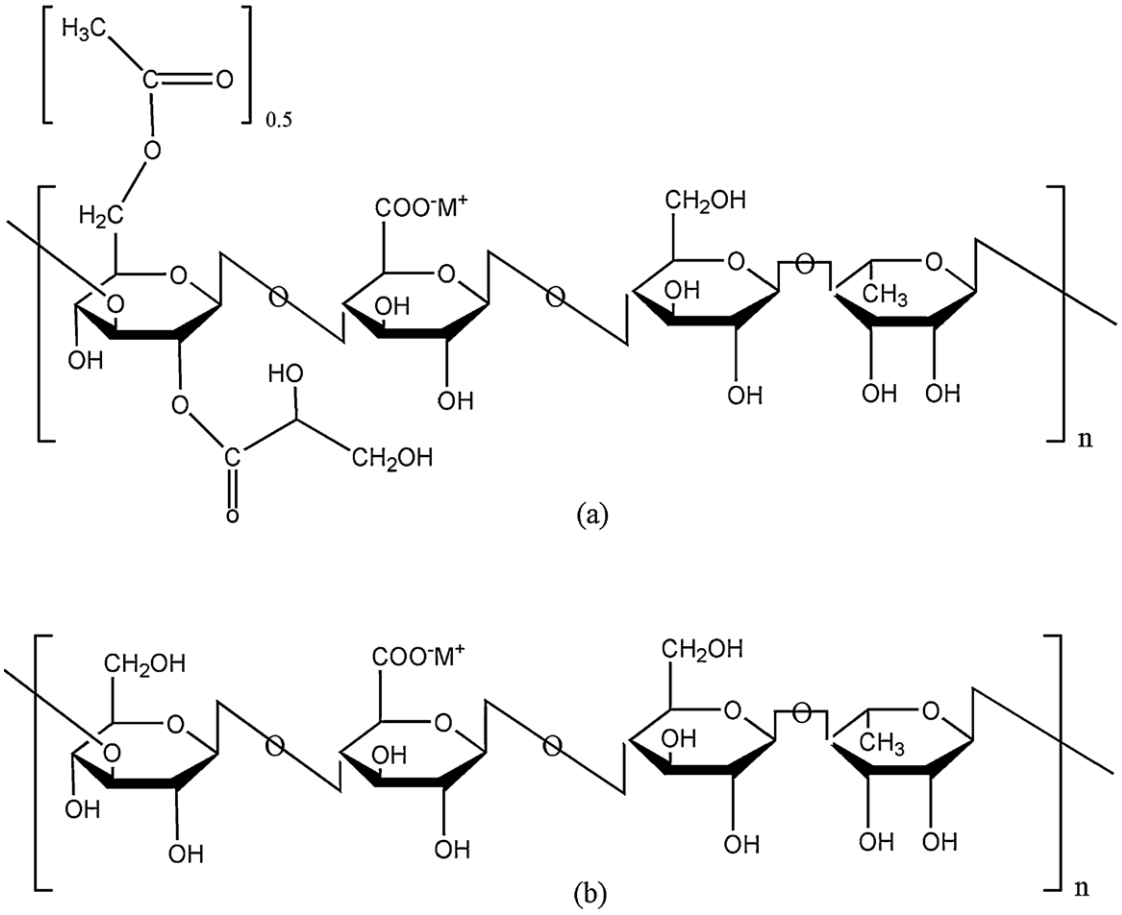

Fig. 2. Chemical structure of native and deacetylated gellan gum.

20 variables tested, molasses, tryptone, casamino acid, disodium orthophosphate and manganese chloride showed significant effect on gellan gum production.

2.1.1.2. Effect of nitrogen source on gellan gum production. Following carbon source, nitrogen is the second most important media. In general, type and concentration of nitrogen source in medium influences the flow of carbon to either biomass or product formation (Ashtaputre and Shah, 1995). With minimal nitrogen, maximum exopolysaccharide was observed. The choice of nitrogen source has a strong effect on gellan broth characteristics. Dreveton, Daniel, and Lonen (1994) reported that organic nitrogen accelerates cell growth and biosynthesis of gellan gum. Hence broth with organic nitrogen is more viscous as compared to the broth without organic nitrogen and hence requires proper impeller system to provide enough oxygen transfer during gellan gum production. Organic nitrogen sources like corn steep liquor (Kang and Colegrove, 1982; Kang & Veeder, 1982) and inorganic nitrogen sources like ammonium nitrate (Lobas et al., 1992) and potassium nitrate (Ashtaputre and Shah, 1995) have been tried for gellan gum production. Hyuck et al. (2003) compared bactopeptone and soyabean pomace (an agroindustrial byproduct) for gellan gum production from *S. paucimobilis* NK 2000 and achieved maximum yield of 3.27 g/L and 7.33 g/L respectively. Bajaj and Saudagar (2006) studied the effect of different nitrogen sources on gellan gum production. Among the various nitrogen sources used, yeast extract supported the maximum gellan gum production.

2.1.1.3. Effect of addition of precursors. Addition of precursor molecules is of considerable importance in polysaccharide synthesis in terms of metabolic driving force. In case of polysaccharide, higher intracellular levels of nucleotide phosphate sugars under nitrogen-limited conditions reportedly enhance metabolite flux of exopolysaccharide synthesis (Kim and Lee, 1999). It is assumed that gellan gum synthesis requires activated precursor before the repeating unit is assembled. These gellan gum precursors were detected by enzyme assays and they were found to be nucleotide phosphate sugars (Giavasis et al., 2000). The repeating unit of gellan gum is a tetrasaccharide composed of glucose, rhamnose and glucuronic acid. The sugar nucleotides providing activated precursors for synthesis of these tetrasaccharide are assumed to be respectively UDP-glucose, TDP–rhamnose and UDP–glucuronic

Table 3
Chemical composition of different types of gellan gum.

Gellan gum	Neutral sugarsGlc/Rha = 6/4	Uronic acid %	Acetyl group %	Protein %	Ash %
Native	69.0	11	3	10	7
Deacetylated	62	13	0	17	8
Deacetylated and clarified	66.5	22	0	2	9.5

acid. Media used for the production of gellan gum usually contains complex media ingredients that supply vitamins and amino acids to enhance cell growth and gellan production (Giavasis et al., 2000). Amino acids have been used by some researchers as nitrogen source or as stimulator of improving gellan gum production (Ashtaputre and Shah, 1995; Nampoothiri and Singhania, 2003). Studies carried out by Bajaj et al. demonstrated that tryptophan at 0.05% concentration gave maximum 139.5 g/L yield of gellan gum.

2.1.2. pH

The pH plays an important role in production of gellan by *S. paucimobilis*, as it significantly influences both cell growth and product formation. The optimal pH value for bacterial polysaccharide production is higher than that of fungal glucan production. The recommended pH value for gellan production ranges from 6.5 to 7 (Dreveton et al., 1994; Manna, Gambhir, & Ghosh, 1996). More acidic or more alkaline environment reduces the cell growth, and consequently gellan production (Nampoothiri and Singhania, 2003).

2.1.3. Agitation rate

An agitation rate of 250 rpm using a helical ribbon impeller is adequate for the mixing of gellan gum broth. Lower levels of agitation were sufficient for homogenous conditions and the broth exhibited gelling characteristics. It was observed that high stirring rates (600–800 rpm) with Rushton turbines lead to cavitations in impeller resulting in formation of stagnant layer due to high shear thinning properties of broth. Consequently, the medium became heterogenous with increased agitation rate, being a major drawback as it causes limitations in heat and mass transfer, and substrate exhaustion in stagnant zones (Dreveton et al., 1994). Giavasis et al. (2000) investigated effects of agitation and aeration on synthesis and molecular mass of gellan gum in batch fermentor cultures of bacterium *S. paucimobilis*. It was observed that high aeration rates and vigorous agitation enhanced growth of *S. paucimobilis*, although gellan gum formation occurred mainly parallel with cell growth. The increased number of cells did not always lead to high gellan production.

2.1.4. Dissolved oxygen and oxygen transfer capacity

Oxygen is suggested as a vital requirement for gellan gum by Rho and Loung (1988). Depletion in oxygen concentration reduced the growth and hence gellan gum production. In contrast to this, Rau (1992) observed an improvement in exopolysaccharide production when cultures of *Sclerotium glucanicum* were grown under limited oxygen supply. To distinguish the above facts, an observation suggested that in case of glucans, exopolysaccharide synthesis follows the growth phase; whereas with gellan, biopolymer is produced at a higher rate during growth phase. Banik and Santhiagu (2006) studied the effects of dissolved oxygen tension (DOT) on cell growth and gellan gum production. It was found that DOT levels above 20% have no effect on cell growth and gellan gum yield however increased to 23 g/L with an increase in DOT levels up to 100% as DOT level acts as a driving force for increased oxygen uptake rate by cells which resulted in higher gellan production. Also higher DOT levels increase viscosity and molecular mass of polymer.

2.1.5. Temperature

The gellan gum production is mostly carried out at 30 °C (Hyuck et al., 2003). It is reported that gellan gum yield reaches its maximum at 20 °C, remains high till 25 °C and significantly decreases above 30 °C (Martin & Sa-Correia, 1993).

2.2. Isolation and purification

Isolation and purification is the crucial step after completion of successful fermentation.

Isolation: As described by Kang, Veeder, and Kaneko (1982), the culture broth is first heated to 90–95 °C for 10–15 min which kills the cells, reduces viscosity of broth and facilitates mixing during precipitation. The polysaccharide is then separated from the cells by filtration or centrifugation. Cell-free supernatant layer was added to ice-cold isopropyl alcohol and mixture was kept at 4 °C for 12 h for complete precipitation of gellan gum. The precipitate formed was then recovered by centrifugation. The product was then dried at 55 °C for 1 h. Clarified gellan gum was obtained by filtration of hot fermentation broth with cartridge filters (0.2 μ), followed by precipitation with isopropyl alcohol.

Purification: The gellan gum obtained after alcohol precipitation was washed repeatedly with acetone and ether. Further it was dissolved in deionised water and dialysed against deionised water by using dialysis tubing with molecular mass cut off of 12,000–14,000. After dialysis for 2–3 days with four or five changes of deionised water, the solution was lyophilized to formulate dry gellan powder (Hyuck et al., 2003). Chromatographic methods like gel filtration chromatography (GFC) can also be employed for purification of gellan gum.

3. Classification of gellan gum

3.1. Native gellan gum

It consists of a backbone of repeating unit of β-1,3-D-glucose, β-1,4-D-glucuronic acid, α-1,4-L-rhamnose and two acyl groups, acetate and glycerate bound to glucose residue adjacent to glucuronic acid (O'Neil et al., 1983).

3.2. Deacetylated gellan gum

The acetyl groups in native gellan gum are removed by alkaline treatment to produce deacetylated gellan gum. The acyl substituents affect the rheology, and deacetylation of native gellan results in a change from soft, elastic, thermoreversible gels to harder, more brittle gels with higher thermal stability (Kang et al., 1982). Steps involved in deacetylation of native gellan gum includes (Kang et al., 1982) immersion of the fermentation broth in boiling water bath for 15 min, followed by cooling and increase in pH up to 10 using 1 M NaOH. The broth was then kept at 80 °C for 10 min and pH was brought down to 7 using 1 M HCl. Cell mass from broth was separated by centrifugation at 8000 rpm for 30 min at 4 °C. The supernatant was then added into three volumes of ice-cold alcohol to precipitate the deacetylated gellan. The precipitated gellan gum was then dried to a constant mass in hot air oven at 80 °C for 12 h.

There are two types of deacetylated gellan gum differentiated on the basis of degree of deacetylation: High acyl gellan gum (partially deacetylated) and low acyl gellan gum (highly deacetylated) (Sanderson & Clark, 1984).

3.3. Clarified gellan gum

Clarified gellan gum results from filtration of hot, deacetylated gellan gum for enhanced removal of cell protein residue. Clarification of gellan gum is of value especially when the gum is to be used as an agar substitute (Kang et al., 1982). The method of clarification of gellan gum was described by Dreveton (1996). Initially, 0.1% solutions of gellan gum were prepared by mechanical stirring at 40 °C for 16 h in deionised water. Then the solutions were heated at 95 °C for 30 min. These heated solutions were then centrifuged at 13,000 × *g* for 30 min. The supernatants obtained were heated to 95 °C and then totally clarified by filtration (0.7 μ).

4. Trade names of gellan gum

4.1. GELRITE

It is a linear polysaccharide comprising of glucuronic acid, glucose, rhamnose and O-acetyl moieties.

Characteristics:

- GELRITE gellan gum disperses and hydrates easily in either hot or cold deionized water, forming viscous solutions in cold distilled water.
- In the presence of soluble salts, GELRITE can be used to provide high gel strength at low GELRITE concentrations, normally at approximately half the concentration required for agar.
- At high temperatures, the low viscosity of GELRITE solutions facilitates pipetting, pumping, and pouring; upon cooling, GELRITE solutions gel quickly and uniformly.
- GELRITE is able to withstand normal autoclaving conditions.
- GELRITE is generally resistant to enzymatic degradation.
- GELRITE itself is chemically inert to most biological growth media additives (additive must be heated to just above GELRITE gel point before incorporation).

4.2. KELCOGEL

It is a hydrocolloid produced by microorganism *Sphingomonas elodea*. Gellan gum is manufactured by fermentation of a readily available carbohydrate raw material. Deacetylation is carried out by treating with alkali. It is commercially available as a free-flowing white powder. It is available in two forms, high acyl and low acyl gellan gum. A comparison of grades of KELCOGEL is shown in Table 4.

4.3. Gel-Gro

Gel-Gro gellan gum is a naturally derived (from *P. elodea*), highly purified polysaccharide. It is an excellent gelling polymer which can be used for a variety of applications in place of agar. Gel-Gro has the ability to form clear gels in the presence of cations, and Gel-Gro gels have agar-like rigidity, thermal stability, clarity and compatibility with nutrient additives. Gel-Gro is an ideal matrix for the preparation of nutrient media for most microbiological applications and plant tissue culture work.

4.3.1. Advantages of Gel-Gro compared to agar

- Gel-Gro may be used at approximately one-fourth to one-half the use level of agar.
- Gel-Gro gels are very clear compared to agar gels.
- Gel-Gro has consistent quality and is not subjected to the uncontrolled natural conditions which affect the basic properties of agar.
- Gel-Gro gels set more rapidly than agar gels reducing plate preparation time.
- Gel-Gro gels are stable at elevated temperatures.
- Gel-Gro contains no contaminating matter often present in agar and toxic to some sensitive organisms.

4.3.2. Chemical composition

It is composed of glucuronic acid, rhamnose and glucose, and O-acetyl moieties.

Appearance: dry, white powder.
Solids: 85–95%
Gel strength: 225–500 g/cm^2 (media formulated with 0.6–0.8% Gel-Gro and 0.10% $MgSO_4$–$7H_2O$).

4.3.3. Characteristics

- Gel-Gro gellan gum hydrates and disperses readily in both hot and cold deionized water. In cold distilled water, it forms viscous solutions.
- Gel-Gro yields high gel strengths at low concentrations |approximately one-half the concentration of agar) in the presence of soluble salts.
- The low viscosity of Gel-Gro solutions at high temperatures permits easy pipetting, pouring and pumping. Gel-Gro solutions gel quickly and uniformly when cooled.
- Gel-Gro can withstand routine autoclaving.
- Gel-Gro is resistant to enzymatic degradation.

5. Applications of gellan gum

Due to its good rheological characteristics, gellan gum is a bacterial polysaccharide with great commercial potential for food, pharmaceuticals, and particularly environmental bioremediation. There are reports that gellan gum can be used in the bioremediation of contaminated soils and aquifers (Johnsen and Karlson, 2004; Moslemy, Guiot, & Neufeld, 2002).

5.1. Applications in food industry (Anderson, Brydon, & Eastwood, 1988; Shungu, Valiant, & Tutlane, 1983)

Gellan gum is a food additive that functions as a stabilizer, thickening agent, structuring and versatile gelling agent in a wide variety of foods and can produce gel textures in food products ranging from hard and brittle to fluid. Types of food products that typically contain gellan gum include: bakery fillings, confections, dairy products, dessert gels, frostings, icings and glazes, jams and jellies, low-fat spreads, microwavable foods, puddings, sauces, structured foods, and toppings.

5.2. Applications in personal care

In cosmetic applications, gellan gum can be used in lotions and creams, make-up, face masks and packs, hair care products, toothpaste, and air freshener gels. Gellan gum can provide effective stabilization and suspension of shampoo and conditioner formulas. It is ideally suited to products requiring a pseudoplastic (shear thinning) rheology.

In creams and lotions, the high yield value of gellan gum fluid gels effectively stabilizes these emulsions and imparts a 'light and silky' feel when rubbed on the skin. Gellan gum also keeps emulsions stable during temperature fluctuations, for consistent quality in transit, as well as on the shelf.

Table 4
Comparison of physical properties of high acyl and low acyl gellan gum.

Name of properties	KELCOGEL (High acyl)	KELCOGEL (Low acyl).
Molecular weight	1–2 × 10^6 Da	2–3 × 10^5 Da (Grasdalen & Smidsrod, 1987)
Solubility	Soluble in hot water	Soluble in hot or cold water
Set temperature	70–80 °C (158–176 °F)	30–50 °C (86–122 °F)
Thermoreversibility	Thermoreversible	Heat stable
Gel formation	Forms gel simply on cooling	Requires cat-ions, acids and soluble solids to form gel

Table 5
Various gellan gum products available in market.

Gellan gum product	Acyl level	Solution clarity	Particle size	Application
KELCOGEL	Low	Transparent	42 (355 μm)	Food
KELCOGEL AFT	Low	Transparent	42 (355 μm)	Industry
KELCOGEL CG LA	Low	Transparent	42 (355 μm)	Pharmaceutical, oral care and personal care
KELCOGEL CG HA	High	Milky	42 (355 μm)	Pharmaceutical and personal care
KELCOGEL F	Low	Transparent	100 (150 μm)	Food
KELCOGEL LT 100	High	Milky	42 (355 μm)	Food
GELZAN CM	Low	Transparent	42 (355 μm)	Microbiological media and plant tissue culture

In suntans and sunscreens, gellan gum stabilizes the oil phase and delivers the important ingredients to the skin in a uniform manner. Gellan gum offers excellent stability over the wide range of temperatures that these products experience.

In toothpaste formulations, gellan gum is beneficial both for its binding properties and its reversible, non-stringy and true-gel structure. It provides excellent flavor release, so significant reductions of flavor and sweetener levels are possible. At typical usage levels, gellan gum contributes very little viscosity during toothpaste preparation allowing the design of fluid formulations that subsequently form a gel after packaging. This low viscosity performance makes manufacturing and packaging easier and allows the incorporation of fragile ingredients such as encapsulated flavors that would not normally be possible with typical binder systems. Blends of low and high acyl gellan gum can produce toothpastes with a variety of binding, stand-up and preparation viscosity.

5.3. Applications in pharmaceutical industry

Gellan gum can be used to produce easy-to-swallow solid dosage forms, such as gels and coated tablets, and to modify the rate of release of active ingredients from tablets and capsules. Gellan gum is also conveniently used for controlled or sustained release of various drugs (Kubo, Miyazaki, & Attwood, 2003; Paul, Morin, & Monsan, 1986) and also for microencapsulation preparation. The bioavailability of theophylline from the gellan gels increases 4–5-fold in rats and 3-fold in rabbits compared to a commercial sustained release liquid dosage form (Miyazaki, Aoyama, Kawasaki, Kubo, & Attwood, 1997).

5.4. Applications in biotechnology Industry

Gellan gum can be used as an alternative to agar for microbiological media (Shungu et al., 1983) and as a bacterial growth media. It is also an ideal medium for plant tissue cultivation (Rozier, Mazuel, & Grove, 1989). It is particularly useful for the culture of thermophilic microorganisms, as the gels are thermostable and can withstand prolonged incubations at high temperatures. In addition, acceptable gel strengths can be obtained using gellan gum at a lower level than agar (Harris, 1985). In these microbiological media applications, the high purity of gellan gum and the water-like clarity of the gels are distinct additional advantages.

In plant tissue culture, gellan gum offers a promising alternative to agar because of its purity (Shimomura & Kamada, 1986). Gellan gum, used at one-fifth of the agar usage level, resists contamination by molds, is easily washed from the plant tissue for transplanting, and allows clear observation of root and tissue development.

It is extremely effective at low levels and forms solid gels at concentrations as low as 0.1%. These are prepared by adding an electrolyte (*e.g.*, a salt, an acid or an anionic surfactant) to a hot gellan solution and then cooling. Air freshener gels are transparent, have a high melting temperature and may contain high levels of fragrance.

In air fresheners, gellan gum enables air freshener gels of crystal clarity to be formulated. The high melting temperature of these gels makes them suitable to be used in hot environments, such as cars.

The utility of gellan gum in various pharmaceutical fields is listed in Table 5.

Various gellan gum products available in market are listed in Table 6.

6. Recent work done on gellan gum

Gellan gum has been recently proposed for cartilage tissue-engineering applications. It can function as a minimally invasive injectable system, gelling inside the body *in situ* under physiological conditions and efficiently adapting to the defect site. So, a study (Oliveira et al., 2009) was carried out using a combination of gellan gum hydrogels and human articular chondrocytes (hACs) which were subcutaneously implanted in nude mice for 4 weeks. The implants were then collected for histological (chemotoxylin, eosin and Alcian blue staining), biochemical (dimethylmethylene blue assay), molecular (real time PCR analysis) and immunological assays. The results showed a homogenous cell distribution and typical round-shaped morphology of chondrocytes within the matrix upon implantation.

Another work using gellan gum in tissue-engineering was done on microfabricated photocrosslinkable polyelectrolyte–complex (PEC) of chitosan and methacrylated gellan gum (Daniela et al., 2012). In this study, photocrosslinkable anionic methacrylated gellan gum was complexed with cationic chitosan and exposed to light forming a PEC hydrogel. This system was found to be potentially useful for a variety of applications including replication of microscale features of tissues for modular tissue-engineering.

It is known that the regenerative capacity of injured adult CNS tissue is very limited. A potential regenerative strategy is stem cell transplantation; however cell survival is found to be typically less than 1%. To improve cell survival, stem cells can be delivered in a biomaterial matrix that provides an environment conducive to survival after transplantation. Hence, gellan gum modified with fibronectin-derived synthetic peptide was used. The study suggested that this strategy may have therapeutic benefit for spinal cord repair (Nuno et al., 2012).

Recently, a new method for the characterization of gellan gum is developed (Danielle et al., 2012). In this method, gellan gum is characterized using a free-solution capillary electrophoresis (CE) or capillary electrophoresis under critical conditions (CE–CC). It is a faster method compared to others in separating the polysaccharide. Gellan gums are shown to be heterogeneous in terms of their electrophoretic mobility at 55 °C revealing: oligomer peak(s), broad peaks of polymers with a random coil conformation with different

Table 6
Various areas highlighting the utility of gellan gum as a polymer.

Drug used	Formulation	Action	Application	References
Clarithromycin	*In situ* floating gel	Anti-bacterial	Gastric ulcers	Dipen (2011)
Levofloxacin hemihydrates	*In situ* floating gel	Anti-bacterial	*Helicobacter pyroli* infections, peptic ulcers	Rajalakshmi (2011)
Naproxen	*In situ* floating gel	Anti-pyretic and NSAID	Rheumatic arthritis, inflammation	Yousif and Khlil (2009)
Cimetidine	*In situ* floating gel	H_2 receptor antagonist	Peptic ulcer	Jayswal (2012)
Acetohydroxamic acid	Floating beads	Anti-bacterial	*Helicobacter pyroli* infections	Brahmeshwar (2007)
Mometasone furoate	Nasal *in situ* gel	Corticosteroid	Allergic rhinitis	Shi-lei (2009)
Metoclopramide HCl	Intranasal microspheres	Anti-emetic	Cancer therapy induced nausea and vomiting, pregnancy, migraine	Hitendra and Surendra (2009)
Glipizide	Gellan gum beads	Hypoglycaemic agent	Diabetes	Rao and Vasundha (2007)
Gellan gum and beverage or food component	Spherical flavored gel bead	Flavourant	Food industry	Chalupa, US Patent
Carvedilol	Hydrogel microspheres	Anti-hypertensive	Hypertension, Angina pectoris	Sunil and Tejraj (2005)
Gatifloxacin	Ocular inserts	Fluoroquinolone antibiotic	Bacterial conjunctivitis	Aashish and Surendra (2009)
Indomethacin	Ophthalmic *in situ* gel	NSAID	Uveitis, inflammation of eyes	Jagdish (2003)
Metformin	Gum cordial/gellan beads	Hypoglycaemic agent	Diabetes	Munish et al. (2010)
Propranolol	Gellan beads	B-blocker	Hypertension	Kedzierewicz (1999)
Paracetamol	Oral *in situ* gel			Wataru, Miyazaki, and David (2007)
Ascorbic acid	Gellan gum films	Nutritional and antioxidant property	Food industry	Paula and Anam (2007)

degrees of acylation (composition), aggregates, and polymers with double-helix conformation.

7. Conclusion

Gellan gum has gained importance in the food or pharmaceutical industries. Its potential use as a replacement for gelatin and agar makes it the most important polysaccharide. The large variety of applications as well as the steadily increasing number of research workers engaged in the studies of gellan gum due to their unique properties, have made significant contribution to many types of formulations and suggest that the potential of gellan gum as a novel and versatile exopolysaccharide will be even more significant in future.

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