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Mini Review

Xanthan, a Versatile Gum With Unique Properties

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Abstract

Xanthan gum is a polysaccharide that is externally produced by the bacterium Xanthomonas campestris. Due to its distinct rheological characteristics, it is currently extensively utilized across a variety of products, such as food items, pharmaceuticals, cosmetics, personal care products, and drilling fluids. This review addressed different aspects of xanthan gum as a naturally occurring polymer, including its historical background, structure, properties, physiological roles, toxicology (safety and regulatory status), methods of analysis and detection, biosynthesis, compatibility with other substances, commercial uses, market size, and future prospects.

Keywords: Xanthan, Xanthomonas campestris, Gum, Viscosity

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Introduction

Numerous novel and valuable polysaccharides with both scientific and commercial significance have been identified throughout the 20th century, which can be derived from microbial fermentation processes (1), including alginate, curdlane, dextran, gellan, glucan, pullulan, and xanthan (2). Dextran, identified in the early 1940s, became the initial microbial polysaccharide to enter the market. Xanthan was the next microbial polysaccharide that was commercialized. It was uncovered in the 1950s by the United States Department of Agriculture (3). Some microorganisms, such as bacteria and fungi, produce three distinct types of carbohydrate polymers:

(1) Extracellular polysaccharides, which can be found either as a capsule that envelops the microbial cell or as an amorphous mass secreted into the surrounding medium
(2) Structural polysaccharides, which can be part of the cell wall
(3) Intracellular storage polysaccharides (4).

Among the various microbial polysaccharides, xanthan is particularly prominent because it can be produced relatively easily and possesses remarkable characteristics. In fact, it is commonly utilized in a diverse array of areas, from additives in food and cosmetics to improving oil recovery processes (5). In addition, this polymer is the most rapidly expanding category within the polysaccharide sector. The highest growth rate of xanthan is projected to occur in food applications, reaching 8.3% annually (6). Microbial polysaccharides are composed of regular repeating units of simple sugars, such as glucose, mannose, fructose, and the like. These polysaccharides are occasionally termed as slime or exopolysaccharides (7, 8). Xanthan is among the most thoroughly studied exoheteropolysaccharides (9). It has a high molecular weight ranging from 1 to 2 million and is generated through the fermentation of carbohydrates by a pure culture of the naturally occurring bacterium Xanthomonas campestris *(10)*. Moreover, it is purified by recovery with alcohol, dried, and mulled (11). Furthermore, xanthan is highly soluble in hot or cold water, hydrates snappily, is formerly dispersed, and provides a water list performing in veritably high-density results at low attention (12). Additionally, its rheological geste enables xanthan to contribute to good sensitive rates, including mouth-sense and flavor release in food (13). Likewise, xanthan results parade largely pseudoplastic inflow. In addition, its viscosity has excellent stability over a wide pH rate and temperature range, and the polysaccharide is resistant to electrolyte assaults and enzymatic declination (14). The polysaccharide responsible for this unusual stability held great promise as a unique new hydrocolloid, if only it could be produced consistently and in large quantities. Fortunately, the bacteria themselves were suitably obliging in terms of chemical uniformity, and as long as the bacteria strain remained pure, everyone would produce the same polysaccharide (15). Xanthan gum represents a synergistic commerce with the galactomannan guar gum and locust bean gum and the glucomannan konjac mannan, resulting in enhanced density with guar gum and at low attention with locust bean gum. Soft, elastic, thermally reversible gels are formed with locust bean gum and konjac mannan at advanced attention (14, 16). Xanthan has become one of the top artificial and food polymers due to its excellent solubility and stability under both acidic and alkaline conditions (17), as well as its stability with salts and its resistance to common enzymes (3).

Historical Outlines

Rutabaga was probably favorable only for those scientists laboring in the Northern Regional Research Laboratory (NRRL) of the United States (U.S.) Department of Agriculture in the late 1950's. At that time, they were striving to comply with a government directive to identify biologically derived products that could be commercialized by the American industry. In addition, they were familiar with the thick, slimy exocellular coating that certain bacteria create to protect themselves from environmental stress. Such coatings are mainly composed of water thickened with a small amount of the polysaccharide synthesized by the bacteria. The NRRL scientists were particularly interested in the polysaccharide produced by the plant pathogen, Xanthamonas campestris. In the 1950s, researchers from the NRRL of the U.S. Department of Agriculture discovered the xanthan gum during a screening process to find microbes that produced commercially valuable water-soluble gums (18). The NRRL team learned how to culture the bacteria and how to produce, isolate, and characterize what they were convinced would be an industrially useful gum. By 1959, they had succeeded in converting rotted rutabaga slime into Polysaccharide B-1459, which is now more commonly known as the xanthan gum (19). This gum was extensively studied because of its properties in several industrial laboratories. The first industrial semicommercial production of xanthan was performed in 1960 as Kelzan® by Kelco® (20), and the product first became commercially available in 1964 (21). Today, xanthan is commercially produced by several companies, including Rhone Poulenc and Sanofi-Elf in France, Jungbunzlauer in Austria, and Merck and Pfizer in the United States (22, 23).

Structure

The xanthan gum's molecular structure (Figure 1) features a polymer backbone of 1,4-linked β-D-glucose, identical to cellulose (24). The trisaccharide side chain imparts a unique quality to the xanthan gum through alternating anhydroglucose units (25, 26). This chain consists of glucuronic acid situated between a terminal mannose unit and mannose acetate. Approximately 60% of these terminal units feature a pyruvate linked to them through a ketal bond. The glycosidic links in the backbone between glucose units restrict molecular movement, which is one of the characteristics of polysaccharides (27).

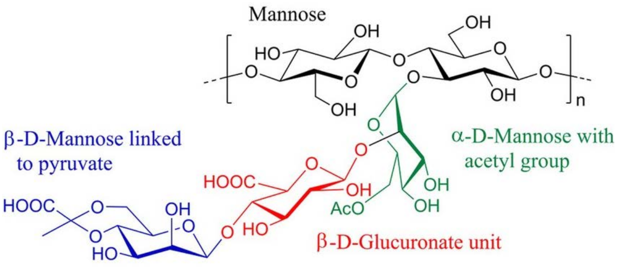

Figure 1. Chemical Structure of the Xanthan Gum

Properties

The most notable property of the xanthan gum is its capacity to create solutions that are highly pseudoplastic and possess a high viscosity when at rest or subjected to low shear forces, often demonstrating a viscosity yield value. This indicates that xanthan solutions behave similar to a thick fluid or soft gel when undisturbed but significantly reduce in viscosity when exposed to shear, such as during stirring or pumping (28). Moreover, the viscosity of xanthan solutions remains consistent across a wide spectrum of salt concentrations, reaching up to 150 g/L of NaCl, as well as over an extensive temperature range up to 90°C, and throughout a broad pH scale from 2 to 11. These distinctive characteristics of xanthan solutions contribute to their exceptional functional properties, including stability and thickening ability, enabling their use in a diverse array of applications (2). Additionally, the xanthan gum exhibits a synergistic effect when combined with various galactomannans (29-31), chitosan (32), and β-lactoglobulin (33), resulting in either heightened viscosity or gel formation, contingent on the specific mixture and its components (2).

Physiological Function

The physiological roles of the xanthan gum have not received as much attention as its production, characteristics, and uses. Bacteria from the Xanthomonas genus, which synthesize the xanthan gum as a secondary metabolite, are typically plant pathogens or may coexist harmlessly with plant tissues or as epiphytes (34, 35). Encasing bacterial cells in exopolysaccharides enhances their survival and boosts resistance to heat and ultraviolet radiation (36, 37). Essentially, the bacterial exopolysaccharide helps retain moisture between cells, which is crucial for colonization (1).

Toxicology Aspects (Safety Alongside Regulatory Status)

Extensive research has been performed on animal models, including dogs and rodent species (mice and rats) regarding the safety of the xanthan gum. Scientific reports following the review of immunological, toxicological, and safety characteristics revealed no acute toxicity, no growth suppression, or no changes in organ weights, blood parameters, or tumor formation in animals fed xanthan, in both short-term and long-term studies. These findings led to its approval by the U.S. Food and Drug Administration (FDA) in 1969, with the Food and Agriculture Organization following in 1974, authorizing xanthan for use in foods without specific quantity limits. The FDA allows xanthan addition to various standardized foods (e.g., cheese, dairy products, dressings, and syrups). France granted approval in March 1978, and Europe followed this process in 1982, assigning it the E number E415. In Europe, the xanthan gum is permitted as a food additive with an “acceptable daily intake not specified,” implying that it can be used as needed for the intended application (3).

Analysis and Detection

Several factors should be considered for characterizing xanthan, including its chemical structure, acetate and pyruvate levels, molecular weight, secondary structure, and rheological properties. Chemical analysis determines the sugar composition and the nature and extent of substituents. Duckworth and Yaphe developed an enzymatic method using lactate dehydrogenase (LDH) as follows (38):

$$\text{Pyruvate} + \text{NADH} + \text{H}^+ \overset{\text{LDH/LD}}{\rightarrow} \text{lactate} + \text{NAD}^+$$

The released nicotinamide adenine dinucleotide is measured at 340 nm. More recent techniques utilize high-pressure liquid chromatography (39) or nuclear magnetic resonance, both enabling simultaneous detection of pyruvate and acetate. The reported molecular weights of xanthan typically range from 4 to 12×10^6 g mol^{-1}. Moreover, the physical and chemical properties of xanthan in water can be explored with atomic force microscopy, a relatively new technique that provides the near-atomic resolution of sample surfaces. Depending on polymer concentration, salt presence, or other hydrocolloids, xanthan can form Newtonian or pseudo-plastic solutions, or gels (40). Finally, rheological behavior is assessed using viscometers to measure shear rate, stress, and viscosity.

Biosynthesis

Xanthomonas campestris bacteria synthesize the polysaccharide at their cell wall surface through a complex enzymatic process during their life cycle. Naturally, these bacteria are found on Brassica vegetable leaves, such as cabbage (41). The xanthan gum is commercially produced from a pure strain of the bacterium through an aerobic submerged fermentation method. The bacteria are grown in an oxygen-rich medium that includes glucose, a nitrogen source, and several trace elements. The inoculum build-up process is conducted in multiple stages to supply seed for the final fermentation phase. Once the final fermentation is complete, the broth undergoes pasteurization in order to eliminate the bacteria, and the xanthan gum is retrieved through precipitation using isopropyl alcohol. Ultimately, the product undergoes drying, milling, and packaging processes (42).

Xanthan Gum Compatibility

Alcohol

Although the xanthan gum does not directly dissolve in alcohol, xanthan gum solutions can mix well with alcohol. Alcohol-containing products can be designed to include as much as 60% water-miscible solvents (e.g., ethanol), allowing it to function as a thickener in alcoholic items, such as cocktails and chocolate liqueurs (14).

Enzymes

The majority of hydrocolloids are broken down to a certain degree by enzymes that are typically found in certain foods. Enzymes frequently found in food systems, including proteases, cellulases, pectinases, and amylases (43), do not break down the xanthan gum molecule. This enzyme resistance is believed to be a result of the configuration of the side chains connected to the backbone. This configuration inhibits the enzymes from targeting the β-(1→4) linkages in the backbone, thus stopping depolymerisation caused by enzymes, acid, and alkali. In practice, the enzyme resistance of the xanthan gum is utilized in food products, such as pineapple items, starch-based systems, spice blends, and various other products with active enzymes (14).

Commercial Applications

1. Food Uses

The xanthan gum is primarily used in food products to regulate the rheological properties of the end result. In executing this functional role, the polymer significantly influences several sensory characteristics, such as texture, flavor release, and appearance, all of which play a crucial part in the product’s acceptability for consumers. Xanthan’s solution characteristics allow it to deliver the desired functionality at a lower concentration than many gums, making it potentially more economical. Furthermore, due to its pseudoplastic characteristics in solution, xanthan presents a less “gummy” mouthfeel compared to gums that display Newtonian behavior. Another benefit of food formulation is xanthan’s antioxidant properties relative to other polysaccharides and additives (44). In addition, xanthan is utilized in creating low-calorie products, representing the second and third generations of fat replacers and stabilizers (45).

2. Cosmetics and Pharmaceutical Uses

The xanthan gum serves as a thickening agent and emulsifier in cosmetics and personal care products. Personal care items, including shampoos, lotions, creams, make-up, hair products, and toothpastes, can incorporate xanthan in their formulations. Moreover, xanthan gives creams and lotions a pleasant “skin-feel” both during and after application. A new xanthan formulation (Ticaxan) has been recently launched in the market for this purpose. In the pharmaceutical sector, xanthan is used to maintain the suspension of medications, such as antibiotics, and to ensure consistent dosage formulations (46). Likewise, it can be utilized to stabilize emulsified cream formulations that include pharmaceuticals. Currently, xanthan is under assessment in controlled-release applications, specifically in gastrointestinal pharmaceutical uses, as rate-limiting membranes for the prolonged delivery of oral formulations (47, 48).

3. Agricultural and Various Industrial Uses

Xanthan is employed in various industrial uses, especially as a thickening or suspending agent. The polymer enhances the flow properties of fungicides, herbicides, and insecticides by evenly dispersing the solid parts of the formulation in a water-based system or by stabilizing emulsions and multiphase liquid formulations (28, 49, 50). Due to its capacity to quickly disperse and hydrate, xanthan is also utilized in jet injection printing. Additionally, it is environmentally friendly and provides an excellent color output. It is further employed in various mining procedures for extracting dissolved metals in a highly efficient manner (51, 52).

Xanthan Market

The xanthan gum leads the microbial gum market, which is expanding at 6–7% annually (53). Global production is estimated at over 50,000 tons per year (54), with a market value between $600 and $800 million (55). In addition, food makes up roughly 70% of overall consumption, with the rest divided among oil production, cosmetics, and various other applications. Overall growth is anticipated to reach around 7.0% per year, with food applications contributing to the majority of the momentum at 8.3% yearly. A market projection indicates that the primary influences on the xanthan market over the next century will be increasing xanthan demand in emerging nations and global energy requirements, thereby promoting enhanced oil recovery activities with a decline in reserves (2).

Conclusion

The achievement of polysaccharides derived from microbes in science and industry is attributed to various factors. They can initially be generated in regulated environments with chosen species; additionally, they frequently exhibit significant structural uniformity, and various microorganisms can produce a diverse array of highly specific ionic and neutral polysaccharides with greatly differing compositions and characteristics. This level of diversity is absent in plant polysaccharides and, possibly more significantly, it cannot be duplicated through synthetic chemistry. The value of water-soluble carbohydrate polymers in industry depends on their diverse functional characteristics. The key feature is their capability to alter the properties of water-based environments, specifically their ability to thicken, emulsify, stabilize, flocculate, swell, suspend, or create gels, films, and membranes. An equally significant factor is that polysaccharides derived from natural, renewable sources are both biodegradable and biocompatible. Xanthan, a biopolymer from the Xanthomonas bacterium, has attracted extensive scientific and industrial attention since its discovery in the late 1950s. In 1999, over 300 citations of articles or patents related to xanthan were documented in Chemical Abstracts, and since then, over 2000 patents have been recorded in the Derwent World Patents Index. This interest arises from xanthan's remarkable characteristics and the effective implementation of an industrial method for its manufacture. It was observed that xanthan solution properties are influenced by the temperature of dissolution, the temperature of measurement, and the existence of other non-xanthan polymers. Despite progress, there remains significant potential for enhancing production and creating new applications.

Competing Interests

The authors declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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