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# Synthesis, physicochemical, structural and rheological characterizations of carboxymethyl xanthan derivatives

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ABSTRACT

The aim of this work was to synthesize a carboxymethylated xanthan (CMXG) via an etherification reaction between different ratios (2, 4, and 6) of xanthan gum (XG) and monochloroacetic acid (MCAA) using the Williamson synthesis method. The synthetized products were characterized in terms of their physico-chemical and rheological properties. Both FTIR and proton nuclear magnetic resonance ($H^1$ NMR) analyses confirmed the grafting of carboxymethyl groups on xanthan hydroxyl groups. The obtained results demonstrated that the degree of substitution was proportional to the chloroacetic acid and xanthan gum ratios. The obtained carboxymethyl derivatives presented greater hydrophilicity and lower molecular weights with increasing degrees of substitution than native xanthan gum. The rheological study revealed that the viscosity of the CMXG derivatives decreased with the degree of substitution and with the conservation of the shear-thinning and weak gel behaviours. The flow curves suggested the existence of two different populations of particles consisting of CMXG particles with a smaller average size and a second population formed by the residual fractions of native XG particles. It was also found that the elastic modulus of XG was largely higher than that of the CMXG derivatives and decreased with increasing DS. For the CMXG derivatives, two regions of viscoelastic behaviour were observed, which were separated by a crossover point corresponding to the critical frequency and relaxation time, i.e., the time required for stress relaxation.



## 1. Introduction

Currently, many types of natural polymers, such as gums, are widely used in the pharmaceutical industry as excipients and are regarded as safe for human consumption. These biomaterials are preferred to synthetic products due to their biocompatibility, low cost and availability (Rashmi, Arora, & Rajesh, 2014).

Xanthan gum as a native polymer is widely used in different fields, such as food, cosmetic and pharmaceutical industries. As a pharmaceutical excipient, it is used as a suspending agent for sustained-release suspensions (Junyaprasert & Manwiwattanakul, 2008) and in sustained-release matrix tablets (Billa, Kah-Hay, Mohamed Ali, & Alias, 2000; Dhopeshwarkar & Zatz, 1993; Lu, Woodward, & Borokin, 1991; Talukdar, Van der Mooter, & Augustijus, 1998). In ophthalmic liquid dosage form, xanthan gum delays the release of active substances, increasing the therapeutic activity of pharmaceutical formulations (Hoepfner, Herbert, Reng, & Schmidt, 2002), and prolongs the retention time of dosages applied to the precorneal area (Ceulemans, Vinckier, & Ludwig, 2002). Xanthan gum can also be used in vaginal (Vermani, Garg, & Zaneveld, 2002) or topical formulations (Chen et al., 2006; Pople & Singh, 2006) to increase bioadhesive strength or as an excipient for spray-drying and freeze-drying processes (Corveleyn & Remon, 1999; Patel, Craddock, Staniforth, Tobyn, & Welham, 2001).

Xanthan gum is a water soluble polysaccharide; however, it presents the disadvantage of a slow rate of dissolution, particularly at high concentrations and in cold water (Su, Ji, Lan, & Dong, 2003). Upon dispersion of xanthan gum in water, lumps called fish eyes are formed (Sandford, Baird, & Cottrell, 1981). This phenomenon is attributed to the bad hydration of xanthan particles that is the consequence of the formation of a gelatinous external layer on the surface of the particles, immediately after dispersion. This gelatinous layer prevents water penetration and the complete dissolution of the particles (Su et al., 2003).

To overcome these limitations, chemical modification of this natural polymer may be necessary to improve its solubility and to develop novel functions that would allow for a wider range of applications (Rana et al., 2011).

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**Nomenclature**

| | |
|---|---|
| $a$ | Mark-Houwink equation parameter |
| CMXG | Carboxymethyl xanthan gum |
| CMX2 | Carboxymethyl xanthan derivative at R = 2 |
| CMX4 | Carboxymethyl xanthan derivative at R = 4 |
| CMX6 | Carboxymethyl xanthan derivative at R = 6 |
| $C_{NaOH}$ | Concentration of NaOH (mol/L) |
| DS | Degree of substitution |
| G' | Storage modulus (Pa) |
| G" | Loss modulus (Pa) |
| K | Consistency index |
| k | Mark-Houwink equation parameter |
| M | Molar mass (g/mol) |
| $m_{CMX}$ | Mass of dry sample (g) |
| n | Flow index |
| $q_{MCAA}$ | Amount of monochloro acetic acid |
| R | Substitution ratio |
| $R^2$ | Coefficient of determination |
| RI | Region I |
| RII–III | Regions II and III |
| T | Transmittance (%) |
| $t_R$ | Relaxation time (s) |
| $V_1$ | Volume of NaOH used for the titration of the sample (mL) |
| $V_2$ | Volume of NaOH used for the titration of the blank (mL) |
| XG | Xanthan gum |
| $\gamma$ | Strain (%) |
| $\dot{\gamma}$ | Shear rate ($s^{-1}$) |
| $\eta$ | Apparent viscosity (Pa.s) |
| $\eta_\infty$ | Apparent viscosity infinite shear rate (Pa.s) |
| $\eta_0$ | Apparent viscosity at zero shear rate (Pa.s) |
| $\tau_0$ | Yield stress (Pa) |
| $\tau_c$ | Critical yield stress (Pa) |
| $\omega$ | Angular frequency (rad/s) |
| $\omega_c$ | Critical yield stress (Pa) |

Among the various methods of the functionalization of biopolymers, carboxymethylation is the most employed technique because it requires few chemicals and simple processing for the chemical reactions (Biswal & Singh, 2004). This technique was used recently for the synthesis of performant biomaterials (Boppana, Kulkarni, Setty, & Kalyane, 2010; Kumar and Ahuja, 2012).

The most interesting derivative of xanthan gum is carboxymethyl xanthan, which is obtained by an etherification reaction between the hydroxyl groups of xanthan gum (XG) and monochloroacetic acid (MCAA) following the Williamson's ether synthesis method (Silva et al., 2004).

As previously reported for guar gum (Honghong et al., 2012), kappa-carrageenan (Leong et al., 2011), and kondagogu gum (Kumar and Munish, 2012), etherification of xanthan gum takes place in two steps. Alkalization is the first step during which the hydroxyl groups of xanthan gum molecules are activated by transforming them into alkoxides (Eq. (1)).

$$XG{-}OH + NaOH \rightarrow XG{-}ONa + H_2O \quad (1)$$

The second step is the formation of carboxymethylated xanthan gum in a reaction between the xanthan gum alkoxide and mononchloroacetic acid (Eq. (2)).

$$XG{-}ONa + Cl{-}CH_2{-}CO{-}ONa \rightarrow XG{-}O{-}CH_2{-}COONa + NaCl \quad (2)$$

Etherification of XG has been previously reported by different authors via different process operating conditions and application targets. Munish, Ashok, & Kuldeep (2012) and Siddhartha and Biswanath (2014) used water as reaction solvent but different concentrations of NaOH and MCAA, reaction times and temperatures. In contrast, Mendes, Erkan, Rui, Helena, & Rui (2012) used a mixture of water and isopropyl alcohol at different mixture ratios to obtain carboxymethyl xanthan gum with different degrees of substitution (DS) during 4-h reactions at 50 °C.

**Table 1**
Quantities of MCAA corresponding to different molar ratios.

| CMXG | CMX2 | CMX4 | CMX6 |
|---|---|---|---|
| R | 2 | 4 | 6 |
| $q_{MCAA}$ (g)/5 g of XG | 1.013 | 2.026 | 3.040 |

The objective of this work was to synthetize carboxymethyl xanthan gum with different degrees of substitution using ethanol as the reaction solvent rather than water or isopropyl alcohol. The obtained xanthan derivatives are intended to be more soluble in water for use as pharmaceutical excipients in various formulations, such as in sustained release tablets or semi-solid preparations as stabilizing agents alone or in combination with other biopolymers.

The etherified derivatives obtained with different DS were characterized by Fourier transform infra-red spectroscopy (FTIR), X-ray diffraction (XRD), proton nuclear magnetic resonance ($H^1$ NMR) and rheological analysis.

## 2. Materials and methods

### 2.1. Materials

Xanthan gum (Rhodicare. S) was purchased from Rhodia-Solvay (France), and monochloroacetic acid, sodium hydroxide, hydrochloric acid, sodium chloride and ethanol were supplied by Sigma-Aldrich (Germany).

### 2.2. Carboxymethylation of xanthan gum

Carboxymethylation of xanthan gum (XG) was similar to that reported by Leong et al. (2011) and by Lefnaoui and Moulai-Mostefa (2015). Five grams of native XG powder was suspended in 100 mL of ethanol and stirred for 30 min at room temperature. Next, 5 mL of NaOH solution (16 N) was added at a rate of 1 mL per 15 min under continuous magnetic stirring at room temperature. Monochloroacetic acid (MCAA) of a specified weight was then added portion-wise to the reaction mixture over a period of 20 min. The reaction mixture was then heated to a temperature of 50 °C during 4 h. The pH of the mixture was first neutralized before the product was filtered via vacuum filtration and washed 2 times with 50 mL of hydro-alcoholic mixture (80% ethanol) and three times with 50 mL of absolute ethanol. The obtained product was then oven-dried (Binder) at 70 °C for 24 h and powdered in a glass mortar. Three powders (Table 1), namely CMX2, CMX4 and CMX6 corresponding, respectively, to ratios of R = 2, R = 4 and R = 6, were characterized by physico-chemical and rheological tests.

### 2.3. Characterization of carboxymethyl xanthan gum

#### 2.3.1. Fourier transform infrared (FTIR) spectroscopy

The samples were subjected to FTIR spectroscopy using a Fourier transform infrared spectrophotometer (Shimadzu, Japan) in the range of 4000–500 $cm^{-1}$ as a KBr pellet (CMXG/KBr = 1:100). Spectrums at 4 $cm^{-1}$ resolution using 10 scans were then recorded.

#### 2.3.2. $H^1$ NMR study

XG and CMXG derivatives were dissolved in $D_2O$ (0.6 mg/mL) at 25 °C to perform the $H^1$ NMR study using a 300-MHz NMR spec-