Rheological and microstructural behaviour of xanthan gum and xanthan gum-Tween 80 emulsions during *in vitro* digestion.

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ABSTRACT

The rheological, texture and microstructure properties of xanthan gum (XG) water solutions and XG emulsions, with and without Tween 80, were investigated and related to the emulsion fat lipolysis during *in vitro* digestion. The effect of digestion on the rheological properties of XG aqueous dispersions and XG-containing emulsions was quite different. The viscoelastic moduli G' and G'' of XG aqueous dispersion decreased after stomach digestion, while an increase was found in the XG emulsion without Tween 80. The viscoelasticity results were explained by the microstructure observations, where fat coagulation in the stomach *in vitro* model (pH 2.5 and pepsin) is observed in the absence of Tween 80, associated with the weaknesses of the XG structure at acidic pH. In all the systems, a decrease in the viscoelastic properties was observed after intestine digestion. In comparison to control emulsions without XG, the XG emulsions partially resist the digestion process, decreasing the quantity of free fatty acids (FFA). In the presence of Tween 80, the decrease in fat digestion was enhanced, the XG-Tween 80 emulsion being the one with the lowest fat digestibility. These results may have important implications for the design of satiating food and food with low fat digestibility.

Keywords: Microstructure, Non-digestible emulsions, Rheology, Xanthan gum

1. Introduction

The design of non-digestible emulsions has gained increasing importance among the rational strategies with which to control excessive dietary fat intake. It has been shown that the rate of fat digestion depends on certain factors, such as the size of emulsion droplets, the degree of mastication, the interfacial composition, the presence of certain food components or the type of emulsifier used. Mun, Decker, & McClements (2007) analyzed *in vitro* digestibility by comparing the influence of different emulsifiers. Tween 20 provided a greater ability to prevent the action of lipase in the emulsified lipids than the other emulsifiers.

In addition to the type of emulsifier, the rheological and structural properties of the continuous phase have also been related to the emulsion digestion properties. The effect of employing gelatin, colloidal casein and a starch dispersion in a 20% oil emulsion with sodium caseinate and monoglycerides as surfactants was studied by Wooster et al. (2014). The incorporation of carboxymethylcellulose in whey protein emulsions reduces the access of lipase to the fat surface, which has been associated with an increase in viscosity (Malinauskyte et al., 2014). Low methoxyl pectin increased fat digestion in 2% corn oil caseinate emulsions, which was attributed to a suppression of fat flocculation by pectin. On the contrary, the incorporation of high levels of pectin in emulsions with lactoferrine and Tween 80 decreases fat digestion, probably due to calcium fixation and the increase in viscosity, which reduces lipase effectivity (Zhang, Zhang, Zhang, Decker, & McClements, 2015). Cellulose ethers have also been found to be an effective tool for the purposes of reducing fat digestion in highly concentrated o/w emulsions (Espert et al., 2017). It is reported that emulsions stabilized by protein-xanthan gum mixtures were more effective for decreasing the digestion rate than whey protein emulsions, as shown by the stability analysis and free fatty acids release rates during *in vitro* digestion (Sun et al., 2018). According to the abovementioned authors, xanthan gum coated proteins located at the interface such that adsorption of lipase and protease was inhibited. On the other hand, xanthan gum altered the mixing and mass transfer processes due to changes in rheology of the mixtures of emulsions and simulated gastrointestinal fluids.

A delayed emptying of the stomach and a prolonged transit of the food through the small intestine has been associated with the control of food overconsumption (Maljaars, Peters, Mela, & Masclee, 2008). A variety of hydrocolloids have been linked with the sensation of satiety, as a consequence of their thickening, gelling and/or non-digestible properties. The acid self-structuring of anionic polysaccharides is regarded as one of the most efficient strategies with which to promote the control of gastric structuring and retard stomach emptying, leading to an enhanced satiety response. Intragastric structural potential has been found in anionic polysaccharides, such as sodium alginate, low methoxyl pectins and low acyl gellan gum. *In vitro* intragastric gelation of a mixed solution of whey protein isolate and pectin has been found (Zhang & Vardhanabhuti, 2014). Methylcellulose with a higher methoxyl content has also been found to increase its viscoelastic properties during incubation at 37°C, as a consequence of thermal gelation (Espert et al., 2017).

Emulsion gelation within the stomach is considered a promising method of preventing emulsion destabilization. In addition, the emulsions that gel intragastrically are anticipated to be highly potent at slowing down the emptying of the stomach, thereby providing an increased sense of fullness (Madadlou, Rakhshi, & Abbaspourrad, 2016).

Emulsifiers have different emulsion-forming abilities due to the differences in how well they adsorb to surfaces, reduce interfacial tensions and prevent droplet aggregation (Ozturk & McClements, 2016). Most polysaccharides are highly hydrophilic molecules that not possess surface activity, and are, therefore, not good emulsifiers. Xanthan gum is a stiff high molecular weight anionic polysaccharide produced by the microorganism *Xanthomonas campestris* (García-Ochoa, Santos, Casas, & Gómez, 2000; Moschakis, Murray, & Dickinson, 2005). Xanthan gum is a representative example of hydrophilic polysaccharide with no surface-active properties; however, it brings about an increase in the viscosity of the aqueous phase, hindering the movement of the drops and, therefore, stabilizing the emulsions. Xanthan gum solutions exhibit shear thinning behaviour, even at very low concentrations, being a suitable thickener for many foodstuffs.

One way to provide surface activity is through the use of surfactants like polysorbates. Polyoxyethylene (20) sorbitan monooleate (Tween 80) is a low molecular weight non-ionic surfactant. By generating short-range hydration/protrusion forces, non-ionic surfactants may prevent emulsion droplets from coming into direct contact with each

other and, hence, can suppress coalescence. Non-ionic surfactants are not influenced by the presence of electrolytes due to the fact that the dimensions of the non-ionic chains are only slightly influenced by electrolyte concentration. Moreover, steric repulsion is fairly insensitive to pH. Emulsifiers are surface-active substances that can be adsorbed at an oil-water interface and prevent the dispersed-phase droplets in emulsions from aggregating. At concentrations higher than the critical micellar concentration (CMC), Tween 80 contributes to a dense adsorption layer, preventing lipase from coming into direct contact with the lipids (Yao et al., 2013). Mun et al. (2007) investigated the intestinal digestion of sodium caseinate, whey protein isolate (WPI) and Tween 20 emulsions. They concluded that the stability of the emulsions to droplet flocculation and coalescence during hydrolysis was dependent on the emulsifier type, with the WPI emulsions being the least stable and the Tween 20 emulsions the most stable.

This study aims to better understand the functionality of xanthan gum during *in vitro* digestion and to evaluate its suitability for either new food applications, such as non-digestible emulsions, or food to increase the sensation of fullness. Three different xanthan gum matrices were studied: a water solution of xanthan gum, a xanthan gum oil water emulsion (without emulsifier) and a Tween 80 o/w emulsion stabilized by xanthan gum. The viscoelastic and textural properties and the microstructure were evaluated after *in vitro* mouth, stomach and small intestine simulation. Free fatty acids were quantified at the end of digestion, as a means of measuring fat digestion.

2. Materials and methods

2.1 Emulsion preparation

2.1.1 Xanthan gum and xanthan gum-Tween 80 emulsions

Four different systems were prepared. These consisted of: sunflower oil (“Koipe Sol”, Deoleo S.A., Spain) (47% w/w), xanthan gum (Cargill, France) (2% w/w) with and without Tween 80 (Sigma-Aldrich Chemical Company) as emulsifier (5%), and water up to 100% (w/w). The XG was first dispersed in the water at room temperature using a Heidolph stirrer at 300-500 rpm for 20 minutes. Then, the oil was gradually added while continuing to stir, increasing the speed up to 1800 rpm. Stirring was maintained for an additional 15 minutes. The 200 g mixture contained in a 500 ml beaker was then

homogenized using an IKA T18 basic (Ultra-Turrax) with the dispersion tool S18N-19G (stator diameter 19 mm and rotor diameter 12.7 mm) at 6500 (1/min) for 30 s, and subsequently at 24000 (1/min) for 60 s. Despite not having emulsifier, the XG emulsions were physically stable at room temperature and they had a weak gel-based structure, which was associated to the high level of XG employed (2%).

Emulsions containing emulsifier followed the same preparation process. In this case, Tween 80 was added before the oil, maintaining the stirring for 5 minutes, and following the same subsequent steps.

The emulsions were stored at room temperature for 24 hours before the measurements.

2.1.2 Control emulsions for the analysis of free fatty acids

To evaluate the effect of XG in fat digestibility, two control emulsions without XG were employed : a whey protein (WP) o/w emulsion and a Tween 80 o/w emulsion. The WP was composed of WP (2%) (w/w), oil (25%) (w/w) and water up to 100%. The Tween 80 emulsion was composed of Tween 80 (5%) (w/w), oil (25%) (w/w) and water up to 100%.

The control emulsions were prepared by dissolving whey protein powder (Best Protein, Barcelona, Spain) or Tween 80 in water at room temperature, stirring at 300 rpm (5-10 minutes) and subsequently adding the sunflower oil slowly. Finally, the mixtures were homogenized under the same conditions as the model emulsions.

2.2 Xanthan gum water solution

A xanthan gum water solution (2% w/w) was also prepared. The XG powder was hydrated by gently mixing with water at room temperature for approximately 20 min (Heidolph stirrer) at 800 rpm, increasing the stirring speed continuously up to 1800 rpm to permit a correct XG hydration.

2.3 *In vitro* digestion model

A three-step *in vitro* digestion model mimicking oral, gastric and small intestinal digestion previously described by Borreani et al. (2017) and Espert et al. (2017) were carried out, maintaining the detailed enzymatic, time and temperature conditions.

Samples were also incubated with only the addition of distilled water, simulating the level of dilution of the stomach and small intestine model. The incubation conditions were the same as those in the digested samples with enzymes.

2.4 Rheological measurements

Small amplitude oscillatory tests were carried at 37 °C using a controlled stress rheometer (AR-G2, TA Instruments) with a Peltier heating system. A serrated plate-plate (40 mm diameter) was employed with 1 mm gap. Vaseline oil was applied to prevent dehydration. The linear viscoelastic region was determined by performing a stress sweep at 1 Hz. Then, frequency sweeps were performed from 10 to 0.01 Hz at a stress wave amplitude within the linear region. The dependence of G' and G'' versus frequency was adjusted to a power law equation:

$$G' = K' * f^{n'}$$

$$G'' = K'' * f^{n''}$$

Where, n' and n'' are the power law indexes related to the slope of the straight lines in the log-log scale; and K' and K'' corresponds to the values of G' and G'' at 1 Hz.

The tests were carried out in the fresh systems (xanthan gum water solutions, xanthan gum-oil systems, and xanthan gum-Tween 80 O/W emulsions) and after incubation in each of the *in vitro* digestion steps (oral, gastric and intestinal), with and without enzymes (effect of water dilution).

2.5 Extrusion properties

The extrusion properties were evaluated using a TA-XT plus Texture Analyzer equipped with the Texture Exponent software (Stable Microsystems, Godalming, UK). A bucket (5 cm in diameter and 7.5 cm in height) was filled with the samples (50 g) and a back-extrusion test was conducted using a compression probe of 4.9 cm diameter. The distance force was 15 mm, the compression rate 1 mm s⁻¹, and the trigger force 10 g. From the force-time profiles obtained, the area under the curve and the maximum force achieved were recorded.

2.7 Microstructure

The microstructure of the emulsions was examined by optical microscopy (Nikon Eclipse 90i, Kanagawa, Japan). A 20x objective was used to observe an aliquot of each sample previously placed on a microscope slide. The systems were observed before and after digestion in the *in vitro* models (mouth, stomach and intestine).

2.8 Free fatty acid release

The release of FFA from the emulsified lipids was determined at the end of *in vitro* digestion by using a titration method previously described by Mun, Decker, & McClements (2007), with some modifications (Espert et al., 2017). Two controls were used without hydrocolloid barrier: a whey protein emulsion and a Tween 80 emulsion (see section 2.1.2).

2.9 Statistical analysis

The data obtained were statistically analyzed by means of an analysis of variance (ANOVA) using Tukey's test in order to establish significant differences between the samples ($P < 0.05$). Calculations were carried out using the XLSTAT statistical software (2009.4.03, Microsoft Excel[®], Barcelona, Spain). The assays were performed in triplicate with samples prepared on different days.

3. Results and discussion

3.1 Effect of *in vitro* digestion on the linear viscoelastic properties

The *in vitro* simulation of the different steps of the digestion process (oral, gastric and intestinal) in the mechanical spectra of the xanthan gum water solution, xanthan gum o/w emulsion and xanthan gum-Tween 80 o/w emulsion is shown in Figure 1.

3.1.1 Xanthan gum water solution

The evolution of G' and G'' versus frequency for the fresh xanthan gum water solution reveals the plateau area of the mechanical spectra with values of G' higher than those of G'' . Xanthan gum produces highly viscous solutions, even at low concentrations (Born, Langendorff, & Boulenguer, 2002; Galindo, 1994; García-Ochoa et al., 2000; McNeely, & Kang, 1973) because of its high molecular weight and its secondary structure (Born et al., 2002; Katzbauer, 1998; Rinaudo, 2001).

Mixing xanthan gum water solution with saliva produces no effect on the shape or on the values of G' or G'' (Figure 1 A). This agrees with previous results, which found no impact of saliva addition on the large or small deformation shear rheological responses in xanthan gum (Choi, Mitchell, Gaddipati, Hill, & Wolf, 2014). However, these authors found an effect of saliva on xanthan gum in filament thinning experiments: the addition of saliva significantly increased filament break-up time in xanthan, whereas it had little effect on the break-up time of the CMC filaments (Choi, Mitchell, Gaddipati, Hill, & Wolf, 2014).

After incubation in the stomach, a significant decrease is observed in both G' and G'' , and an increase in $\tan \delta$ (Table 1), in comparison to the saliva sample, which implies decreased viscoelasticity. To differentiate the effect of the specific conditions of the stomach (pH and enzymes) on the dilution effect, the stomach sample was compared with a stomach water dilution sample (incubation with the same dilution factor and conditions, but at neutral pH and without the addition of pepsin). The stomach sample showed significantly lower G' and G'' values and lower viscoelasticity ($\tan \delta: G''/G'$) than the stomach dilution sample, which revealed a specific effect of the stomach condition on the xanthan gum structure. Due to the anionic nature of xanthan gum, the effect could be related to the decrease in the electrostatic repulsion at acidic pH, creating a more flexible chain.

Finally, after intestinal incubation (neutral pH), the values of G' and G'' increase once again until they are higher than after stomach incubation, despite the greater dilution in the intestinal system. This implies that, at neutral pH, the electrostatic repulsion increases again leading to the expansion of the xanthan gum chains and the increase in viscoelasticity. In the intestinal phase, no differences were found among the intestine sample and the intestine dilution sample.

The dependency of G' and G'' versus frequency was adjusted to a power law equation. The values of the parameters K' , n' (corresponding to G' curves) and K'' , m' (corresponding to G'' curves) for the different samples are shown in Table 2. As observed in the mechanical spectra, the most remarkable effect on the XG water solution systems is the lower value of K' in the stomach than in the stomach water dilution, which implies that the XG water solution is specifically affected at the stomach level by the enzymes and the acidic pH. The n' value, which reflects the dependence of G' versus frequency, was significantly higher in the stomach in comparison with the

stomach water dilution, revealing a greater frequency dependence (steeper slope). An increase in the frequency dependence of G' indicates a decrease in the degree of structure of the system.

3.1.2 Xanthan gum emulsion

During digestion, the xanthan gum emulsion behaved completely differently from the xanthan gum water systems (Figure 1 B). The effect of saliva on the behaviour of the fresh samples was similar in both the water system and the o/w emulsion. The difference between both systems is related to the effect caused by stomach incubation. Contrary to the xanthan water dilution, no appreciable decrease in the values of G' was observed after stomach incubation in the case of the xanthan o/w emulsion when compared to the fresh samples, despite the greater dilution of the stomach samples. The comparison between the stomach sample and the stomach water dilution sample is shown in Table 1. Although no significant differences in G' were found between the fresh sample and the stomach sample, there were significant differences found between the stomach and the stomach water dilution sample. These results imply that the xanthan gum emulsion suffered a structural change at stomach level, which caused an increase in the viscoelastic properties, contrary to what happened in the xanthan gum water solution. The structural changes that explain the increase in viscoelasticity in the emulsions at stomach level are later discussed in the microstructure section. After intestinal incubation, a decrease in the moduli is observed. In this case, no significant differences were found between the intestine sample and the intestine diluted sample. The same conclusions are obtained from the parameters, K' , n , K'' and m (Table 2). The parameter K' , indicative of the consistency of the sample associated with G' , was significantly higher in the stomach than in the stomach dilution sample, this implies that, at that level, an increase in consistency associated with the stomach enzymes and the low pH is observed.

3.1.3 Xanthan gum Tween 80 emulsion

The behaviour of the xanthan gum Tween 80 o/w emulsion when digested is shown in Figure 1 C. In this case, no significant differences were found between the G' and G'' values of the stomach sample and the stomach water dilution sample. Nor were any significant differences found between the K' and n' parameters (Table 2). Therefore,

in the presence of Tween 80, there was no increase in viscoelasticity in the gastric phase. After intestinal incubation, a decrease in the moduli was observed.

3.2 Effect of *in vitro* digestion on textural properties.

The extrusion force versus time corresponding to the fresh, saliva, stomach and stomach water dilution samples are shown in Figure 2 A (xanthan gum water solution), B (xanthan gum o/w emulsion) and C (xanthan gum-Tween 80 o/w emulsion). The texture properties after intestinal incubation were not studied due to the liquid consistency of the samples, which makes measuring impossible. The mean values of the area under the curve and maximum force are shown in Table 3.

Correlations between the texture results and the previously discussed rheological results were found. Accordingly, the xanthan water solution exhibited the greatest decrease in force after stomach incubation, the force of the stomach water dilution sample being greater than that of the stomach sample. In the xanthan emulsion on the other hand, a significantly greater extrusion force was found in the stomach sample than in the diluted one. This behaviour of the xanthan emulsion in the stomach is not observed in the presence of Tween (no significant differences were found between the stomach and the stomach water dilution samples), which may be explained by the fact that the Tween emulsifying properties are maintained after stomach digestion, as later explained in the microstructural section. The increase in consistency of the xanthan gum emulsion (without Tween) at stomach level may be considered an interesting point for applications where what is desired is precisely an increase in consistency at stomach level: for example, for the purposes of delaying gastric emptying or in the design of food for satiety control.

3.3 Microstructure during *in vitro* digestion

The microstructure of the samples was analysed with the aim of better understanding the rheological and textural properties.

The microstructure during digestion is shown in Figure 3. In the fresh xanthan gum emulsions (no emulsifier), the fat globules are very big in size (around 60 and 80µm, respectively), dispersed in a xanthan gum water-based continuous phase. The fat globules are expected to be large, as xanthan gum is not an emulsifier, and only acts as

an emulsion stabilizer by thickening the continuous phase. The incorporation of the Tween emulsifier into the system leads to a marked reduction in the fat globule size (fat globules from 5 to 20 μm).

The incorporation of saliva does not produce a big change in the microstructure in any of the systems. After stomach incubation, coalescence is observed in the xanthan gum emulsion without emulsifier (fat globules higher than 100 μm can be observed). This change in the fat microstructure after stomach incubation explains the increase observed in the viscoelastic properties and the textural parameters, as fat coalescence is associated with an increase in both consistency and viscoelasticity. This phenomenon could be linked to the sensitivity of the xanthan gum structure to the stomach conditions. The weaknesses of the xanthan gel matrix at acidic pH will favour physical contact among the fat globules, which are only stabilized in the system due to the physical support of the xanthan matrix structure. In the presence of the Tween emulsifier, this increase in the size of the fat globules after stomach digestion is not observed, only the appearance of a small degree of fat flocculation is observed,; in this case, fat globules are emulsified by the presence of Tween, which is not affected in the acidic conditions of the stomach, due to their resistant behaviour. Non-ionic surfactants and phospholipids provide more protection in emulsions against lipase-induced destabilization in the presence of bile salts than proteins. The accessibility of pancreatic lipase in emulsions stabilized by surfactants (e.g. Tween 20 and lecithin) is much more limited than in emulsions stabilized by casein and whey protein (Chang & McClements, 2016; Van Aken et al., 2011; Mun, Decker, & McClements, 2007).

After intestinal incubation, there is an observed decrease in the size of the fat globules in the xanthan gum emulsion, in comparison with the stomach microstructure, which is associated with the emulsifying effect of the bile salts present in the intestinal digestion fluid. Xanthan gum does not have surface active properties; therefore, the fat globule surface is freely available for the bile salts to conduct their physiological emulsifying function. On the contrary, in the presence of Tween as emulsifier, no appreciable change in the microstructure of the fat globules can be visualized, revealing the barrier effect caused by both xanthan gum in the continuous phase and also by Tween in the oil interface against the action of the digestive fluids.

3.4 Free fatty acids after *in vitro* intestinal digestion

Two controls were employed to evaluate the effect of both xanthan gum and Tween-80 on fat digestion: a whey protein o/w control emulsion and a Tween-80 o/w control emulsion (Table 4).

The whey protein emulsion exhibited by far the greatest generation of free fatty acid, followed by the Tween control emulsion. The effectivity of Tween in comparison to protein-based emulsifiers against fat digestion has been previously described (Chang & McClements, 2016; Van Aken et al., 2011; Mun, Decker, & McClements, 2007).

In the xanthan emulsions, in both the absence and presence of Tween as emulsifier, a significantly less free fatty acid was generated, in comparison to the controls without xanthan gum (65.6% reduction in comparison to whey protein and 12.5% reduction in comparison to Tween o/w emulsion). This reduction increases significantly in the system where xanthan gum is combined with Tween (84.4% reduction in comparison to whey protein emulsion and 66.6% in comparison to Tween o/w emulsion). The presence of xanthan gum at 2% concentration in the continuous phase, acts as a physical barrier, enhancing the barrier effect of Tween at the oil interface.

4. Conclusions

Xanthan gum at 2% concentration was effective at reducing fat lipolysis in o/w emulsions with 47% fat content. The order of fat lipolysis, from the highest to the lowest, was: whey protein emulsion, Tween-80 emulsion, xanthan gum emulsion and xanthan gum-Tween-80 emulsion (lowest lipolysis).

The viscoelastic properties of a water solution of xanthan gum decrease after stomach incubation, due to the fact that there is less electrostatic repulsion at acidic pH, creating more flexible chains. In this regard, the xanthan gum water solution should not be the first option when an increase in consistency at stomach level is desired. On the contrary, in the XG emulsion, an increase in viscoelasticity is observed at stomach level, due to the fat coalescence and coagulation induced by the weakness of the supporting XG structure. This increase in viscoelasticity at stomach level is not observed if Tween 80 is employed as emulsifier, as Tween 80 functionality is stable at stomach level and no changes in the fat microstructure are observed.

This study opens up new applications for the use of XG in emulsions. In the presence of the Tween 80 emulsifier, the barrier against fat digestion is enhanced. On the other hand, in the absence of an emulsifier, an increase in the consistency of the xanthan gum

emulsion occurs at stomach level, which may be of interest for applications requiring the generation of a feeling of fullness or a delay in gastric emptying.

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TABLES

Table 1. Viscoelastic parameters (at 1 Hz) of the XG water solution and XG o/w emulsions before and after *in vitro* digestion.

Sample	XG WATER SOLUTION			XG O/W EMULSION			XG + TWEEN O/W EMULSION		
	G' (Pa)	G'' (Pa)	tan δ	G' (Pa)	G'' (Pa)	tan δ	G' (Pa)	G'' (Pa)	tan δ
FRESH	160ab (17)	31a (2)	0.193abc (0.010)	305a (6)	37ab (1)	0.120c (0.002)	333a (29)	42a (4)	0.126c (0.004)
SALIVA	193a (4)	32a (1)	0.171c (0.000)	245a (6)	30abc (1)	0.131b (0.001)	298a (40)	37ab (6)	0.125c (0.003)
STOMACH	81c (3)	18b (0)	0.221a (0.008)	297a (37)	39a (6)	0.130b (0.007)	230b (23)	30b (3)	0.132c (0.005)
STOMACH WATER DILUTION	112bc (27)	20b (4)	0.180bc (0.010)	164b (13)	26bc (3)	0.160b (0.008)	204b (14)	31b (3)	0.152b (0.006)
INTESTINE	102c (1)	19b (0)	0.188abc (0.001)	82c (20)	13d (3)	0.161b (0.004)	123c (7)	18c (1)	0.150b (0.004)
INTESTINAL WATER DILUTION	106c (22)	21b (4)	0.202ab (0.005)	104bc (6)	18cd (1)	0.181a (0.000)	112c (4)	20c (0)	0.175a (0.003)

^{abcd} Within the same column, values with the same letter are not statistically different according to the Tukey test ($p > 0.05$).

Values in parentheses are standard deviations.

Table 2. Power law parameters: K' and n (G' versus frequency) and K'' and m (G'' versus frequency) for the different systems and after the different incubation steps.

		$G' = K' * f^n$		$G'' = K'' * f^m$	
		K' (Pa s ⁿ)	n	K'' (Pa s ⁿ)	m
XG WATER SOLUTION	FRESH	129ab (16)	0.12b (0.01)	28ab (1)	0.08a (0.01)
	SALIVA	158a (3)	0.11b (0.00)	30ab (1)	0.06a (0.00)
	STOMACH	63c (4)	0.145a (0.01)	15c (0)	0.09a (0.00)
	STOMACH WATER DILUTION	111abc (24)	0.11b (0.00)	22bc (4)	0.06a (0.01)
	INTESTINE	80bc (0)	0.13ab (0.00)	17c (0)	0.06a (0.01)
	INTESTINE WATER DILUTION	74c (11)	0.13ab (0.00)	17c (2)	0.09a (0.00)
XG O/W EMULSION	FRESH	261a (6)	0.08b (0.00)	37a (1)	0.04b (0.00)
	SALIVA	210a (3)	0.08b (0.00)	30ab (1)	0.04b (0.01)
	STOMACH	250a (39)	0.09ab (0.01)	39a (8)	0.01c (0.01)
	STOMACH WATER DILUTION	135b (9)	0.10ab (0.00)	25abc (3)	0.05ab (0.01)
	INTESTINE	78b (5)	0.10a (0.00)	14c (0)	0.06a (0.00)
	INTESTINE WATER DILUTION	85b (5)	0.11a (0.00)	17bc (1)	0.06a (0.00)
XG + TWEEN O/W EMULSION	FRESH	284a (32)	0.08d (0.00)	40a (6)	0.05ab (0)
	SALIVA	258ab (48)	0.08d (0.00)	36a (7)	0.05ab (0)
	STOMACH	198abc (22)	0.08cd (0.00)	29ab (2)	0.03b (0)
	STOMACH WATER DILUTION	168bcd (16)	0.09b (0.00)	30ab (4)	0.06a (0)
	INTESTINE	106cd (3)	0.09bc (0.00)	18b (0)	0.06a (0)
	INTESTINE WATER DILUTION	93d (4)	0.11a (0.00)	18b (0)	0.07a (0)

^{abcd} For each sample, values in the same column with the same letter are not statistically different ($p < 0.05$) according to the Tukey test.

Table 3. Extrusion parameters of the xanthan gum (XG) water solutions and XG o/w emulsions before and after *in vitro* digestion.

Sample	XG WATER SOLUTION		XG EMULSION		XG + TWEEN EMULSION	
	Area under the curve (N mm)	Maximum force (N)	Area under the curve (N mm)	Maximum force (N)	Area under the curve (N mm)	Maximum force (N)
FRESH	28.78a (2.56)	2.15a (0.16)	17.93a (0.85)	1.19a (0.10)	23.06a (1.28)	1.53a (0.08)
SALIVA	26.59ab (1.61)	2.02a (0.11)	17.04ab (0.29)	1.13ab (0.05)	21.04ab (0.95)	1.40ab (0.06)
STOMACH	17.55c (1.48)	1.27b (0.14)	12.75c (0.93)	0.85c (0.20)	11.77c (1.33)	0.78c (0.09)
STOMACH WATER DILUTION	20.31bc (3.33)	1.47b (0.25)	8.50d (0.80)	0.56d (0.03)	10.90c (1.04)	0.72c (0.07)

^{abcd} Within the same column, values with the same letter are not statistically different according to the Tukey test ($p > 0.05$).

Values in parentheses are standard deviations.

Table 4. Oleic acid values after *in vitro* digestion.

	g oleic acid / g fat
WHEY PROTEIN CONTROL EMULSION	0.32a (0.03)
XANTHAN GUM O/W EMULSION	0.11cd (0.02)
TWEEN CONTROL EMULSION	0.15b (0.01)
XANTHAN GUM + TWEEN O/W EMULSION	0.05e (0.01)

^{abcde} Within the same column, values with the same letter are not statistically different according to the Tukey test ($p > 0.05$).

Values in parentheses are standard deviations.

FIGURE LEGENDS

Figure 1. G' and G'' as a function of frequency at 37 °C of the xanthan gum water solution (A), the xanthan gum o/w emulsion (B) and the xanthan gum Tween 80 o/w emulsion (C) after the different *in vitro* digestion steps.

Figure 2. Effect of *in vitro* digestion on the extrusion profiles. A: xanthan gum water solution; B: xanthan gum o/w emulsion; C: xanthan gum-Tween 80 o/w emulsion.

Figure 3. Microstructure of the fresh xanthan gum o/w emulsions and after *in vitro* digestion at 37 °C.

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Figure 2. Effect of *in vitro* digestion in the extrusion profiles: A) xanthan gum water solution, B) xanthan gum o/w emulsion and C) xanthan gum-Tween 80 o/w emulsion.

Fig. 3. Microstructure of the fresh xanthan gum o/w emulsions and after *in vitro* digestion at 37 °C.