Effect of xanthan gum on palm oil *in vitro* digestion. Application in starch-based filling creams.

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ABSTRACT

The purpose of this study was to investigate the influence of xanthan gum (XG) on the structural changes of palm oil during *in vitro* digestion and to evaluate the application of the XG-palm fat system in filling creams. The textural, rheological and microstructural properties were studied in three systems: a XG-palm fat system, a filling cream with the XG-palm fat system, and a control filling cream with palm oil but without xanthan gum. Free fatty acids were measured at the end of the *in vitro* digestion as indicators of fat digestion and related with the structural changes.

The incorporation of palm oil inside the xanthan gum matrix significantly reduces fat digestion. In comparison to the control cream, the microstructure reveals the presence of undigested fat when XG is present at the end of intestine *in vitro* incubation, while the presence of fat was significantly reduced in the control cream. After stomach incubation, an increase in the extrusion force and in the elastic and viscous modulus was observed in the xanthan gum systems, this was despite the greater water dilution, which was associated with an increase in fat globule size. In the control cream, a decrease in viscoelasticity is observed after stomach incubation.

The results of the present research may have applications in the design of low-fat food and in applications where stomach content structuring is desired.

Key words: *in vitro* digestion, rheology, food structure, structuring/destructuring, palm fat

1. Introduction

In the last decades consumption of high lipid content food stuff has increased in developed countries. This has led directly to a greater prevalence of both obesity and also several afflictions, such as diabetes or cardiovascular illnesses and certain types of cancer (Bray, Paeratakul, & Popkin, 2004; Chajès et al., 2008; Mozaffarian, Aro, & Willett, 2009). The challenge faced nowadays is that of producing nutritional, healthy foodstuffs without neglecting the organoleptic properties, for the purposes of obtaining a high level of consumer acceptance. The reduction of the lipid content poses many problems, as lipids are responsible for several technological and sensorial characteristics of the foodstuffs (Drewnowski, 1992).

Solid fat, rich in saturated fatty acids, cannot be directly replaced by liquid fat without it producing a negative effect on the quality of the final product due to perceptible changes in color, flavor, texture and stability, among other things. This is why there is still a great number of products made using high quantities of saturated and even *trans* fats on the market. Palm oil or fat is one of the most widely used in the Food Industry because of its physicochemical properties. The fact that it is made up of saturated and unsaturated fatty acids (nearly 50/50) makes it ideal for the elaboration of shortenings, ice creams, food for frying, among many others (Mba, Dumont, & Ngadi, 2015). Despite the fact that it contains beneficial compounds, such as vitamin E, carotenoids and sterols (Edem, 2002; Mba, Dumont, & Ngadi, 2015), numerous studies link it with several cardiovascular illnesses due to its high content in saturated fatty acids (Fattore & Fanelli, 2013; Mancini et al., 2015; Sun et al., 2015). However, studies such as that by de Lucci et al., refute this hypothesis and conclude that palm oil produces effects similar to those generated by olive oil on human plasma lipids, due to its oleic acid content. (Lucci et al., 2016).

Several fat substitutes have been developed for the purposes of reducing fat consumption or improving the lipid profile, with physical, chemical and sensorial properties similar to those of fats, but little or no calorie content (ADA, 2005). The fat substitutes are classified according to whether they are based on carbohydrates, proteins or fats. Choosing the fat substitute will depend on the chemical composition and on the food matrix in which it is to be used.

The development of emulsion with low fat digestibility is a recent strategy in the topic of low fat food. The incorporation of hydrocolloids in the continuous phase of emulsions has been found an effective tool to reduce fat lipolysis (Beysseriat, Decker, & McClements, 2006; Gidley, 2013; Pasquier et al, 1996a; Qin, Yang, Gao, Yao, & McClements, 2017). However, there exists some contradictory information regarding the effectivity of hydrocolloids to reduce fat digestion.

Malinauskyte et al. (2014) studied the impact of carboxymethyl cellulose (CMC) on both lipid digestion and on the physicochemical properties of whey protein-stabilised emulsions during digestion. The thickening network formed in the continuous phase by CMC limits the interaction of fat droplets with gastrointestinal fluids, slowing down the rate of lipid digestion. Methylcellulose, chitosan and pectin were also found to be effective (Espinal-Ruiz, M., Parada-Alfonso, F., Restrepo-Sánchez, L.P., Narváez-Cuenca, C.E., & McClements, D.J., 2014), as well as gelatin, colloidal casein and starch dispersion (Wooster et al., 2014). Methylcellulose and hydroxypropylmethylcellulose reduce fat lipolysis in 47% oil emulsion (Espert et al, 2017).

Low methoxyl pectin incorporation into caseinate-stabilized emulsions with 2% corn oil increased the rate of digestion, which was attributed to the pectin exerting a suppressive effect on the flocculation process. However, incorporating high levels of pectin in lactoferrin and Tween 80 emulsion, decreased the digestion rate, possibly due to the calcium fixation and the rise in viscosity that restricts lipase access to the surface of the fat (Zhang, Zhang, Xhang, Decker, & Mc Clements, 2015).

Qiu, Zhao, Decker, & Mc Clements (2015) studied the influence of xanthan gum and pectin on the lipid digestibility of fish oil emulsions stabilized by wheat proteins. In this case, surprisingly, the polysaccharides promoted the lipid digestion process. This fact was associated to their ability to alter the aggregation state of the oil droplets, thereby increasing the amount of lipid phase exposed to the lipase.

Xanthan gum, widely used because of its thickening properties in aqueous solutions (Garcia-Ochoa, Santos, Casas, Gomez, 2000; Palaniraj & Jayaraman, 2011), possess a pseudoplastic behavior that enhances sensory qualities (flavor release, mouth feel) in food products, and the thermal and pH stability of this gum is superior to many other water-soluble polysaccharides (Katzbauer, 1998). It has recently been shown that the use of sunflower oil emulsions estabilised with xanthan gum allows for both the substitution of conventional fat and the reduction in lipid bioaccessibility. It has also

been seen that the presence of xanthan gum during gastric digestion (pH 2) increases the viscosity of the system, producing a possible satiating effect (Espert, Salvador, & Sanz, 2018).

The primary objective of this study was to assess the structure of a palm oil-water system stabilised with xanthan gum after the *in vitro* digestion processes and to evaluate the digestibility of the fat. The second one was to gauge the application of this system as a substitute for conventional fat in food products, such as filling creams. For this purpose, the structural changes during *in vitro* digestion in a filling cream with the palm oil xanthan system and in a control filling were studied and related to fat digestibility.

2. Materials and Methods

2.1 Materials and reagents

Xanthan gum-palm oil system was prepared with commercial palm oil (KECOM TDS, Guinea, Africa), drinking water and xanthan gum (Cargill France SAS). Filling creams were composed of sugar (Disem, Spain), skimmed powdered milk (1% fat) (Central Lechera Asturiana, Spain), starch (CTex 06205, Cargill BV, Netherlands), drinking water and the XG-palm oil system. For the control cream, the XG-palm oil system was replaced by palm oil.

Simulated Saliva Fluid (SSF) was composed of 5.2g of NaHCO_3 , 1.37g of $\text{K}_2\text{HPO}_4 \cdot 3\text{H}_2\text{O}$, 0.88g of NaCl , 0.48g of KCl and 0.44g of $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, dissolved in 1L of bidistilled water. 8.70g of α -amylase from porcine pancreas (A3176-1MU) and 2.16g of mucin from porcine stomach (M2378) (Sigma-Aldrich Chemical Company) were added to this solution (Mishellany-Dutour et al., 2011).

Simulated Gastric Fluid (SGF) was prepared according to a previous study (Sanz, Handschin, Nuessli, & Conde-Petit, 2007) with some modifications. 3.10g of NaCl , 0.11g of CaCl_2 , 1.10g of KCl and 5.68ml of Na_2CO_3 (1M) were dissolved in 1L of bidistilled water. The solution was adjusted to pH 2. 0.15g of pepsin from porcine gastric mucosa (P7000) (Sigma-Aldrich Chemical Company) was dissolved in 1L of SGF.

Simulated Intestinal Fluid (SIF) was composed of an electrolyte solution and bile and pancreatin solutions. The electrolyte solution was prepared by dissolving 1.25g of NaCl, 0.15g of KCl and 0.055g of CaCl₂ in 1L of distilled water. Phosphate buffer solution was prepared (103.5mg NaH₂PO₄·2H₂O and 44.5mg Na₂HPO₄·2H₂O in 100ml of distilled water), setting the pH to 7.0 if necessary to prepare bile (bile extract B8631) and pancreatin (P1750) (Sigma-Aldrich Chemical Company) suspensions. (Sanz et al., 2007).

2.2 Preparation of XG-palm oil system

XG-palm oil system was prepared in the following proportions: water 102g, palm oil 94g and xanthan gum 4g, for a total final mass of 200g. The XG was first dispersed in the water at room temperature using a Heidolph stirrer at 300-500 rpm for 10-12 minutes. Then, palm oil previously heated at 45°C, was gradually added while continuing to stir, increasing the speed up to 1800 rpm. Stirring was maintained until a homogeneous mixture was obtained (10-15 minutes). The total mixture (200g) was 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⁻¹) for 60 s, 13500 (1 min⁻¹) for 60 s and subsequently at 17500 (1 min⁻¹) for 60 s. Finally, it was stored at 5°C for 24 hours before the measurements.

2.3 Filling cream preparation

One filling cream with XG-palm oil system and one control cream without XG were prepared. The ingredients used for the preparation of the different cream formulations are shown in Table 1.

The preparation of the filling creams was performed in a TM31 Thermomix (Thermomix, Vorwerk, Wuppertal, Germany) and was carried out in two stages. In the first step, sugar, milk powder, starch and water were mixed at speed 2 for 6 minutes at 90°C and then the mixture was allowed to cool to 30°C. In the second stage, the palm oil previously heated at 55°C fat (control cream) or the XG-palm oil system was added by mixing at speed 2 for 5 minutes. The resulting creams were stored at 5°C for 24 hours before the measurements.

2.4 *In vitro* digestion

An *in vitro* digestion model, consisting of oral, gastric and intestinal phases previously described by Borreani et al. (2017) and Espert et al. (2017), was used to simulate the digestion process in the gastrointestinal tract in humans.

- Oral phase: 0.5 mL of Simulated Saliva Fluid (SSF) was added to 25 g of sample and mixed for 5 s in a water bath at 37°C.
- Gastric phase: The “bolus” sample from the oral phase was mixed with 8 mL of Simulated Gastric Fluid (SGF) to obtain a final enzyme-sample ratio of 1:250 (v/v). The pH was adjusted to 2.0 with HCl (6 N) (Scharlab S.L., Spain) and the mix was maintained at 37°C in a water bath with continuous stirring (60 min⁻¹) for 1 hour.
- Small intestinal phase: After gastric step, 5.3 mL of bile extract (46.87mg/mL) solution dissolved in phosphate buffer and 2 mL of electrolyte solution were added to the sample, and the pH was adjusted to 7.0 using NH₃ (25% w/w) (Scharlab S.L., Spain). Then, 2.67mL of pancreatin dissolved in phosphate buffer was added to the mix (1:14 (v/v) ratio) and it was incubated for two hours with continuous agitation (60 min⁻¹) at 37°C.

2.5 *Texture analysis*

A TA-XT plus texture analyzer equipped with the Texture Exponent software (Stable Microsystems, Godalming, UK) was used to evaluate the texture of the samples. A back extrusion assay was carried out using an A/BE back extrusion cell (40 mm diameter). 50g of sample were placed into an extrusion cylinder (50 mm diameter and 75 mm height) and the extrusion cycle was applied. The distance force was 15 mm, the compression rate 1 mm s⁻¹, and the trigger force 10g. From the force time profiles obtained, the area under the curve (N s) and the maximum force achieved were recorded.

2.6 *Linear viscoelastic properties*

Linear viscoelastic properties were studied using a controlled stress rheometer (AR-G2, TA Instruments (Crawley, England)) with a Peltier heating system. A 40 mm roughened parallel plate and a gap of 1 mm were used. Samples were protected with vaseline oil (Panreac, Barcelona, Spain) in order to prevent them from drying during measurements. Stress sweep tests were performed at 1 Hz to determine the linear viscoelastic region (LVR). Frequency sweeps were performed from 10 to 0.01 Hz at a stress wave amplitude inside the linear region. Storage modulus (G'), loss modulus (G'') and loss tangent ($\tan \delta = G''/G'$) values were recorded. The tests were carried out in the fresh emulsions and after each digestion stage at a temperature of 37° C.

2.7 Microstructure analysis

The microstructure of the systems was evaluated using light microscopy (Nikon Eclipse 90i, Kanagawa, Japan). A small aliquot of each sample was placed on a glass slide and observed at 20X magnification. The images were captured from fresh samples and after digestion in *in vitro* models of the mouth, stomach and intestine.

2.8 Free Fatty acid (FFA) content

The amount of FFA was determined after total *in vitro* digestion by the previously described titration method (Mun, Decker, & McClements, 2007), with some modifications. After intestinal incubation, 15mL of ethanol (96%) (Scharlab S.L., Spain) was added to the digesta (6.25g of fresh sample with the digestion fluids) and was centrifuged for 10 min at 10.000 rpm (Sorvall® RC-5B Refrigerated Superspeed centrifuge). The total supernatant was quantified and the free fatty acids were determined in 10 ml of the supernatant by titration with 0.05 M NaOH (Panreac Química, Spain) and phenolphthalein (Sigma-Aldrich Chemical Company (St Louis, MO)) as an indicator to end point (pink color). The FFA concentration of the samples was calculated from a standard curve, previously prepared using oleic acid (0, 50, 100, 150, 200 and 250 mM). The total amount of FFA were calculated considering the total volume of supernatant present in each sample. The results are expressed as "g oleic acid/g fat".

2.9 Statistical analysis

For each test, three replicates were performed with samples prepared on different days. An analysis of variance (ANOVA) was performed using XLSTAT statistical software (version 2009.4.03, Addinsoft, Barcelona, Spain). Tukey's test was used to determine the least significant differences ($P < 0.05$).

3. Results and discussion

3.1 Texture analysis

Figure 1 shows the effect of oral and gastric digestion on the extrusion profiles of the palm oil-XG system, the control cream and the cream prepared with the palm oil-XG system. To evaluate the effect associated with water dilution, the profiles corresponding to the water-diluted systems are also shown. Table 2 shows the mean values of the areas under the curve.

The cream with the XG-palm oil emulsion showed the highest extrusion force and AUC, implying the highest consistency.

The effect of saliva (oral digestion) was different in the creams than in the XG-palm oil system. In the latter system, no significant differences were found as regards the AUC of the fresh, saliva and saliva-diluted samples. On the contrary, in both types of creams (with and without xanthan), the addition of saliva produced a significant decrease in the extrusion force, the values of AUC being lower for the saliva than for the corresponding water dilution systems. This structure breakdown in the creams upon incubation with saliva is associated with the presence of starch in the formulation of both creams (Robyt, 2008; Sanz and Luyten, 2006). The saliva structure breakdown in starch-based systems is recognized as a relevant fact for oral processing and for sensory perception (Lapis, Penner, Balto, & Lim, 2017; Prinz, Janssen, & de Wijk, 2007).

After stomach incubation, the significant increase in the extrusion force in the XG- palm oil system is noteworthy. This phenomenon has also been observed in xanthan gum sunflower oil systems and is associated with the weaknesses of the anionic XG matrix

in the acidic stomach conditions, which produce fat coalescence and the subsequent increase in the consistency of the system (Espert et al., 2018).

With regard to the creams' behaviour after stomach incubation, a significant decrease in AUC is observed in the control cream (no xanthan gum), but no significant differences were found between the stomach sample and the water-diluted sample. On the other hand, the creams containing the XG- palm oil system exhibit no decrease in the AUC after stomach incubation. No significant differences were found between the saliva and stomach samples, the AUC corresponding to the water-diluted sample being significantly lower. This phenomenon indicates that the increase in consistency observed in the XG-palm oil system after stomach incubation is also evident in the cream matrix. This increase in consistency in the presence of xanthan gum at the level of the stomach may be an interesting strategy for the possible design of food to increase satiety as, in principle, an increase in the stomach consistency is a good means of promoting satiety signals (Juvonen et al., 2009; Schroeder, Marquart, & Gallaher, 2013).

3.2 Linear viscoelastic properties

To better understand the structural changes that took place, the mechanical spectra were studied. The effect of digestion on the viscoelastic properties of the samples is shown in Figure 2.

The plateau zone of the mechanical spectra was visualized, with values of G' always higher than G'' and only a mild dependence on frequency in the available frequency window. This shape of the mechanical spectra was maintained in all the samples during digestion, with the exception of the control cream, which became fluid after intestine incubation. The XG-palm oil system showed the highest values of G' and G'' (Table 3). Mixing with saliva produced a significant decrease in G' and G'' in the two types of creams (control and with XG-palm oil system), although in the cream with XG-palm oil system no significant difference in viscoelasticity ($\tan \delta$ values) was observed, implying a weaker effect of saliva in comparison with the control cream.

Similarly to the results found in the texture analysis, the presence of xanthan gum affected the behaviour upon stomach digestion. In the XG-palm oil system, the stomach sample showed no significant decrease in comparison with the saliva sample, in spite of the higher dilution level of the stomach. In the Xanthan cream, values of G'

significantly increased and $\tan \delta$ decreased (increase in viscoelasticity) after stomach incubation. As explained before, this increase in the consistency of the system is expected to be associated with fat coalescence and coagulation due to the weakness of the xanthan gum matrix in the acidic conditions, which favours the instability of the fat globules. In the case of the control cream, stomach incubation significantly decreased G' and viscoelasticity.

After intestine incubation, a decrease in both the viscoelastic moduli and the viscoelasticity was found in every system. In the control cream, the viscoelastic properties were not measured due to the fluid behaviour of the sample.

3.3 Microstructure analysis

Light micrographs corresponding to the XG-palm oil system and the two types of creams are shown in Figure 3. The microstructure of the fresh XG-palm oil system corresponds to an o/w emulsion of mainly fat crystals, spheroid in shape, embedded in a continuous phase composed of the hydrated xanthan gum. The microstructure is more complex in the creams and it is composed of gelatinized starch granules, liquid fat and fat crystals embedded in a milk and sugar water dilution (control cream) or in a milk, sugar and xanthan gum one (XG-palm oil cream). The appearance of fat crystals was noticeably more limited in the creams in comparison to the XG-palm oil system, which was attributable to the fat melting while the cream was being prepared. The fat microstructure in both creams was also found to be different. In the control cream, the fat was mainly dispersed as it was not emulsified before its incorporation into the cream, while in the XG –palm oil cream, fat globules are observed.

After saliva incubation at 37°C, most of the fat crystals melt. This phenomenon is particularly evident in the XG-palm oil system, which contains the highest fat proportion. In the creams, saliva induces starch structural breakdown and fat flocculation associated with the mucin present in saliva is observed (van Aken, Vingerhoeds, & de Hoog, 2005), particularly so in the control cream.

After stomach incubation, the control cream exhibits smaller fat globules, while a general increase in the fat globule size is observed in the XG-palm oil cream. This growth in size is in accordance with the increase in the viscoelastic properties found after stomach incubation when in the presence of xanthan gum, and it is associated with

a weakness of the xanthan gum network under the acidic conditions. The carboxylic groups of XG are not ionized at acidic pH, and the electrostatic interactions and the hydrocolloid network become weak. The presence of other gums in an emulsion also increased the droplet size in stomach conditions (Pasquier et al., 1996b).

After intestine incubation, every system experiences important changes in the microstructure. In the control cream, the fat almost disappears and only some remaining fat globules may be visualized. The existing fat is expected to have been digested by the combined action of bile and the lipase activity. In both the XG-palm oil cream and the XG-palm oil system, the fat globules are observed to be smaller, which is associated with the surfactant effect of bile salts; however, an extensive amount of fat globules is observed, implying that the fat digestion process is still not completed. The role played by the xanthan gum network prevents the fat digestion process from functioning effectively (Sasaki & Kohyama, 2012; Espert et al., 2018).

3.4 FFA release during *in vitro* digestion

The amount of free fatty acids released after intestine *in vitro* digestion, expressed as oleic acid, is shown in Table 4. The amount of oleic acid is an indicator of the free fatty acids generated in the system as a consequence of triglyceride digestion by lipase activity. In the digestion process, bile salts adsorb on to the lipid droplet surface facilitating the emulsification of the lipids, then pancreatic lipase adsorbs on to the surface of the emulsified lipids and breaks the fat into free fatty acids (Mc Clements, Decker, & Park, 2007).

The amount of oleic acid was significantly lower in the presence of xanthan gum. Despite both creams having the same initial amount of palm oil, free fatty acid generation in the XG cream was significantly lower than in the control cream. A reduction of 68% in free fatty acid content was found in the XG cream in comparison to the control cream. The incorporation of the palm oil by means of the XG-palm oil system represents a barrier to fat digestion. Bile salts and enzymes have limited access to the oil phase and, therefore, lipase does not act efficiently on the surface of the fat. This FFA reduction agrees with the hypothesis shown by Pasquier et al. (1996b), which indicates that the presence of soluble fibers such as guar gums could alter the emulsification of dietary lipids and, subsequently, lower the extent of fat lipolysis.

Data obtained coincides with the microstructural images, where an almost complete disappearance of the fat globules was found in the control cream; in the cream with the XG-palm oil system, however, a considerable amount of fat globules can still be observed after intestine digestion.

4. Conclusions

The incorporation of palm oil into a cream filling as a XG-palm oil system was investigated. XG-palm oil systems were developed and applied in the formulation of a low-fat cream filling. The texture, rheology and microstructure were studied and related with the fat digestion process.

Systems with xanthan gum showed a significant increase in viscoelastic properties during stomach digestion, which was mainly associated with the acidic pH conditions. This increase in the consistency of the systems may have an application when some type of food structuring is required during digestion; for example, for the purposes of developing food with satiating properties, among other applications.

Moreover, there was less lipid digestion observed in the presence of XG. This is an indicator of the degree of structural resistance provided by the hydrocolloid network in the continuous phase.

In conclusion, the application of XG in a fat matrix is very valuable when designing foods with novel functionalities. Firstly, the greater viscosity of the system in the stomach is expected to slow down gastric emptying, increasing the perception of satiety. Secondly, the decrease in fat bioaccessibility makes the product an interesting option when a fat reduction is desired. Future studies will be focused on the analysis of the XG-palm oil cream sensory properties.

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TABLES

Table 1. List of ingredients of the filling creams.

Ingredients (g/400 g cream)	Control	Cream with XG-palm oil system
Sugar	20	20
Milk powder	8	8
Starch	16	9
Water	262	163
XG-palm oil system	-	200
Palm oil	94	-

Table 2. Area under the curve (AUC) of force versus time values during extrusion.

	DIGESTION STEP	AREA (N•s)
XG-palm oil system	Fresh	4.29 ^B ± 0.45
	Saliva	4.86 ^B ± 1.15
	Saliva dilution	4.56 ^B ± 1.43
	Stomach	8.82 ^A ± 0.58
	Stomach dilution	3.64 ^B ± 0.20
Control cream	Fresh	10.54 ^A ± 0.93
	Saliva	5.01 ^B ± 1.58
	Saliva dilution	8.72 ^A ± 0.10
	Stomach	1.70 ^C ± 0.09
	Stomach dilution	1.43 ^C ± 0.02
Cream with XG-palm oil system	Fresh	15.30 ^A ± 1.27
	Saliva	8.76 ^B ± 1.07
	Saliva dilution	13.40 ^A ± 0.60
	Stomach	7.71 ^B ± 0.98
	Stomach dilution	4.59 ^C ± 0.12

^{ABC} Means in the same column without a common letter differ ($P < 0.05$) according to Tukey's test.

Table 3. Viscoelastic rheological parameters at 1Hz of the different systems, before and after *in vitro* digestion.

	Digestion step	G' (Pa)	G'' (Pa)	tan δ
XG-palm oil system	Fresh	1051.95 ^A $\pm$ 142.91	233.75 ^A $\pm$ 47.59	0.27 ^A $\pm$ 0.05
	Saliva	643.15 ^B $\pm$ 155.06	184.10 ^{A,B} $\pm$ 71.56	0.28 ^A $\pm$ 0.04
	Stomach	519.07 ^B $\pm$ 80.00	123.40 ^{A,B} $\pm$ 48.52	0.23 ^A $\pm$ 0.06
	Intestine	163.83 ^C $\pm$ 6.29	37.31 ^B $\pm$ 2.43	0.23 ^A $\pm$ 0.01
Control cream	Fresh	349.20 ^A $\pm$ 20.39	69.57 ^A $\pm$ 4.40	0.20 ^B 0.00
	Saliva	91.25 ^B $\pm$ 60.46	28.12 ^B $\pm$ 16.38	0.32 ^A $\pm$ 0.03
	Stomach	63.25 ^B $\pm$ 12.56	11.97 ^B $\pm$ 2.37	0.19 ^B $\pm$ 0.00
Cream with XG-palm oil system	Fresh	374.40 ^A $\pm$ 10.25	83.08 ^A $\pm$ 3.66	0.22 ^B $\pm$ 0.00
	Saliva	169.43 ^C $\pm$ 30.21	39.75 ^C $\pm$ 7.82	0.23 ^B $\pm$ 0.00
	Stomach	315.87 ^B $\pm$ 9.85	54.78 ^B $\pm$ 0.63	0.17 ^C $\pm$ 0.00
	Intestine	34.31 ^D $\pm$ 4.79	10.94 ^D $\pm$ 1.08	0.32 ^A $\pm$ 0.01

^{ABCD} Means in the same column without a common letter differ ($P < 0.05$) according to Tukey's test.

Table 4. Oleic acid values generated in the different systems after *in vitro* digestion

	g oleic acid/g fat
XG-palm oil system	$0.06^B \pm 0.02$
Control cream	$0.25^A \pm 0.02$
Cream with XG-palm oil system	$0.08^B \pm 0.01$

^{AB} Means in the same column without a common letter differ ($P < 0.05$) according to Tukey's test.

FIGURE LEGENDS

Figure 1. Effect of *in vitro* digestion on the extrusion profiles. A: XG-palm oil system; B: Filling cream control; C: Filling cream with XG-palm oil system.

Figure 2. G' and G'' as a function of frequency of the fresh samples and after *in vitro* digestion at 37 °C (A: XG-palm oil system; B: Filling cream control; C: Filling cream with XG-palm oil system).

Figure 3. Microstructure of the different systems before and after *in vitro* digestion.

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