Xanthan gum as an alternative to replace the fat for coating and flavoring the extruded snacks

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Abstract

Food industries are modifying their products and processes in order to adapt to the needs and desires of consumers for a healthy diet. Extruded snacks are products where 10-20% of fat is sprinkled on the product to fix flavors, seasonings and salt. Considering the need to flavoring snacks and simultaneously reducing the calorie's intake, an alternative to fat based on polysaccharides, was studied.

This work aimed to evaluate the impact of aqueous xantham gum solutions, at different levels (0.25, 0.5, 1.0 %) under two pH conditions (7.0 and 3.5) as a coating to flavor the snacks, replacing the fat portion. Rheology features of the coatings, in terms of flow behaviour and viscoelastic profile (storage and loss moduli), were assesed. Texture profile analysis, in compression mode, to evaluate the snacks firmness, was applied. Other quality attributes, such as moisture content, water activity, rectraction and agglomeration index of the coated snacks, were also evaluated.

Results for the aqueous xhantan gum coatings were very encouraging showing good coating properties and not damaging the texture of the extrudates, comparing well with the oil-based coatings for sensory evaluation. Sensory analysis results reflected a good overall acceptability of these snacks, comparing to control snacks.

1. Introdution

The extrusion process is commonly used to produce several foods such as salty snack foods, breakfast cereal, pet foods, and pasta. Cereal flours with different granulometric sizes are the main raw materials of these products. For salty snack foods, the most widely employed cereal is maize, which is degerminated and milled to obtain the gritz form. These snacks are products where 10-20% of fat is sprinkled to fix flavors, seasonings and salts.

The manufacture of salty snacks consists of corn gritz extrusion to obtain a product with almost no taste and aroma, composed basically of carbohydrates. To make the product more sensorially attractive, flavoring is performed (Capriles, Soares & Areas, 2007), which consists of spraying 10 to 20% (w / w) of vegetable fat on the extrudates followed by the addition of flavorings, seasonings and salt (Monteiro, Marques, Marchi, Chinellato, Berwig, & Wolf, 2016). Fat plays an important role in this process, as it is responsible for the adherence of flavorings and salt in snack foods. On the other hand, the food industry has been under pressure from regulators and consumers to develop healthier products, since high fat content intake is one of the nutritional factors that can cause obesity and contribute to the onset of serial several chronic diseases (Geremias-Andrade, Souki, Moraes & Pinho, 2017; Salgado, Giraldo & Orrego, 2017). The extruded snack foods present a high calorie value, since the carbohydrates and fat are the major components, being unhealthy food for consumers (Korkerd, Wanlapa, Puttanlek, Uttapap, & Rungsardthong, 2016). Food industries are researching for new healthier alternatives in order to answer the needs of consumers, aligned with the food market trends. Xanthan gum (Xg) is a polysaccharide produced by the microorganism *Xanthomonas campetris* fermentation activity (El-Sayed, El-Gawad, Murad, & Salah, 2002). It is approved for food use and has been widely employed in different food products, due to their emulsifier and tickeness effects and can be used as a fat replacer (Lii, Liaw, Lai, Tomasik, 2002). Furthermore, the xanthan gum acts as a soluble fiber in human body, since it is not absorbed in small gut but is fermented in large intestine by bacteria microbioma, adding nutritional arguments to its use instead of starch (Gularte, & Rosell, 2011). Xantham gum presents a high number of functional properties that justified their extensively use in food industry: solubility in cold and hot water, rapid hydration, water binding capacity generating high viscosity systens even at low levels, thermal and pH stability. In terms of rheology properties, presents shear thining behaviour and have slight variation in viscosity with changing temperature (Gyawali, & Ibrahim, 2016). Considering the need for flavoring snacks and simultaneously reducing the calorie's intake, xantham gum, which acts as a fibre, can be an interesting alternative to replace the fat fraction on coating solution (Busch, Delgado, Santagapita, Wagner, & Buera, 2018; Tunnarut & Pongsawatmanit, 2018).

The use of a thickening agent to replace vegetable fat to coat the flavors in extruded corn chips was performed by Monteiro, et al. (2016) and Marques, Berwig, Monteiro, Oliveira, & Monteiro, (2017), through a complete replacement of fat by cassava starch. From the sensory, nutrititional and shelf-life points of view, these previous works presented positive results. However, based on industrial scale-up, starch solutions generated high agglomeration effects on snacks, making the process industrially unworkable.

This work aimed to evaluate the effect of aqueous xantham gum solutions, prepared at different levels (0.25 up to 1.0%) and two pH conditions (pH 7.0 and 3.5) as fat replacer to coat and flavor the extruded snacks. Rheology properties of xantham gum solutions, based on flow behaviour and viscoelastic functions (storage and loss moduli) were assessed. Firmness of coated snacks were characterized by texture profile analysis, in compression mode. Other quality attributes, such as moisture, water activity, retraction and agglomeration index of the coated snacks, were also evaluated. Sensory analysis by untrained panel, to evaluate the overall aperrance and acceptability of the snacks, was also performed.

2. Materials and methods

2.1. Raw materials

The snacks used were prepared under industrial conditions using only maize grits (KOWALSKI ALIMENTOS S.A., Rio Verde, Brazil), with 1515 of granulometry. Xanham gum (SOSA INGREDIENTS, S.A., Barcelona, Espanha) was used to coat the snacks and soy oil as the control (SADIA, S.A., Santa Catarina, Brazil).

To snacks flavoring, herbs and salt: 25% Parsley, 15% oregano, 10% basil (YOKI ALIMENTOS, S.A., São Paulo, Brazil), and 50% sodium chloride (SAL CISNE, S.A., Rio de Janeiro, Brazil), was employed.

2.2. Snacks extrusion

Snacks were prepared at Laboratory of Cereal Technology at State University of Maringa, Brazil, using a single screw (50 mm in diameter and 200 mm longer) extruder (Inbramaq, model IB-50) with a nominal capacity of 50 kg / h and die plate with two 3 mm diameter holes. A single batch of snacks was prepared with enough sample to carry out all treatments, and then the snacks were dried in a rotating drum at 65ºC for 30 minutes and conditioned in polypropylene bags until the time of use.

2.3. Coating and flavoring of the extruded snacks

Coating solutions were prepared by dispersing xantham gum in destiled water at two pH conditions: pH 7.0 and at pH 3.5, under 10 min at constant mixing, and then storing at room temperature for 7 h, before use. The pH was adjusted by citric acid (MERCK Group, Darmstadt, Germany).

Six treatments using Xg at different levels (0.25, 0.50 and 1.00 %) and two pH values (7.0 and 3.5), were performed. Coating with soybean oil (10%), as well as a blank with no Xg were used as the control.

2.4. Rheology characterization of the coating solutions

The xanthan gum coating solutions were submitted to a rheological characterization using a controlled-stress rheometer (Haake Mars III – Thermo Scientific, Germany) coupled to a UTC-Peltier system for temperature control.

The effect of different levels of xanthan gum addition on coating solutions, based in two fundamental rheology measurements, was evaluated:

Steady shear flow behaviour, using a 2°cone and plate sensor system (PP35), ranging the shear rate from 1.0×10^{-1} to 1.0×10^{3} s^{-1}.

Experimental data of apparent viscosity (η - Pa. s) *versus* shear rate ($\dot{\gamma}$ - s^{-1}), was fitted to the Power-Law model, according to Equation 1:

$$\eta_{ap} = K\,(\dot{\gamma})^{n-1} \qquad (1)$$

where η_{ap} indicates the apparent viscosity (Pa.s), K is the consistency index (Pa.s^n), $\dot{\gamma}$ corresponds to the shear rate (s^{-1}) and "n" is the flow index, the dimensionless parameter of the Power-Law.

Frequency sweep, expressed in terms of the viscoelastic functions, storage (G´) and loss (G") moduli changes, ranging the frequency from 0.001 Hz to 10.0 Hz, at a constant shear stress for each concentration, previously determined by a stress sweep, respectively: 0.25%Xg - 1 Pa; 0.5%Xg - 5Pa; 1.0%Xg - 10 Pa), was assessed. Therefore, viscoelastic functions were determined within the linear viscoelastic region of each sample, previously determined (at 1 Hz). All assays were performed at 20°C and repeated at least three times.

2.5. Texture characterization of coated snacks

The impact of xhantan gum coating solutions at different levels, comparing to a control coating (soybean oil) on snacks firmness values, using a texturometer TA-XTplus (Stable MicroSystems, UK), in compression mode, was evaluated. An acrylic cylindrical probe with 25 mm of diameter (P/25L) at 1 mm.s^{-1} of test speed with a load cell of 5 kg, was applied.

2.6. Moisture, water activity, rectraction (RI) and agglomeration index (AI)

Moisture was determined by oven drying the snacks at 105°C (AACC 44-15.02). The Hygrolab (Rotronic, UK) was used to determine the a_w of the snacks, at constant temperature (20.0 ± 0.2ºC).

The retraction index (RI) was calculated based on the decrease of the specific volume (SV) as a function of time, by measuring the diameter of the spheric coated snacks before and after the coating procedure, according to Equation 2.

$$RI = \frac{Final\ SV}{Initial\ SV} \qquad (2)$$

The agglomeration index was carried out according Nakagawa, et al. (2019), and consisted in measuring how adhesion of each coating type can affect the snacks quality during flavouring mixing. Randomized samples of 100 g snack were weighted after flavouring and drying, and the formation of agglomerates was counted for each type of cover used. A higher counting of agglomerates indicates that the coating adhesion in relation to the snacks is high and may affect the product quality turned it unscalable.

2.7. Sensorial Analysis

Sensory analysis of flavored coated snacks was carried out at Laboratory of the Department of Food Engineering of the State University of Maringá, in sensory evaluation room with individual

cabinets, under white light, at room temperature, by a panel of 112 untrained panelists, ages between 20–35, who were regular consumers of snacks.
Samples with approximately 10 snack units in randomly coded disposable in plastic cups, were served.
The experimental protocol was approved by the Research Ethics Committee of the Maringá State University (protocol CAAE 18718013.3.0000.0104).
Flavored coated snacks were sensory analised after 24 h after preparation, based on their sensory acceptance, scoring with the descriptors: aroma/ taste, appearance and overall acceptability on a nine-point hedonic scale, where 1-"dislike extremely and 9-"like extremely".

2.8. Statistical Analysis

The analyses were performed in triplicate except for hardness where 20 replicates were performed. The results are presented as the average values and standard deviations. The data were analyzed by the statistical analysis of variance (ANOVA) with subsequent post-hoc analysis by the Tukey test at 95% confidence.

3. Results and discussion

3.1. Coating rheology characterization

3.1.1. Flow behaviour

Flow measurements to evaluate the effect of aqueous coating solutions prepared with different levels of Xg addition, as well as the impact of two pH conditions on flow behaviour, were evaluated.
From Figure 1, it can be observed that increasing the concentration of Xg, the apparent viscosity of the aqueous solutions increased significantly ($p < 0.05$).

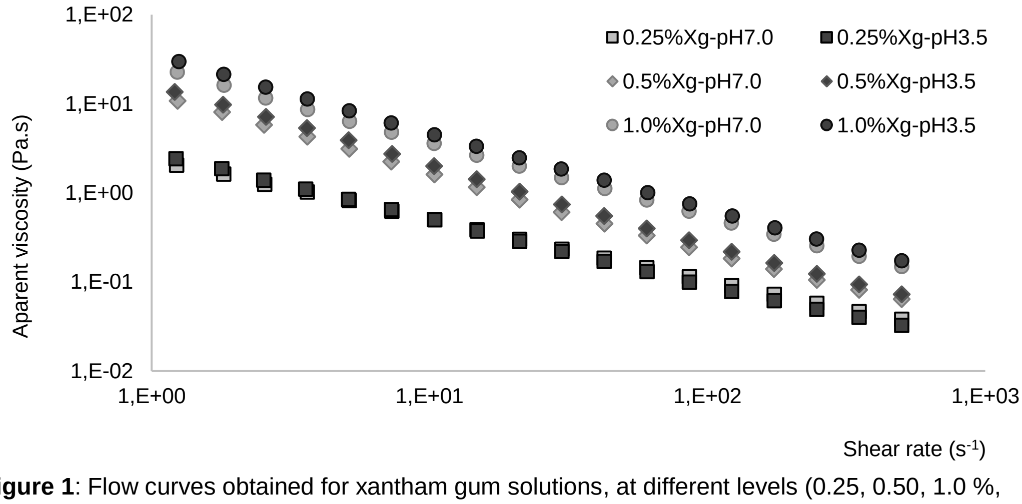

Figure 1: Flow curves obtained for xantham gum solutions, at different levels (0.25, 0.50, 1.0 %, w/w), under two pH conditions (pH 7.0 and 3.5)

In addition, it can also be seen that the viscosity of the Xg solutions decreased as the shear rate increases, revealing a typical shear-thinning behaviour.

These results agree with those obtained by several authors and are typical of hydrocolloids flow behavior, e.g.: Tunnarut, & Pongsawatmanit (2018), from a study of quality modification of seasoning syrup, using Xg as a coating and to enhance properties of a food model. No significant differences on apparent viscosity were registered at the different pH conditions (pH 7.0 and 3.5) tested.

The experimental data was fitted to a Power Law model (Eq. 1), to describe the flow behavior of the aqueous solutions with different Xg additions, and a good correlation was registered (R^2 >0.9993).

Results of fitted rheology parameters are summarized at Table 1. As it can be seen from this table the consistency coefficient (K) values of coating solutions increased as the Xg content increased ($p < 0.05$), varying from around 2.50 Pa.s^n for lower concentration of Xg (0.25%Xg) to 27.00 Pa.s^n for the higher level tested (1.0%Xg). The addition of Xg also changed the flow behaviour index (n) from around 0.30 (0.25%Xg) to around 0.15 (1.0%Xg). Lower flow index value (n) characterizes good mouth feel food properties (Ahmed, & Ramaswamy, 2004). These findings suggested that Xg can be used to enhance the viscosity of the coating solutions and to modify the flow index, increasing the shear-thinning behaviour. From industrial point of view, these rheology features can constitute an advantage to flavoring coating as well as the adhrerence on snacks.

In addition, results showed that both pH conditions tested (pH 7.0 and 3.5) had no significant impact on flow rheology properties, as it was expected since xanthan gum is known to be stable in flow at temperature, ph and salt variations. One can say that pH 3.5 is most favorable to replace soybean oil by Xg aqueous coatings, since this pH is better in terms of snacks preservation and taste.

Table 1: Fitted power law rheology parameters estimated to aqueous coatings obtained with different levels of xantham gum tested (0.25, 0.5, 1.0 %), at two pH conditions (pH 7.0 and 3.5)

	Power-Law parameters		
Coating solutions	**K (Pa.s^n)**	**n-1**	**R^2**
$Xg_{0.25\%\text{-}pH7.0}$	2.50^a	0.33^a	0.9996
$Xg_{0.25\%\text{-}pH3.5}$	2.80^a	0.30^a	0.9993
$Xg_{0.5\%\text{-}pH7.0}$	15.30^b	0.13^b	0.9990
$Xg_{0.5\%\text{-}pH3.5}$	16.00^b	0.12^b	0.9993
$Xg_{1.0\%\text{-}pH7.0}$	27.00^c	0.15^b	0.9994
$Xg_{1.0\%\text{-}pH3.5}$	30.30^d	0.14^b	0.9993

*Different letters (a, b, c, d) within the same column indicate significant statistical differences at $p \leq 0.05$, (Tukey test), compared with the control snacks parameters.

3.1.2. Coating solutions viscoelastic profile

The impact of xanthan gum additions on viscoelastic functions of the coating aqueous solutions, based on storage (G´) and loss (G”) moduli changes, by frequency sweep measurements, was assessed.

From Figure 2 A-C, it is evident that the Xg concentration promoted a significant impact on viscoelastic behaviour of coating solutions. Lower values of Xg (0.25%) (Fig.2A) resulted in a coating solution with a viscoelastic fluid behaviour (Picout, & Ross-Murphy, 2003), expressing values of G” higher than G´, in almost whole range of frequency applied. This behaviour was more pronounced at neutral pH tested. These results are in line with those obtained by Busch, et al. (2018), by rheology characterization a galactomannan extracted from Prosopis ruscifolia seeds. However, increasing the levels of Xg on aqueous solutions a typical weak gel behaviour (Picout, & Ross-Murphy, 2003) can be observed, by the dominance of the G´values over the G”, with a slight frequency dependence (Razmkhah, Razavi, Mohammadifar, 2017). A remarkable effect on coating structuration was obtained for higher level of Xg tested (1.0%Xg), and no significant impact of the pH conditions tested was registered. Intermediate Xg concentration (0.5%Xg) revealed a certain instability under neutral pH tested, at lower frequency values.

It can be stated that the concentration of Xg has an important role on coating solutions structuration, and the acid pH conditions is preferable to guarantee the stable viscoelastic properties.

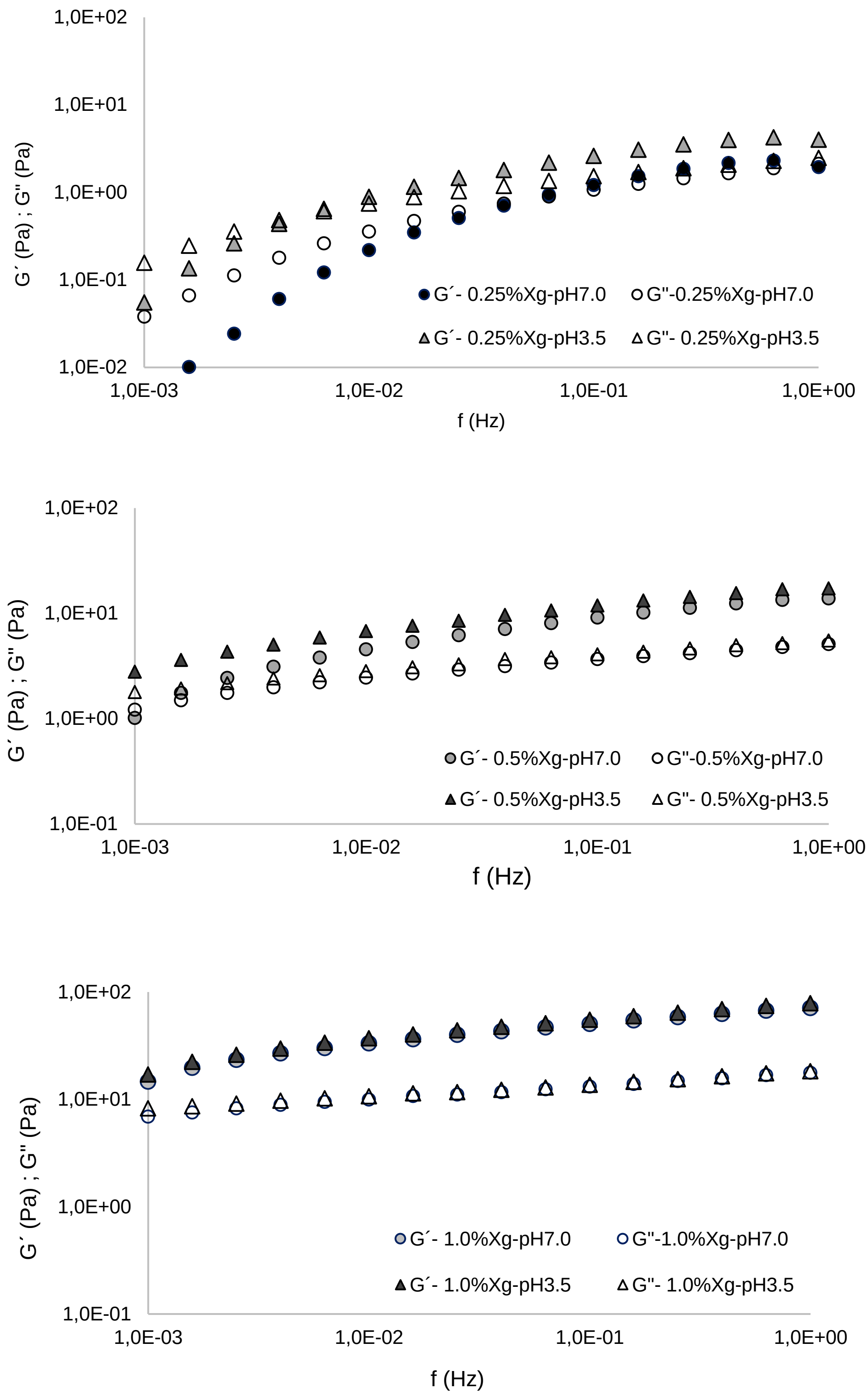

Figure 2: Viscoelastic profile, express in storage (G´) and loss (G”) moduli (in Pa), of the aqueous solutions produced with different levels of Xg addition (0.25, 0.5 and 1.0%), at two pH conditions (pH 7.0 and 3.5)

3.2. Charaterization of the flavored coated snacks

The effect of the coating solution, with different Xg content, at two pH conditions (pH 7.0 and 3.5), was evaluated based on snacks quality parameters: texture profile in terms of firmness, water activity (aw), retraction and agglomeration index. Results of snacks quality attributes was compared to control, i.e., snacks coated by soybean oil (10%).

Figure 3 shows the impact of the flavoring coating solutions, at different levels of Xg and pH conditions, on snacks firmness values, ranging from 50.48 N for control snacks (coated by soybean oil) to 49.52 N (pH 7.0) and to 53.41 N (pH 3.5) for higher level of xhantan gum used as coating (1.0%Xg). As it can be seen (Fig.3), significant differences were only observed at snacks coated with 0.25% of Xg under both pH conditions, and for coating solutions obtained with 0.5 % of Xg at pH 7.0.

These results showed some consistency with those obtained by rheology characterization, since the coatings solutions obtained from 0.25% and 0.5% of Xg under pH 7.00 showed certain rheology instability, that can influence negatively the texture of snacks after coating.

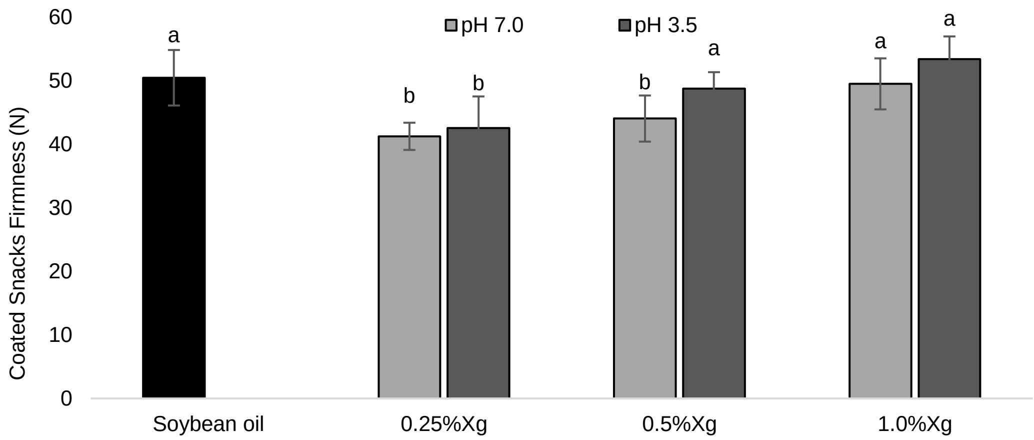

Figure 3: Comparation of the firmness values of flavored coated snacks, with a aqueous xhantan gum solution, at different levels (0.25, 0.5, 1.0 %) and pH conditions (pH 7.0 and 3.5) in comparison to control snacks flavored coated by soybean oil (10%)

These results suggest that xhantan gum solutions obtained with 0.5% and 1.0 %, at acid conditions, can be a potential fat replacer to produce a coating solution to flavour the snacks, since the firmness values of these snacks presented no significant differences, comparing to control (with soybean oil).

Texture and moisture are important quality parameters directly related to the acceptance of snacks by consumers (Wami, & Kumar, 2016).

From Table 2, moisture values of the snacks coated with aqueous xhantan gum solutions showed no significance differences, comparing to control snack values, varying from 4.98 % for control to 5.01 % (pH 7.0) and to 5.18 % (pH 3.5) for 1.0%Xg solution. The same trend was also observed on water activity (a_w) values, ranging from 0.183 for control to 0.186 (pH 7.0) and 0.182 (pH 3.5) for 1.0%Xg. Water activity is a quality parameter highly related to food stability, based on chemical rections and microbial growth (Tunnarut, & Pongsawatmanit (2018), since it is directly related to the immobilization of the system, with molecules "freezed" inside the structure at low values of a_w (free water), unable to react or to feed microorganisms. In addition, no significant differences ($p > 0.05$) between the different treatments applied, on moisture and water activity values was obtained, compared to control snacks.

These results of moisture content and water activity can be attribute to the water binding and holding capacity of xhantan gum (Gyawali, & Ibrahim, (2016).

Similar findings were obtained by other authors (Busch, et al. 2018), by rheology characterization of vinal gum (e.g.: xhantan gum), with different pH and ionic strength conditions.

Retraction index (RI) is another quality parameter widely used to physical characterization of the coated snacks, based on the relationship between the final volume (flavored and coated snacks) and the initial volume (before flavoring and coating procedure). Table 2 shows the results obtained for the retraction index, where no significant differences can be observed between control and coated snacks by xhantan gum aqueous solution. These results are in line with those obtained by Monteiro, et al. 2016, studing the potential of fat replacement by an aqueous solution of cassava starch, to coating the snacks.

Table 2 : Quality parameters of flavored coated snacks, by aqueous xhantan gum solutions, (0.25, 0.5, and 1.0 % of Xg) under two pH conditions (7.0 and 3.5), compared with control snacks (soybean coating, 10% – SBo10%): moisture (%), water activity (aw) and rectraction index *

Coating solution	Moisture (%)	Water activity	Retraction Index
SBo10%	$4.98^a \pm 0.19$	$0.183^a \pm 0.003$	$0.968^a \pm 0.008$
Xg0.25%pH7.0	$5.08^a \pm 0.13$	$0.209^b \pm 0.003$	$0.966^a \pm 0.009$
Xg0.25%pH3.5	$5.10^a \pm 0.15$	$0.210^b \pm 0.003$	$0.969^a \pm 0.011$
Xg0.50%pH7.0	$4.97^a \pm 0.26$	$0.187^a \pm 0.004$	$0.962^a \pm 0.007$
Xg0.50%pH3.5	$5.01^a \pm 0.13$	$0.185^a \pm 0.003$	$0.986^a \pm 0.009$
Xg1.00%pH7.0	$5.05^a \pm 0.22$	$0.186^a \pm 0.005$	$0.985^a \pm 0.008$
Xg1.0%pH3.5	$5.18^a \pm 0.26$	$0.182^a \pm 0.002$	$0.997^a \pm 0.007$

*Different letters (a, b, c) within the same column indicate significant statistical differences at $p \leq 0.05$, (Tukey test), compared with the control bread parameters.

Regarding the agglomeration index, the results obtained (data not shown) suggested that the xhanthan gum solution showed to be an efficient coating to flavour the snacks and can be sucefully used in industrial scale-up as a coating, since no agglomeration effects were observed. This result shows problably be better than that found by Nakagawa, et al. (2019) with guar gum and starches, in which up to 20 agglomerates were obtained in 100 g of sample.

3.3. Sensorial analysis

The results of sensory analysis obtained for the flavored snacks by coating with aqueous Xg solutions, in comparation to control snacks flavored by coating with soybean oil, showed no significant differences detected in, appearance, flavor/aroma and overall acceptability, with high scores around 7 to 8, between all the chips evaluated from all the coatings and blanks tested. The overall acceptability scored very high as well, around 8.3.

Therefore, results for sensory characteristics indicated that a replacement of fat (soybean oil) by xhantan gum can be a potential industrial procedure to produce coating solutions, with no significant impact on overall consumer acceptability, and a considerable reduction on calories.

4. Conclusion

From this study, the potential of xhantan gum as fat replacer in flavor coating solutions of extruded snacks was evaluated, focused on rheology properties of the solutions and quality parameters of the coated extrudates.

Results of the present work, based on coating rheology properties, showed that 0.5 and 1.0% of xhantan gum at acid pH (3.5) condition, can be used to produce coating solutions with desirable rheology features in terms viscosity and shear thinning behaviour, expressing a weak gel-like structure in terms of viscoelastic functions.

Based on snacks quality attributes, these xhantan gum coating solutions compared well with the oil-based coatings, for texture profile, water activity, retraction and agglomeration index.

Sensory analysis scores reflected a good overall acceptability of these snacks (8/9) with good scores also for the flavor, aroma and appearance, none significantly different from control snacks.

In conclusion, it can be stated that it is possible to replace the fat portion by an aqueous solution of xanthan gum to flavor the snacks, and obtain a good quality final product, with better healthy benefits to consumers.

Author Contributions: A. Monteiro conceived and planned the experiments and supervised the research work; C. Graça, contributed to the acquisition of rheology data, data analysis, interpretation of the results and wrote the manuscript; D. Marques performed all samples preparation and performed the analysis, I. Sousa supervised the rheology work, data analysis, and interpretation of the results and revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

5. References

Ahmed, J., & Ramaswamy, R.S. (2004). Effect of high-hydrostatic pressure and concentration on rheological characteristics of xanthan gum. Food Hydrocolloids, 18, 367–373.

Ascheri, J. L. R., Ribeiro, M. M., Carvalho, C. P., & Ascheri, D. P. R. (2005). Isotermas de adsorcíon de água y estabilidad de harinas extruídas de amaranto, arroz y maíz: estudio comparativo. Alimentaria, Madrid, 42,363,100-107.

AOAC Association of Official Analytical Chemists, (2005), Official methods of analysis of the AOAC International, 17, Gaithersburg.

Capriles, V. D., Soares, R. A. M., & Areas, J. A. G. (2007). Development and assessment of acceptability and nutritional properties of a light snack. Ciência e Tecnolologia Alimentar. Campinas, 27, 3, 562-566.

El-Sayed, E., El-Gawad, I. A., Murad, H., & Salah, S. (2002). Utilization of laboratoryproduced xanthan gum in the manufacture of yoghurt and soy yoghurt. European Food Research and Technology, 215, 298-304.

Gates F.K., Dobraszczyk B.J., Stoddard F.L., Sontag-Strohm T., & Salovaara H. (2008). Interation of heatmoisture conditions and physical properties in oat processing: I. mechanical properties of steamed oat groats. Journal of Cereal Science, 47, 239-244.

Márcia Arocha Gularte, M. A., & Rosell, C. M. (2011). Physicochemical properties and enzymatic hydrolysis of different starches in the presence of hydrocolloids. Carbohydrate Polymers 85, 237–244.

Gyawali, R., & Ibrahim, S. (2016). Effects of hydrocolloids and processing conditions on acid whey production with reference to Greek yogurt. Food hydrocolloids, 56, 61-76.

Geremias-Andrade, I. M., Souki, N. P.D.B.G., Moraes, I. C.F., & Pinho S. C., (2017). Rheological and mechanical characterization of curcumin-loaded emulsion-filled gels produced with whey protein isolate and xanthan gum. LWT - Food Science and Technology, 86, 166-173.

Hundschell, C. S., & Wagemans, A. M. (2019). Rheology of common uncharged exopolysaccharides for food applications. Current. Opinion. in Food Science, 27,1–7.

Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap D., & Rungsardthong V. (2016). Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. Journal of Food Science and Technology, 53, 561.

Lii, C.Y., Liaw, S., Lai, V.-F., & Tomasik, P. (2002). Xanthan gum and gelatin complexes. European Polymer Journal, 38, 1377-1381.

Monteiro A., Marques D., Marchi L., Chinellato M., Berwig K., & Wolf B. (2016). Eliminating the use of fat in the production of extruded snacks by applying starch coating, Chemical Engineering Transactions, 49, 625-630.

Marques D.R., Berwig K., Monteiro C.C.F., Oliveira D.M., & Monteiro A.R.G. (2017). Shelf life evaluation of extruded snacks coated with maize starch to eliminate the use of fats in the flavoring process, Chemical Engineering Transactions, 57, 1921-1926.

Nakagawa A, Mendes, M.P., Raniero G. Z., Berwig K. P., Pimentel T. C., Monteiro C. C. F., & Monteiro A. R. G. (2019). The use of waxy starch and guar gum in total substitution of vegetable oil in extruded snack aromatization Chemical Engineering Transactions, 75 283-288.

Picout, D., & Ross-Murphy. (2003). Rheology of Biopolymer Solutions and Gels. *The Scientific World Journal,* 3,105-21.

ROSALAM, S.; & ENGLAND, R. (2006). Review of xanthan gum production from unmodified starches by Xanthomonas campestris sp. Enzyme and Microbial Technology, New York, 9, 2, 197-207.

Razmkhah, S., Razavi, S., & Mohammadifar, M. (2017). Dilute solution, flow behavior, thixotropy and viscoelastic characterization of cress seed (Lepidium sativum) gum fractions. *Food Hydrocolloid*s, 63, 404-413.

Salgado, N., Giraldo, G.I., & Orrego, C. E. (2017) Influence of the extrusion operating conditions on the antioxidant, hardness and color properties of extruded mango, LWT - Food Science and Technology, 86, 209-218.

Tunnarut, D., & Pongsawatmanit, R. (2018). Modified quality of seasoning syrup for coating and enhancing properties of a food model using xanthan gum. Agriculture and Natural Resources, 52, 298-304.

V.M. Busch, V. M., Delgado, J. F., Santagapita, P. R., Wagner, J. R., & Buera, M. P. (2018). Rheological characterization of vinal gum, a galactomannan extracted from Prosopis ruscifolia seeds. Food Hydrocolloids, 74, 333-341.

Williams, P.A. (2007). Handbook of Industrial Water Soluble Polymers. Blackwell Publishing, Oxford, U.K.

Wami, S. A., & Kumar, W. P. (2016). Moisture sorption isotherms and evaluation of quality changes in extruded snacks during storage, LWT - Food Science and Technology, 74, 2016, 448-455.