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Research Article

Rheological Behavior of Dehydrated Creams of Barracuda (*Sphyraena ensis*) Flour with Pregelatinized Corn, Cassava and Yam Starch

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Abstract: The aim of this study was to investigate the rheological behavior of a dehydrated cream based on fishmeal using as thickener pregelatinized corn, cassava and yam starch. Three sources of pregelatinized starch (corn (PCS), cassava (PCAS) and yam (PYS)) were evaluated, varying in ratios of 20/40, 30/30 and 40/20 starch/fishmeal. Solubility in Cold Water (SCW), Water Absorption Capacity (WAC), flow behavior and viscoelastic properties were determined in a rheometer, compared to a commercial cream. The highest SCW values were achieved with PCAS and for WAC in PCS. The rheological behavior was adjusted to the Power Law model evidenced pseudoplasticity. The highest values of the consistency index (K) and viscosity were reached with PCS and PCAS. The viscoelasticity of the creams allowed to define them as real weak gels, showing predominance of the elastic modulus on the viscous and values similar to the commercial cream on the loss tangent with PCAS and PCS. This may be due to the behavior of starch-protein-fat complexes, which form a three-dimensional network leading to a molecular interaction that prevents the easy release of absorbed water, becoming more resistant with the increase of the starchy component. The creams with PCAS and PCS in 30/30 and 40/20 starch/flour ratios showed *K* values, viscosity and tangent of loss closer to the commercial cream.

Keywords: Flow curves, food industry, starchy, structure, viscoelasticity

INTRODUCTION

Cassava (*Manihot esculenta* C.) and yam (*Dioscorea rotundata*) are some of the most profitable tubers in the agroindustrial sector in Colombia, especially in the Caribbean Region (González Vega, 2012; AGRONET, 2015). The main product that can be obtained from these crops is starch, one of the most used additives in the food industry as a stabilizing, gelling, binder or thickener agent (Alvis *et al*., 2008). Starch in its native state has limitations that prevent the diversification of its use, therefore, it is necessary to resort to enzymatic, chemical or physical modifications (Galliard, 1987; Vaclavik and Christian, 2002; Hirashima *et al*., 2005). Among these modifications, the food industry has opted for the use of physically modified starches, due to the absence of chemicals in their production (Jayakody *et al*., 2009).

Pregelatinization is a physical process consisting on the partial or total rupture of the starch granule in suspension by the effect of the temperature, causing the leaching of the amylose and a consequent increase in the viscosity of the paste. These starches alter some of their functional properties, solubilize and disperse better in cold water, increase the capacity to absorb water, improve their stability, achieve lower levels of retrogradation and high viscosity values when they are heated (Adedokun and Itiola, 2010; Hesso *et al*., 2015; Barragán-Viloria *et al*., 2016; Majzoobi *et al*., 2016). Its properties have made it suitable in food applications such as baby purees, sauces, desserts, low fat emulsions, dehydrated creams, among others, which are part of the trend food category in the world market (Pacheco, 2001; Ravindran and Matia-Merino, 2009; Bortnowska *et al*., 2014).

Dehydrated creams have been considered as foods that provide calories and other nutrients that vary according to the raw material. Some investigations have evaluated the use of flours of leguminous and other vegetables, in order to improve nutritional quality obtaining better results compared to commercial creams. It has been possible to increase fiber and protein levels up to 8-16% and 6.5-11.5%, respectively. (Pacheco, 2001; García *et al*., 2007; Praderes *et al*., 2010). However, it has been found in fish a good alternative to provide high levels of protein in these

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foods, indicating its great biological value (Barragán *et al*., 2016).

In spite of the above, the interest of the investigations about dehydrated creams is not only focused on its nutritional quality but also in the quality control on the process. Some reports have shown that the steady-state and dynamic study of food dispersions allows to evaluate its stability and structure through flow behavior and viscoelastic properties, finding that they have a pseudoplastic behavior and are described weak gel-like. (Ravindran and Matia-Merino, 2009; Ahmed *et al*., 2014). This behavior is mainly due to the starch used as one of the main ingredients, according to specifications of technical standards (Barragán *et al*., 2016). Different authors have made starch variations between 16-45% for the formulations of dehydrated creams, which has allowed to consider that the viscosity is one of the most relevant quality parameters in these products (García *et al*., 2007; Praderes *et al*., 2010; Wongsagonsup *et al*., 2014).

In general, the rheological parameters in a food matrix allow to determine its stability, texture and structure, besides generating knowledge about its formulation, processing and storage (Rao and Anatheswaran, 1982). In this way, the importance of the network structure that originates from the interaction among amylaceous substances, proteins and lipids in a dispersion it is highlighted (Pietrasik, 1999). However, there are few studies that report rheological parameters on dehydrated creams especially fish. Therefore, the objective of this study was to investigate the rheological behavior of a dehydrated cream based on fishmeal using as a thickener pregelatinized maize, cassava and yam starch.

MATERIALS AND METHODS

Location: The experiment was carried out at the facilities of the Unit Operations Pilot Plant of the University of Sucre ("Los Pericos" Farm), located in Sampués, Sucre and at the Food Analysis Laboratory of the Food Engineering program of the University of Córdoba (Sede Berástegui), located at of Ciénaga de Oro, Córdoba.

Materials: Barracuda fishmeal (*Sphyraena ensis*) was obtained at the laboratory level from fish from the local market of the city of Sincelejo. The Pregelatinized Corn Starch (PCS) was purchased from the company Surtiquímicos-Brenntag Colombia.

The Pregelatinized Cassava (PCAS) and yam (PYS) starches were obtained from the Unit Operations Pilot Plant of the University of Sucre ("Los Pericos" Farm), following the methodology of Barragán-Viloria *et al*. (2016), from native starch from the Almidones de Sucre S.A.S. Plant (Cassava) and by a continuous bubbling process for the recovery of starch (yam) (Pérez *et al*., 2015). The other ingredients: Dexactated milk powder, monosodium glutamate, salt and spices (onion, garlic, pepper and cumin) were obtained from local commerce in the city of Sincelejo.

Barracuda fishmeal: On the fishmeal production, the fish were washed and baked at 65°C for 15 min. Then they were pulped and pressed at 2500 psi for 10 min. The cake obtained was dried at 65°C for 5 h in a forced ventilation oven. Finally, the samples were ground, sieved and packed in metalized plastic bags, to be used later.

Pregelatinized starch: The pregelatinization batch type process was performed from starch suspensions in water (50% w/v), simulating a complete mixing reactor, with a continuous stirring and heating system at 65°C (Cassava) and 81°C (Yam) for 10 min at 300 rpm. It was added 0.5 mL of ethanol for each gram of starch while stirring for 1 h and then methanol, equivalent to one-third of the water in the suspension, shaking for 7 and 5 h, respectively. Finally, the samples were ground and subjected to a standard Tyler sieve system (Mesh 100).

Preparation of simples: Samples of dehydrated creams (20 g) were prepared for each starch source and each starch/fishmeal ratio. The ingredients in fixed proportions for each formulation were: Milk powder (15%), monosodium glutamate (1.5%), salt (6%), spices (16.5%) and stabilizing agent. They were mixed at 250 rpm for 5 min. Subsequently, the samples were rehydrated in 250 mL of water for the rheological tests and subjected to heating for 10 min, stirring occasionally.

Behavior of the cold and hot paste: The behavior of the cold and hot paste was determined by a gel test. The viscoamylogram curves were performed on a rheometer (Anton Paar, MCR 302, Austria) using suspensions of 2 g of dry sample in 25 mL of water, guided by the methodology proposed by Figueroa Flórez *et al*. (2016). The results obtained from the test were processed using software RheoCompass, version 1.12.

Tecno-functional properties: The Cold Water Solubility (CWS) was determined by weighing 0.4 g of dehydrated cream on a dry basis in a centrifuge tube. It was added 40 mL of distilled water and homogenized at 5,000 rpm for 1 min and then at 10,000 rpm for 2 min until the entire sample was solubilized. It was centrifuged at 3,500 rpm for 15 min. From the supernatant were extracted 10 mL of aliquot that were deposited in petri boxes, previously washed, dried and weighed. Finally it was carried to a stove at 110°C for 4 h and placed in a desiccator (Majzoobi *et al*., 2016). By weight difference the porcentage of solubility was determined:

$$\%SCW=\frac{\text{Grams of solids in the supernatant x 0.4}}{\text{Grams of the sample}} \text{ x 100}$$

To determine the Water Absorption Capacity (WAC) 1 g of dehydrated cream was deposited in a centrifuge tube, 10 mL of distilled water were added, stirred gently to homogenize and centrifuged for 15 min at 3500 rpm. The supernatant was then removed and the tube was allowed to stand with the precipitate for 30 min inverted at a 45° angle to finally to be weighed (Majzoobi *et al*., 2016). The mass gain was the water absorption capacity of the simple:

$$\%WAC=\frac{\text{Retsined mass of water (g)}}{\text{Mass of the sample (g)}} \text{ x 100}$$

Flow properties: Flow curves were tested in a rotational mode to determine the flow behavior using a concentric cylinder geometry (SC4-21, 2,5 cm in diameter) in a rheometer (Anton Para, MCR 302, Austria). To eliminate the possible thixotropy presented by the creams, deformation rate (γ) sweeps were performed in the range of 0,1 to 100 s^{-1}, first in ascending order, then in descending order and finally in ascending order. The curve obtained from the last procedure was taken as a reference, to study the rheological behavior of creams. The experimental values of the flow curves were fitted to rheological models of the Power Law Eq. (1), Herschel-Bulckley Eq. (2), Casson Eq. (3), Mizrahi-Berk Eq. (4) and Newton Eq. (5), where *n* is the flow index, *K* is the consistency coefficient (Pa.sn), σ is the shear force (Pa) and σ_o is the minimum effort to start the flow (Augusto *et al*., 2012; Quek *et al*., 2013):

$$\sigma = K(\dot{\gamma}^n) \quad (1)$$

$$\sigma = \sigma_0 + K(\dot{\gamma}^n) \quad (2)$$

$$\sigma^{0.5} = (\sigma_o)^{0,5} + K\,(\dot{\gamma}^{0,5}) \quad (3)$$

$$\sigma^{0.5} = (\sigma_o)^{0,5} + K\,(\dot{\gamma}^n) \quad (4)$$

$$\sigma = K(\dot{\gamma}) \quad (5)$$

Viscoelastic behavior: The behavior of viscoelasticity of the creams was determined in the rheometer operating in oscillatory mode using the parallel plate geometry with a diameter of 25 mm (P-PTD 200/E, Anton Paar, MCR 302). It was set a 1.0 mm gap between dishes. Initially, an amplitude sweep was performed at a strain between 0-100% and a frequency of 1.0 Hz to determine the region of linear viscoelasticity. The viscoelastic characterization of the material was obtained by frequency sweeps, varying the frequency between 0.01 and 100 Hz (Augusto *et al*., 2012). Rheological measurements were carried out in triplicate. The storage modulus (G') a measure of the elastic property and the loss modulus (G") a measure of the viscous property, were fitted to a power law model Eq. (6) and (7) *K', K'', n', n''* are constants and ω is the angular frequency. The loss factor (tan δ = G"/G') was estimated at 0.1 Hz to evaluate the stability of the creams under low creep conditions, as well as the time sweep (20 min). The behavior of the variables mentioned above was studied at a temperature of 40°C. The temperature ramps were run in a range of 20-90°C at 0.1 Hz and a deformation of 0.5%:

$$G' = K'(\omega)^{n'} \quad (6)$$

$$G'' = K''(\omega)^{n''} \quad (7)$$

Statistical analysis: It was performed in a 3×3 factorial arrangement with three sources of starch and three starch/fishmeal ratios, for a total of nine treatments, which were done in triplicate, obtaining a total of 27 experimental units. Data were analyzed statistically using the statistical package R 3.2.1 free version, using an analysis of variance (ANOVA) ($p \leq 0.05$). To compare the obtained results a test of multiple ranges of comparison of means of Tukey was used. The three sources of pregelatinized starch were: corn, cassava and yam, varying in ratios 20/40, 30/30 and 40/20 starch/fishmeal. The analyzed variables were compared with a Commercial Cream (C.C) of seafood brand Knorr®, due to the absence in the market of fish creams.

RESULTS AND DISCUSSION

Pastification properties of pregelatinized starches: The properties of the pastification of pregelatinized starches are shown in Table 1. The PCAS showed a lower gelatinization temperature. This could be due to the low incidence of the process of modification in the structure of cassava starch; since, starch molecules heated in a suspension, generally at temperatures close to their glass transition, they achieve a weaker structural and molecular reorganization (mainly in the amorphous region), requiring less energy for the gelatinization process occurs again. However, this phenomenon may be limited by the amylose content, the cooking temperature and the source of starch, among others (Jayakody *et al*., 2009; Barragán-Viloria *et al*., 2016). Similar results were reported by Oginni *et al*. (2015), where pregelatinized cassava starches reached lower gelatinization temperatures compared to the gelatinization temperatures reached in different varieties of yams (Jayakody *et al*., 2009; Adedokun and Itiola, 2010).

Table 1: Pastification properties of pregelatinized corn, cassava and yam starches

Amilaceous source	Corn	Cassava	Yam
A*	71.4±0.35c	65.5±0.70e	83.9±0.06a
B	3632±19a	1990.5±0.75b	1094.3±5.36c
C	1763±99.5a	1026.9±0.98b	0±0c
D	1793±12.5a	796.6±17.8b	703.2±2.01c

A: Temperatura inicial de pasta (°C); B: Máxima viscosidad (cP); C: Estabilidad (breakdown); F: Asentamiento (setback); * Letras diferentes en la misma fila muestran diferencias estadísticas significativas (p≤0.05).

Table 2: Tecno-functional properties and rheological parameters of the model Power Law of fish creams

	Starch/Flour ratio		
Starch source	20/40	30/30	40/20
	SCW		
APM	40.45±0.35bB	42±0.28bA	42.55±0.78bA
APY	42.95±0.49aC	44.9±0.56aB	46.3±0.85aA
APÑ	40.9±0.17bA	41.4±0.57bA	41.7±1.55bA
C.C	44.35±0.21		
	WAC		
APM	320.28±2.49aC	431.31±3.83aB	577.17±8.31aA
APY	143.3±1.95bA	146.5±9.35bA	147.02±0.34cA
APÑ	141.45±2.67bB	149.18±2.02bB	177.39±7.27bA
C.C	65.3±1.7		
	N		
APM	0.445±0.001aA	0.312±0.001bAB	0.261±0.002bB
APY	0.440±0.001aA	0.4±0.001abA	0.396±0.002bA
APÑ	0.525±0.0003aAB	0.484±0.001aB	0.662±0.20aA
C.C	0.5049±0.005		
	K ($Pa.s^n$)		
APM	0.487±0.004bC	2.854±0.04aB	5.895±0.12aA
APY	0.622±0.01aC	1.567±0.003bB	2.301±0.04bA
APÑ	0.195±0.0007cC	0.419±0.007cB	0.845±0.026cA
C.C	1.3475± 0.032		
	µ (mPa.s)		
APM	477.93	2583	5260.8
APY	632.13	1694.7	2531.97
APÑ	174.04	381.87	759.02
C.C	1994.65		

*Means with different letters in columns (Lower case, comparison between Starch source) and rows (Capital letters, comparison between starch/flour ratio) indicate significant statistical differences (p≤0.05), according to the Tukey test

The PYS presented the lowest values of breakdown and setback, related to greater stability and better settling properties, respectively, unlike the PCS, which did not show great stability in heating. However, the PYS, obtained the lowest peaks of viscosity, while PCS reached higher initial viscosity and peak of viscosity. On the other hand, the PCAS showed a good performance in terms of its stability and viscosity, compared to PCS and PYS. Possibly this was associated with the amylose content and the granule structure, with cassava starch being easier to modify, the rearrangement of the amylose linear chains could be affected, improving its stability (Adedokun and Itiola, 2010; Figueroa Flórez *et al*., 2016; Barragán-Viloria *et al*., 2016).

Tecno-functional properties: The results of the functional properties of the fish creams are shown in Table 2. For each of the starch/flour ratios, the highest valuesof SCW of the creams were found with the PCAS, achieving with the ratio 40/20 the highest solubility. Praderes *et al*. (2010) reported values of solubility of 81.5% in instant soups with flour of ahuyama and quinchoncho, where 20% of modified starch was used. These values exceed the percentage of SCW obtained in fish creams. However, the creams with PCAS in starch/flour ratios of 30/30 and 40/20, obtained values very similar to those of commercial creams used as reference.

Regarding the WAC, statistical differences ($p\leq0.05$) were evidenced, where it was observed that for all the starch/flour ratios, the PCS achieved the highest values. Some studies report WAC percentages of 340 and 460% in ahuyama soups (Praderes *et al*., 2010) and 500-700% in arracacha soups (García *et al*., 2007). Although these results are greater than those obtained in fish creams, it is important to note that the data in this study exceed the values of the commercial cream used to compare the evaluated treatments.

Flow properties: In their order, R^2 and CME values of 0.998, 0.02; 0.999, 0.001; 0.354, 2.11; 0.88, 0.34 and 0.713, 0.003 were obtained; for the models that fitted the experimental data of the fish creams flow curves: Power Law, Herschel-Bulckley, Newton, Casson and Mizrahy-Berk. It is evidenced that the models of Power Law and Heschel-Bulckley presented a better fit ($R^2>0.99$ and MSE near 0). However, the yield stress values for the Heschel-Bulckley model were very low ($\sigma_o \approx 0$), so they could be omitted. In this sense, the rheological parameter analysis was limited to the Power model, considering its simplicity and its wide use in the study of the rheological behavior of soups and food dispersions with gums and native and modified starches (Ravindran and Matia-Merino, 2009; Choi and Yoo, 2009; Wongsagonsup *et al*., 2014).

Table 2 shows significant differences ($p \leq 0.05$) for the values of flow behavior index *n* and coefficient of consistency *K*. A pseudoplastic behavior was evidenced for all the starch/flour ratios evaluated in each of the sources of starch, with values of *n* less than unity ($n<1$). Similar results (0.20-0.51) were found in different investigations that worked with legume soups, using cassava starch and in mixtures of starches with xanthan gum (Ravindran and Matia-Merino, 2009; Wongsagonsup *et al*., 2014).

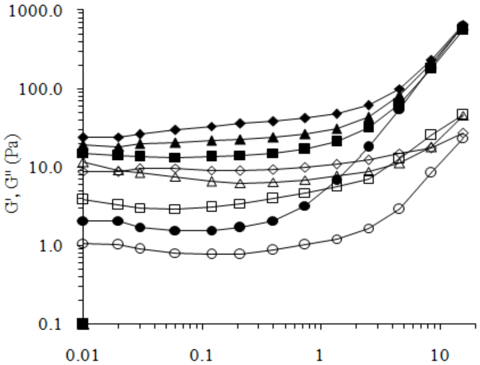
On the other hand, it was observed that for each starch/flour ratio there were differences in *K* values, showing a tendency of higher indexes with PCS and lower values of *K* with PYS. Likewise, an increase of the parameter *K*, for each source of starch, is appreciated, as its concentration in the starch/flour ratio increases. Possibly, the above may be associated to the behavior of starch-protein-fat complexes, which form a three-dimensional network leading to a molecular interaction that prevents the easy release of the absorbed water and which becomes much more resistant with the increase of the starchy component (Caparino *et al*., 2017). Similarly, this could be related to the hydrophilic capacity of the protein, hygroscopic power and particle size of the ingredients in the formulation (Pietrasik, 1999; Albano *et al*., 2014). Thus, by absorbing more water, it would reach a higher peak of viscosity, being reflected in a greater resistance to the flow in the creams studied (greater values of coefficient of consistency). Some studies in traditional dehydrated and legume soups reported values of *K* between 0.36-3.53 and 17.6-32.2 Pa.s^n, respectively (Choi and Yoo, 2009; Wongsagonsup *et al*., 2014). Although some of these values exceed those obtained in fish creams, it is important to note that there was similarity with the commercial cream (1,347 Pa.s^n).

The values of the apparent viscosity of the fish creams at low strain rates are shown in Table 2. It is evidenced that the creams with PCS in 30/30 and 40/20 ratios; and PCAS in the 40/20 starch/flour ratio, presented higher apparent viscosity values than those referred to the commercial cream at low strain rates. Meanwhile, the treatment with PCAS in the 30/30 starch/flour ratio is lower only by some units. This may be related to starch pastification properties (Table 1), in which PCS showed a higher viscosity peak, followed by PCAS, which in turn is associated with the consistency coefficient and WAC. This is of great relevance, Taking into accountthat viscosity is one of the most important quality parameters in these products (Ravindran and Matia-Merino, 2009; Saha and Bhattacharya, 2010).

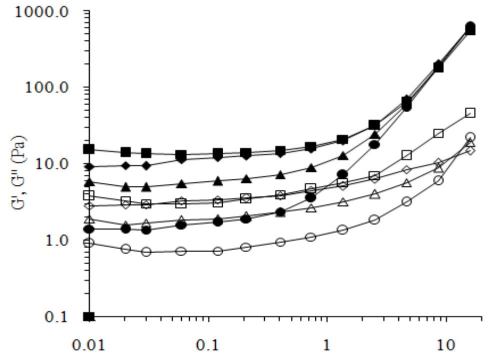
García *et al*. (2007) and Praderes *et al*. (2010) reported values of apparent viscosity between 2,200 and 2,800 mPa.s in arracacha and ahuyama creams, respectively, justified by the increase in flow resistance, which could be due to the components of the cream, proteins, pregelatinized starch, species, milk powder and gum, could be rehydrated and undergo a rearrangement. However, they agree that the presence of starch in the cream, once subjected to heating, favors the formation of the gel and consequently, the thickening properties, which are reflected in the viscosity of the creams.

Viscoelastic behavior: The variation of the dynamic modules with the frequency of fish creams with PCS, PCAS and PYS are shown in Fig. 1. In all case the preponderance of the storage module on the loss modulus $G'>G''$, indicating that the elastic forces predominated over the viscous forces in the frequency range studied. Research has shown that the use of hydrocolloid substances such as gums and amylaceous substances in food dispersions presents this behavior, attributed mainly to the network structure that characterizes them (Saha and Bhattacharya, 2010). Thus, a similar behavior was reported in low fat emulsions with pregelatinized corn starch (Bortnowska *et al*., 2014), soups with cassava starch (Wongsagonsup *et al*., 2014) and fish creams with native corn starch (Barragán *et al*., 2016).

The estimated viscoelastic parameters for the power law model of dehydrated fishmeal creams had significant differences ($p \leq 0.05$), with R^2 values of 0.996 for K' and n' and 0.954 for K'' and n' (Table 3). It is evidenced that when the starch content increases in the starch/flour ratio, the creams with PCS reach the highest K' and K'' values, in the 40/20 starch/flour ratio, while the creams with PYS obtained the lowest values. This is possibly associated directly with the consistency coefficient of the creams. Taking into account that $K'>K''$ and the values of n' and n'' in each starch/flour ratio for each source of starch were low but different from zero, it is valid to assume that the rheological behavior of the creams can be defined like real weak gels. This can be related to the loss and storage modules, indicating that, by subjecting the feed to a sufficiently high stress, the weak gel network structure they form can be easily broken (Quek *et al*., 2013). Some studies report similar results in mixtures of sweet potato starch with xanthan gum, arguing that high molecular weight hydrocolloids constitute associations of ordered chain segments favoring the formation of three-dimensional networks of weak gels even more, when mixed with starches (Choi and Yoo, 2009). Likewise, it has been found that, by increasing the



(a)



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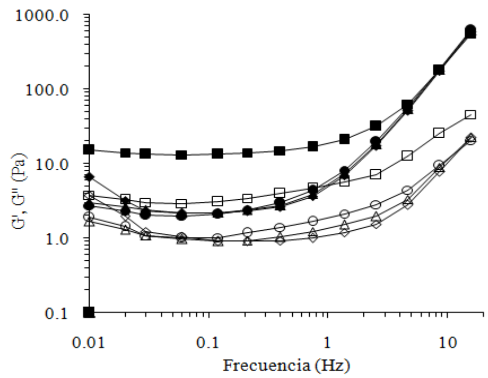

(c)

Fig. 1: Variation of the dynamic modulus G '(Black Symbols), G' '(White Symbols) with the frequency for fish creams with; (a): PCS; (b): PCAS and; (c): PYS in ratios starch/flour (●, ○) 20/40, (▲, Δ) 30/30 and (♦, ◊) 40/20, compared to a commercial cream (■, □)

Table 3: Estimated viscoelastic parameters for the power law model

Starch source	Starch/Flour ratio 20/40	30/30	40/20
	K’		
PCS	2.692±0.001aC	5.790±0.052aB	11.065±0.016aA
PCAS	2.695±0.042aC	3.320±0.004bB	4.971±0.004bA
PYS	2.544±0.023bC	2.662±0.012cB	2.840±0.036cA
C.C	4.1360±0.0014		
	K’’		
PCS	0.268±0.005aC	3.640±0.060aB	9.732±0.040aA
PCAS	0.139±0.003bC	1.884±0.002bB	4.207±0.024bA
PYS	0.236±0.031aC	0.420±0.034cB	0.907±0.004cA
C.C	3.5173± 0.0017		
	n'		
PCS	1.975±0.039aA	1.699±0.001cB	1.519±0.013cC
PCAS	1.966±0.010aA	1.888±0.033bB	1.811±0.050bB
PYS	1.970±0.025aA	1.965±0.022aA	1.952±0.009aA
C.C	1.7597±0.008		
	n’’		
PCS	1.614±0.015bA	0.882±0.01bB	0.269±0.001cC
PCAS	1.828±0.003aA	0.815±0.031cB	0.370±0.014bC
PYS	1.643±0.010bA	1.439±0.014aB	1.123±0.017aC
C.C	0.9216±0.0006		
	Tan (δ)		
PCS	0.486±0.015bA	0.304±0.002bB	0.274±0.008bB
PCAS	0.419±0.004cA	0.317±0.014bB	0.281±0.034bC
PYS	0.550±0.035aA	0.427±0.004aB	0.420±0.001aB
C.C	0.2276±0.0016		

* Means with different letters in columns (Lower case, comparison between Starch source) and rows (Capital letters, comparison between starch/flour ratio) indicate significant statistical differences (p≤0.05), according to the Tukey test

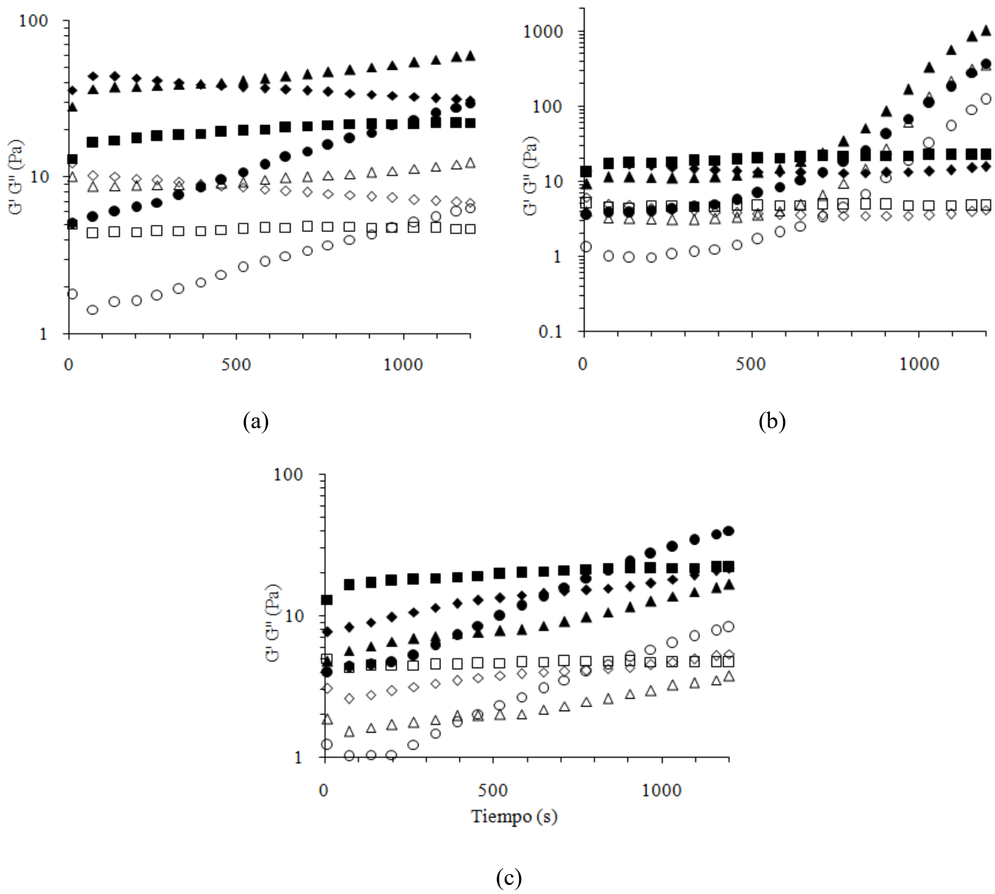

Fig. 2: Variation of the dynamic modules G' (Black Symbols), G'' (White Symbols) over time for fish creams with; (a): PCS; (b): PCAS and; (c): PYS in ratios starch/flour (●, ○) 20/40, (▲, Δ) 30/30 and (♦, ◊) 40/20, compared to a commercial cream (■, □)

concentration of the protein component in low fat emulsions, *K′* became greater than *K″*, suggesting a development of viscoelasticity with an increasing concentration of waxy corn starch, making the emulsion more stable (Bortnowska *et al*., 2014).

As for the loss tangent, significant differences were reported ($p \leq 0.05$), showing that in the 30/30 and 40/20 starch/flour ratios were the same for PCS and PCAS, with the lowest values, achieving a behavior similar to that of the commercial cream (0.2276±0.0016). All data reported was less than unity ($\tan \delta < 1$), thus confirming the viscoelastic gel behavior of the creams. One way to establish the stability of food dispersions is through the loss factor, pointing out that with values lower than 0.5, stability is favored, reducing the risk of phase separation (Espinosa-Dzib *et al*., 2012). However, in this case, it is observed that the tan δ for the creams with PYS presented the highest values, suggesting that even when the creams are stable, it can be noted that they are more susceptible to phase separation, compared to creams with PCS and PCAS. This likely it is associated with the values of the *G′* and *G″* modules indicating that the smaller the difference between their values indicates that a lower percentage of stored energy is recovered (Quek *et al*., 2013). Some studies have reported similar results in low fat emulsions (Bortnowska *et al*., 2014), soups systems (Ravindran and Matia-Merino, 2009) and in fish creams with different concentrations of xanthan gum (Barragán *et al*., 2016).

In addition, it can be considered that the stability of the creams is probably related to the WAC since the degree of association of the starch polymers allows that, when raising the temperatura, the solubility levels of the amylose are increased and consequently a viscosity is reached, according to a gel of stable consistency in the product (García *et al*., 2007). In the same way, the presence of lipids, fiber and sugar compounds limits the formation of the micellar network, which provides stability to food dispersion (Ahmed *et al*., 2014; Albano *et al*., 2014).

The behavior of the viscoelastic modules as a function of time is observed in Fig. 2. In all cases, the storage module predominates over the loss modulus which reiterates the elastic forces of the creams. The treatments with PCS and PCAS in the 40/20

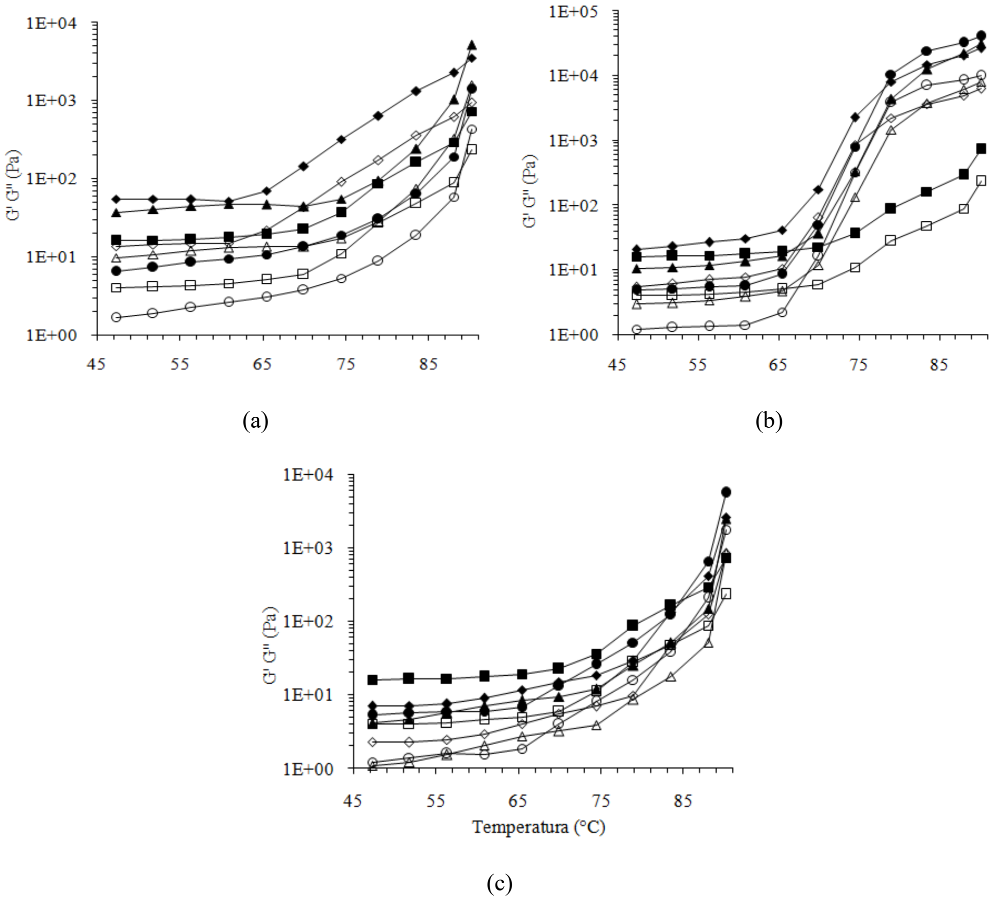

Fig. 3: Variation of the dynamic modules G' (Black Symbols), G'' (White Symbols) with the temperature for fish creams with; (a): PCS; (b): PCAS and; (c): PYS in ratios starch/flour (●,○) 20/40, (▲,Δ) 30/30 and (♦,◊) 40/20, compared to a commercial cream (■,□)

starch/flour ratio had a similar behavior to the commercial cream. This allows to suggest that the modules become more stable to higher concentrations of starch in the formula of the cream, which agrees with the behavior of the Tan δ. Similar results were found in rheological studies of arracacha starch gels (Albano *et al*., 2014).

The viscoelastic modules with respect to temperature are shown in Fig. 3. It is evidenced the predominance of the elastic modules on the viscous ones and an increase of them with the temperatura. This could be due to the behavior of the starches, in which the gelatinization temperature is in accordance with what is observed in the ramps of the fish creams, being noticed a greater increase to lower temperatures in the creams with PCAS. Albano *et al*. (2014) and Ahmed *et al*. (2014) reported similar results on gels of Peruvian carrot starch and on pumpkin flour dispersions.

CONCLUSION

The PCS presented the best techno-functional properties. However, it did not show the best heating conditions, thus PCAS was considered an alternative to improve dispersion in cold water, to absorb and retain water and to reach high peaks of viscosity at low gelatinization temperatures in food matrices.

The rheological behavior of the creams with PCAS and PCS in 30/30 and 40/20 starch/flour ratios showed values of consistency index, viscosity and tangent of loss closer to commercial cream, based mainly on the behavior of starch in cold and hot and its functional properties.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this study.

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