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Research Article

Functional and Rheological Properties of Yam (*Dioscorea rotundata*) Mucilage

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Abstract: The objective of the present study was to evaluate the functional and rheological properties of mucilage of Hawthorne bread of yam (*Dioscorea rotundata*). The extraction of mucilage was performed by continuous bubbling method and then its functional (solubility at 30 to 70°C, water absorption index, water solubility index, swelling capacity, stability and clarity of the paste, oil absorption capacity, emulsifier activity, stability of emulsion, total phenols and antioxidant capacity) and rheological (stationary test and viscoamilogram) properties were evaluated. The results indicate a greater solubility (96.96% to 30°C and 88.76% to 70°C) and stability of emulsion (68.89%); however, total phenol content and antioxidant capacity lower to other mucilage, possibly due to the extraction method employed (bubbling). The method that best represented the rheological behavior of suspensions of mucilage of yam was that of Oswald de Waele, categorizing it as dilatant fluid (n>1) and the viscoamilogram demonstrates the low starch content in mucilage, showing a setback of 11.43 mPa.s, which indicates high stability of this polymer. The functional properties show the potential of mucilage as emulsifier and its easy inclusion in food matrices.

Keywords: Antioxidant capacity, breakdown, dilatant, natural gums, solubility

INTRODUCTION

Yam is produced in around 47 countries over the world, wherein they are sown in around 5 million hectares, the African countries being the biggest producers, all together accounting for a 96.6% (Etim *et al*., 2013; FAOSTAT, 2016), whereas America contributes 2.5% of its worldwide production. Colombia is one of twelve most producing countries, with 421,396 tons and is one of the best in its production (Polo and Arana, 2016).

Yam is used to obtain flour and starch, which are used as raw material in order to develop both conventional and new food products. Starch is used a lot in food and non-food industries and many extraction methods have been used to make its usage manifold (Techeira *et al*., 2014). However, starch obtained from yam is of low quality due to the presence of non-starchy components, such as the mucilage, which makes the procurement process slower and that is why study of this material is important in order to search alternatives for its separation through different methods like centrifugation, bubbling (whose basis is flotation) and to use chemical compounds such as ammonia or a combination of these (Contado *et al*., 2009; Fu *et al*., 2014; Pérez *et al*., 2015).

Mucilage is a colloidal lypophilic fluid system and a hydrogel that provides functional and rheological properties unique to the products in which it is used, due to viscosity of its gel; which is why it could be used to thicken and modify the texture of the food products. The systems to which it is added do not flocculate, it also reduces their surface or interfacial tension and hence could be used in manufacturing jelly, marmalades and baked goods, in the pharmaceutical industry, in the production of drinks and also as stabilizing agent in emulsions in the ice cream industry (Andrade *et al*., 2015; Abraján, 2008; Contreras-Padilla *et al*., 2016; Hou *et al*., 2002; Huang *et al*., 2010; Misaki *et al*., 1972; Njintang *et al*., 2014; Tavares *et al*., 2011).

The chemical structure of mucilage is similar to gel, as it has cellulosic polysaccharides like galacturonic acid, mannose, xylose and proteins that make those solutions, in which they are applied, stable. Besides, their use is determined by the physicochemical, rheological, structural and functional properties they carry, which is why there differ in terms

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of their rheological properties from other mucilage, like the one produced from taro (*Colocasia esculenta l. schott*) and Creole yam (*Dioscorea alata*), stipulating that they comply with the model of power law with a pseudo-plastic behavior. Nonetheless, mucilage can be sensitive to other physicochemical parameters such as pH and acidity (Abraján, 2008; Capitani, 2013; García-Cruz *et al*., 2013; Han *et al*., 2016; Martin *et al*., 2017; Njintang *et al*., 2014; Rao, 1999; Razavi and Karazhiyan, 2009; Tavares *et al*., 2011). This study aims to evaluate the functional and rheological properties of mucilage of Hawthorne yam (*Dioscorea rotundata*).

MATERIALS AND METHODS

Raw material and extraction of mucilage of yam: Yam (*Dioscorea rotundata*) used in this study came from Sucre state (Colombia). For extraction of mucilage, bubbling method was used. The equipment consistently at a pilot scale placed in the facility of the University of Sucre's Unit Operations Plant, which operates in environmental conditions with a yam solution ratio of: Water 1:8 and whose basis is the flotation due to the presence of air. The liquid mucilage was dried in a Freezone vacuum lyophilizer (Labconco, USA) for 60 h, for that purpose it was first frozen at -50°C, after drying it was macerated for later use (Tavares *et al*., 2011; Pérez *et al*., 2015).

Functional properties: The following functional properties were achieved in lyophilized mucilage of yam.

Solubility: It was determined following the technique proposed by Betancur-Ancona *et al*. (2004). A 30 mL solution of mucilage was prepared at 1% (p/v) in erlenmeyers of 50 mL capacity. These were then immersed in a water bath at 30°C, with continuous agitation for 30 min. Consequently, the content was transferred to centrifuge tubes of 50 mL capacity and was spun at 2750 for 15 min. Aliquots of 10 mL supernatant were placed in pre-weighed porcelain pots and were put in Kiln-drying at 120°C for 4 h. Once taken out of Kiln-dryer, they were left to cool down in desiccators and were then weighed. In the same way, solubility was measured at 70°C, performing the same procedure but placing the suspension of mucilage in a water bath at 70°C (Capitani, 2013). The solubility was calculated according to the Eq. (1):

$$\%\ Solubility = \frac{dry\ weight\ x\ 300}{Initial\ sample\ weight} \quad (1)$$

Water Absorption Index (WAI), Water Solubility Index (WSI) and swelling capacity (SC): 1 g mucilage was weighed on dry basis in a pre-weighed centrifuge tube, 25 mL distilled water at 60°C was added. This solution was immersed in a water bath at 60°C for 30 min, shaking the suspension after 10 min of 10 min after the heating was started, afterwards it was spun at 2700 rpm for 15 min, then the supernatant was extracted and the volume was measured (V).

An aliquot of 10 mL was taken from the suspension and was placed in a pre-weighed Petri box, the supernatant was put to Kiln-drying at 70°C for 16 h and weight of the Petri box was measured with the insoluble's and the centrifuge tube that contained the gel. The calculations were done according to the Eq. (2), (3) and (4) (Betancur-Ancona *et al*., 2004):

$$WAI = \frac{Soluble\ weight(g)x\ v}{Sample\ weight(g)x\ 10} \quad (2)$$

$$WSI = \frac{Gel\ weight(g)}{Sample\ weight(g)} \quad (3)$$

$$SC = \frac{Gel\ weight(g)}{Sample\ weight(g) - soluble\ weight(g)} \quad (4)$$

Stability and clarity of the paste: Mucilage suspensions were prepared at 4% p/v. In order to do that, 0.4 g of mucilage was taken and distilled water was added to it to complement it till 10 mL at atmospheric temperature (25°C) and at 4°C, using test tubes with lids, which were then immersed in water to boil for 30 min, the tubes were shaken vigorously every minute for the first 5 min, then they were left to cool down at the atmospheric temperature and transmittance percentage (%T) was evaluated at 650 nm in a spectrophotometer (Merck's UV-VIS Pharo Spectroquant 300 Merck), water as blank was used. The samples were stored at atmospheric temperature and at 4°C and then transmittance was measured in 0, 24, 48 y 72 h (Bello-Pérez *et al*., 2002).

Oil Absorption Capacity (OAC): 1 g as simple was weighed and 10 mL edible oil was added to it and it was shaken in a vortex at 2200 rpm for 30 s to homogenize the samples. Then it was spun at 3500 rpm for 15 min. Consequently, the supernatant oil was taken out and the precipitate was drained placing the tubes at an angle of 45° for 10 min. And then finally they were weighed (Beuchat, 1977). The results were expressed in terms of gram of oil retained per gram of the sample and they were calculated according to the Eq. (5):

$$\mathrm{OAC} = \frac{Oil\ retained\ (g)}{Sample\ (g)} \quad (5)$$

Emulsifying Activity (EA): 1 g as sample was taken and 25 mL distilled water was added to it and shaken slowly and then this suspension was mixed with 25 mL of vegetable oil in a homogenizing device for 1 min at 10000 rpm and it was spun at 4000 rpm for 10 min. The emulsifying activity was expressed in terms of percentage, as the height of the emulsified layer in relation to the total layer of the liquid, as in the Eq. (6) (Yasumatsu *et al*., 1972):

$$EA = \frac{Length\ of\ the\ emulsified\ layer(cm)}{Length\ of\ total\ tube\ content(cm)} x100 \quad (6)$$

Stability of Emulsion (SE): The same procedure was followed as in the emulsifying activity, but before spinning it was heated at 80°C for 30 min, then it was left to cool down in water for 15 min, to spin. Stability of emulsion was expressed in terms of percentage as in the Eq. (7) (Yasumatsu *et al*., 1972):

$$SE = \frac{Length\ of\ the\ emulsified\ layer(cm)}{Length\ of\ total\ tube\ content(cm)} x100 \quad (7)$$

Total phenols: It was conducted in Merck's spectrophotometer UV-VIS Pharo Spectroquant 300. The methodology advised by Tovar (2013) was followed with some modifications made by University of Sucre's Research Laboratory in Natural Products (GIPNUS). The reactive of Folin-Ciocaulteu was diluted 1:50 (v/v) in distilled water and it was then followed to establish the calibration curve with Gallic acid at concentrations from 0 to 10 µg/mL. The sample of lyophilized mucilage of yam was evaluated at 2000 µg/mL. In both the cases the reaction was carried out in quartz cells after adding 500 µL reactive of Folin-Ciocaulteu, 500 µL standard solution or mucilage solution, as may be the case and 1000 µL NaOH solution 0.35 M. The measurement of absorbance was done after 3 min of reaction in darkness at 760 nm wavelength. The total phenol content was expressed in equivalents of Gallic acid-EAG (Gallic acid µg/mucilage mg). All these tests were done in triplicate.

Antioxidant activity: To calculate the antioxidant activity, free-radical scavenging activity was measured 2,2-diphenyl-1-picrylhydrazyl (DPPH) and acid 2,2'-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS) on the part of mucilage suspensions. At first, a DPPH of 26 µg/mL in methanol solution was prepared; the methanol solutions of mucilage were prepared at 500, 1000 and 2000 µg/mL; and the standard agent, ascorbic acid, at concentrations of 50, 100 and 200 µg/mL. The reaction was started incorporating directly in the quartz cell 3 mL of DPPH and 0.1 ml as sample and it was monitored from 20 to 120 min in 517 nm wavelength. The control absorbance matched to the first measurement done before adding the sample (Castillo, 2016). To evaluate the entrapment capacity the remnant DPPH % was calculated, average Effective Concentration (EC50), required time for EC50 to reach to stationary state (TEC50) and Antioxidant Effectiveness (AE) in the following way:

$$Percentage\ of\ entrapment = \frac{A_{ss}}{A_o} x\ 100 \quad (8)$$

EC50 was determined by graphing the remnant DPPH % vs. concentration, so to be able to be determined later against free-radicals to obtain TEC50:

$$AE = \frac{1}{EC50\ x\ TEC50} \quad (9)$$

where,

Ass = The absorbance of the mucilage simple in a stationary status

Ao = The absorbance of the DPPH solution control

In the second instance, ABTS 7 mm in distilled water was prepared and it was made to react with potassium persulphate 2.45 mm in darkness for 16 h. This solution was diluted in such a way that its absorbance at 732 nm be the same at 0.7±0.02 (Tovar, 2013). The entrapment analysis was conducted in the same way as with DPPH. All these measurements were done in triplicate.

Rheological behaviour: Some stationary tests and viscoamilogram were done on the suspensions of lyophilized mucilage yam.

For the stationary tests, 10 mL suspension of mucilage was taken at four concentrations (0.5, 1, 1.5 and 2%) and they were placed in rheometer Anton Paar MCR 302 controlled by the software RheoCompass 1.12, with an accessory of concentric cylinders (CC24-38036). Suspension of mucilage were subjected to a lineal increasing shear rate in continuous ramp from 0.1 to 100 s^{-1} in 2 min, followed by a steady shear at 100 s^{-1} for 1 min and finally a decreasing shear rate from 100 to 0.1 s^{-1} in 2 min. The experimental values of flow curves were adjusted to the rheological models of Newton Eq. (10), Oswald deWaele Eq. (11), Bingham Eq. (12) and Herschel-Bulkley Eq. (13) (Capitani *et al*., 2015; Chen and Chen, 2001; Chien *et al*., 2013):

$$\sigma = k\,\gamma \quad (10)$$

$$\sigma = k\,\gamma^n \quad (11)$$

$$\sigma = \sigma_o + k\,\gamma \quad (12)$$

$$\sigma = \sigma_o + k\,\gamma^n \quad (13)$$

where,

σ : Shear stress (Pa)

γ : Shear rate (s^{-1})

k : Consistency coefficient ($Pas.s^n$)

n : Flow behavior index (dimensionless)

σ_o : Yield stress (Pa)

Viscoamilogram: The pasting properties of mucilage suspensions were determined using a rotational rheometer (Anton Paar, MCR 302, Austria). A 4% mucilage-water suspension was prepared and treated with a heating-cooling cycle. The samples were equilibrated at 50°C for 1 min, heated from 50 to 95°C at a heating rate of 6°C/min, then held at 95°C for 5 min. After the paste was cooled to 50°C at 6°C/min and

kept at 50°C for 2 min. Spindle speed was set at 160 rpm in this analysis. The parameters evaluated were initial temperature of paste, maximum viscosity at 95°C, maximum viscosity, final viscosity, breakdown and setback. Three replicates of each sample were carried out. Data were processed using RheoCompass 1.12 software (Nasrin and Anal, 2014).

Statistical analysis: In order to select the best model of stationary rheology the coefficient of determination and root mean square error.

RESULTS AND DISCUSSION

Functional properties of mucilage of Hawthorne yam: In the Table 1 the results of solubility at 30 and 70°C, the Water Absorption Index (WAI), Water Solubility Index (WSI), Swelling Capacity (SC), Oil Absorption Capacity (OAC), Emulsifying Activity (EA) and Stability of Emulsion (SE) are listed.

Lyophilized mucilage of yam has solubility of 30°C at temperature around 97% and of 70°C around 89%. Similar values to one reported for mucilage of chia (*Salvia hispanica*), with solubility at 77 to 95% at temperatures between 30-80°C (Capitani, 2013). However, it shows an opposite behavior when the temperature is increased. Besides, mucilage of Hawthorne yam showed superior solubility values to those reported for mucilage of linen (*Linum usitatissimum*) from 15-40% at atmospheric temperature (Kaewmanee *et al*., 2014). The dispersion of hydrocolloids in water depends mainly on its chemical structure, which is why high levels of solubility in mucilage yam could be due to its structure, which is more ramified that of starch (Andrade *et al*., 2015; Capitani, 2013; Njintang *et al*., 2014). It is important to note that the high solubility at temperatures approaching 30°C, would aid in the incorporation of mucilage of yam in food matrices.

The Water Solubility Index (WSI), Water Absorption Index (WAI), Swelling Capacity (SC), showed 46, 95 and 76%, respectively. Higher values than those in flour, native and modified starch of yam (*Dioscorea alata*) with values between 2-5% for water absorption index, 2-10% for water solubility index and 4-5% for swelling capacity at 60°C (Techeira *et al*., 2014). These results are important because the use of hydrocolloids depends upon the capacity to blend with water and to change the properties of the ingredients of the food products represented by the said functional properties (Li and Nie, 2016).

The value of Oil Absorption Capacity (OAC) of lyophilized mucilage of yam was higher than what was found in natural gums (guar gum 0.57 and xanthan gum 0.79 g of oil/g of dry test sample) (Thanatcha and Pranee, 2011) and native and modified starch of yam with values from 0.437 to 1.053 g/g (Falade and Ayetigbo, 2015; Techeira *et al*., 2014). However, it was lower than that of mucilage of badari (*Ziziphus mauritiana lam*) with an average of 4.96 g of oil/g de dry test sample. The oil absorption capacity is due to the presence of non-polar molecules in hydrocolloids as in mucilage that can retain a large number of oil particles and, therefore, can avoid oil loss in food systems. In this manner, mucilage could be used as a functional ingredient in food products needed to avoid the separation of their constitutive phases (Kalegowda *et al*., 2017).

Table 1: Functional properties of lyophilized mucilage of yam

Functional properties	Temperature	Values
Solubility	30 °C	96.96±1.07
	70 °C	88.76±1.25
Water absorption index (WAI)		45.58±0.91
Water solubility index (WSI)		94.89±1.02
Swelling capacity (SC)		76.01±0.82
Oil absorption capacity (g of oil/ g of dry test sample) (OAC)		2.02±0.05
Emulsifying Activity (EA)		33.07±0.25
Stability of Emulsion (SE)		68.89±4.27

Emulsifying Activity (EA) in lyophilized mucilage of yam was the same as in some hydrocolloids used in the industries: yellow starch yam (*Dioscorea cayenensis Lam*) with 33.7% value (Falade and Ayetigbo, 2015), pectin (30.3%), PG-alginate (38.1%), methylcellulose (40.6%) y acacia gum (41.0%) and lower than the mucilage of nopal (*Opuntia dillenii*) 52-60% (Kalegowda *et al*., 2017), that is why it could be considered as a hydrocolloid with high capacity to retain the emulsion (Zeng and Lai, 2014). On the other hand, its stability of emulsion was higher than the mucilage of chia, 8.9-47.4% (Campos *et al*., 2016), bradari, 52.22% (Thanatcha and Pranee, 2011) and nopal (*Opuntia dillenii*) 38-45% (Kalegowda *et al*., 2017). The structural characteristics such as the substituent groups and protein content provide non-polar properties to hydrocolloids; they increase the viscosity and the emulsion capacity, which makes the mucilage able to stabilize emulsions (Kaewmanee *et al*., 2014).

In the Fig. 1 it is shown that suspensions of lyophilized mucilage of yam indicated high stability showing 0.01 to 0.02% of transmittance over time. Transmittance varied a bit with changes in temperature y maintained itself over time. In native and modified starch of different breads, transmittance percentage at 25°C remains constant, while at 4°C this property decreases with time, due to the retro-gradation of starch and formation of gels (Techeira *et al*., 2014). This shows that lyophilized mucilage of yam could keep it stable during its inclusion in the food matrix and its subsequent cooling.

Mucilage of yam showed a total phenol content 2.96±0.028 µg gallic acid/mg mucilage, value lower than that in mucilage of creole yam, 6.6 (Chung *et al*.,

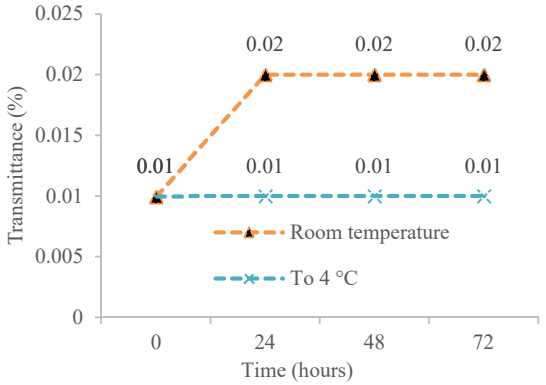

Fig. 1: Stability and clarity of the pastes (% T a 650 nm) of lyophilized mucilage of yam at temperature of 25ºC and 4°

2008) and mucilage of sugar yam (*Dioscorea esculenta*), 7.9 (Murugan and Mohan, 2012). This may be due to the separation method employed (bubbles), which allows the phenol compounds to interact constantly with oxygen thus causing a possible rusting of these substances, which are highly sensible to light which is why too much exposure to it could have adverse results (Málaga-Barreda *et al*., 2013).

The antioxidant capacity due to the radical entrapment technique DPPH showed an exponential behavior in 3 phases: high, medium and show speed, similar to the findings of Castillo (2016) for copper wood extracts (*Bursera simaruba*). In a stationary state remnant DPPH percentage (Table 2) was calculated for every concentration evaluated, showing low remnant DPPH percentage and for radical entrapment ABTS on the part of isolated mucilage of yam showed values lower to the obtained by DPPH. The results found were lower to than the ones reported in mucilage of Chinese yam (*Dioscorea batatas*) within an entrapment activity of radicals DPPH of 16.7, 29.2 and 54.2% at concentrations of 250, 500 and 875 µg/mL, respectively (Hou *et al*., 2002), but similar to the mucilage of yam (*Dioscorea opposite thunb*) with entrapment percentage of DPPH of 5% at a concentration of 1000 µg/mL (Nagai *et al*., 2006) and mucilage of jacaratia with an entrapment percentage of 27.46% of ABTS at a concentration of 1000 µg/mL. The low values obtained could be due to the time difference since the extraction of mucilage till the time they were taken to freeze for their later drying. The importance of antioxidant capacity is that because they are such agents that naturally fight with cardiac diseases, cancer and diabetes caused by the oxidative stress, which is why, due to its health benefits quantitative and sensitive tests for a quick detection of antioxidants is becoming more important these days (Bener and Apak, 2017; Riebel *et al*., 2017).

In the Table 3 the average effective concentration is indicated, the time needed for the average effective concentration to reach to stationary state and the antioxidant effectiveness of lyophilized mucilage of yam, due to the techniques of DPPH and ABTS. The values obtained in EC50 exceed 1 mg/mL, indicating high concentrations of mucilage for a favorable response to the entrapment capacity (Nagai *et al*., 2006), which is related to minimum total phenol content in the lyophilized mucilage of yam. Mucilage of yam has values lower than those of the mucilage of Chinese yam (*Dioscorea batatas*) that has EC50 of 1620 µg/mL against DPPH (Murugan and Mohan, 2012) and of partially purified mucilage of yam bread *Dioscorea alata L. cv. Tainong, Dioscorea alata L. cv. Tainong*2 and *Dioscorea alata L. var. Purpurea*, with values of EC50 of 279, 653 and 631 µg/mL against DPPH, respectively (Lin *et al*., 2005).

Antioxidant effectiveness is a reflection of the entrapment capacity of radicals and the time required to complete it. Lyophilized mucilage of yam turned out to be more effective against ABTS in comparison to DPPH. Amzad Hossain and Dawood Shah (2015) reported that there is a relation between plant's phenol content and their antioxidant activity; however, it would be a mistake to think that antioxidant activity occurs only due to the presence of phenol compounds, since in their chemical composition there may be other secondary metabolites who contribute to its antioxidant capacity due to their structure.

Table 2: The antioxidant capacity in suspensions of lyophilized mucilage of yam

Concentration, µg/ml	% DPPH remnant of mucilage	% DPPH mucilage trapping	% ABTS remnant of mucilage	% ABTS mucilage trapping
500	96.5±0.6	3.5±0.6	90.3±1.6	9.7±1.6
1000	93.5±0.4	6.5±0.4	74.3±5.9	25.7±5.9
2000	87.4±1.3	12.6±1.3	60.6±4.2	39.3±4.2

Table 3: Average effective concentration (EC50), time required for EC50 to reach the stationary state (TEC50) and antioxidant effectiveness in mucilage

EC50 (µg/mL)		TEC50 (min)		AE	
DPPH	ABTS	DPPH	ABTS	DPPH	ABTS
8131.9	2494.5	61	22.67	1.24E-04	1.77E-05

Table 4: Rheological parameters of lyophilized mucilage of yam

		Concentrations (%)			
Models	Parameters	0.5	1.0	1.5	2.0
Newtonian	μ(mPa·s)	0.818±0.091	1.009±0.011	1.066±0.033	1.184±0.042
	R^2	0.952	0.971	0.973	0.982
Oswald de Waele	*n*	1.426±0.013	1.298±0.012	1.264±0.027	1.165±0.019
	K (mPa·s^n)	0.13±0.014	0.279±0.009	0.341±0.018	0.581±0.005
	R^2	0.939	0.993	0.974	0.996
Bingham	*K* (mPa·s^n)	0.929±0.032	1.112±0.044	1.164±0.08	1.253±0.063
	σ_o (Pa)	-7.665±0.001	-7.031±0.003	-6.739±0.002	-4.697±0.001
	R^2	0.934	0.972	0.973	0.983
Herschel-Bulckey	*n*	1.57±0.022	1.397±0.016	1.351±0.011	1.236±0.019
	K (mPa·s^n)	0.065±0.001	0.173±0.057	0.225±0.017	0.412±0.166
	σ_o(mPa)	3.239±0.129	3.128±0.098	2.972±0.081	2.975±0.165
	R^2	0.933	0.938	0.937	0.94

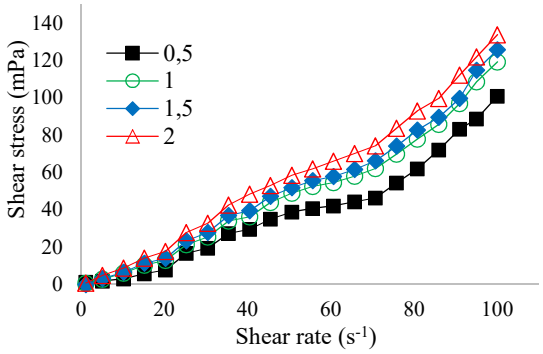

Fig. 2: Flow curves of suspensions of lyophilized mucilage of yam at different concentration

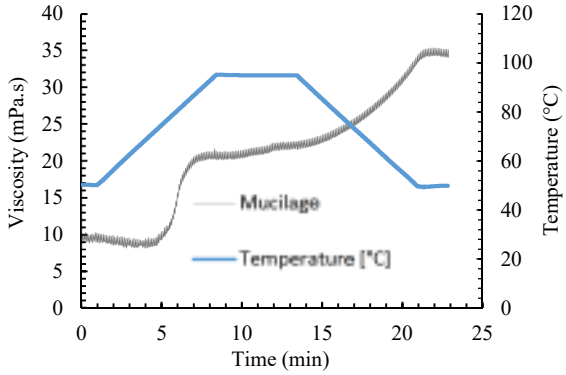

Fig. 3: Viscoamilogram of suspensions of lyophilized mucilage of yam

Rheological properties of lyophilized mucilage of yam: In the Fig. 2 the flow curves of suspensions of lyophilized mucilage of yam are shown at four concentrations (0.5, 1, 1.5 and 2%). It is seen that as the mucilage content in the suspension increases, it provides more resistance to the flow, besides the rheograms are typical of dilatant fluid.

In the Table 4 the rheological parameters of the suspensions of lyophilized mucilage of yam are shown as per the Newtonian model, Oswald de Waele, Bingham and Herschel-Bulckey. All these models accurately represent the rheological data; however, Bigham model shows a negative yield stress, which is why it was not taken into account. The model that best represented the rheological data was the Oswald de Waele with an adjusted coefficient of determination (adjusted R^2) between 94 and 99%. For this model, all the values in flow behavior index (*n*) were higher than one, indicating the fact that suspensions of lyophilized mucilage of yam show a behavior of dilatant fluid. Suspensions of mucilage of different vegetable breads have been characterized based on their rheological properties showing a pseudoplastic behavior: taro (*Colocasia esculenta l. schott*), creole yam (*Dioscorea alata*), pitahaya (*Hylocereus undatus*), salep (*orquídeas terrestres silvestres*), balangu seeds (*Balangu lallemantia royleana*), nopal (*Opuntia ficus-indica*) and chia (*Salvia hispanica L.*) (Abraján, 2008; Capitani, 2013; García-Cruz *et al*., 2013; Han *et al*., 2016; Njintang *et al*., 2014; Razavi and Karazhiyan, 2009; Rao, 1999; Tavares *et al*., 2011). This difference in the behavior could be attributed to the fact that the disperse phase of mucilage could cause a bundling of the particles, leaving no space for the continuous phase (Mezger, 2006; Steffe, 1996).

On the other hand, it is noted that as the concentration of suspensions of mucilage of yam increases, the flow behavior index (*n*), gets lower approaching to one, thus the fluid keeps losing its dilatancy and it is more consistent with Newtonian behavior. Besides the coefficient of consistency increases with the increment of the concentration of mucilage in the suspension, this shows an increase in consistency of the suspension. This behavior is similar to what was found in suspension of mucilage of nopal (*Opuntia ficus*) in concentrations of 1 at 5% and different states of maturity (Contreras-Padilla *et al*., 2016).

In the Fig. 3 and Table 5 the viscoamilogram and properties of the paste of suspension of lyophilized mucilage of yam during the heating and cooling period are shown. The mucilage shows viscosity values lower than those found in starch of the Hawthorne yam (*Dioscorea rotundata*). Mucilage of yam shows a lower

Table 5: Pasting properties of suspensions of lyophilized mucilage of yam

Properties	Value
Pasting temperature (°C)	71.0±1.0
Maximum viscosity at 95°C (mPa.s)	22.13±0.21
Peak Viscosity (mPa.s)	34.35±0.85
Final viscosity (mPa.s)	34.17±1.23
Breakdown (mPa.s)	-11.36±0.72
Setback (mPa.s)	11.43±0.55

peak point of viscosity during its heating in relation to native starch of Hawthorne yam, 2449 Pa.s (Paternina *et al*., 2016). The low values of setback shown by the mucilage of yam demonstrate that there will not be any retro-gradation when the solution is made, unlike what was found in starch of Hawthorne yam (2059 Pa.s) (Paternina *et al*., 2016). differences may be due to the composition and molecular structure that is typical in mucilage, consisting of monosaccharide like: gallactose, mannose and arabinose and amino acids such as: aspartic acid, asparagines acid, glutamic acid, glutamine and glycine that are more ramified than the native starch of Hawthorne yam which is made up by amylase and amylopectin (Andrade *et al*., 2015; Nasrin and Anal, 2014; Njintang *et al*., 2014).

The lyophilized mucilage of yam maintains an adequate stability (breakdown) in the viscosity during the constant heating phase, due to the presence of protein, mineral and fiber material having good water absorption and retention properties (Larkin, 2011; Nasrin and Anal, 2014). Similar results were found in the lyophilized mucilage of yam, but in this retro-gradation and viscosities are more close to those in starch, due to its high starch content, 50% (Tavares, 2013). These results ably show the purity of the mucilage and that this value will not have any effect in the food matrices in which it is used.

CONCLUSION

The values of emulsifying activity, stability of emulsion and oil absorption capacity, shows the potentiality present in lyophilized mucilage of yam as an emulsifier; likewise the stability and clarity of the pastes show the stability of the suspensions of lyophilized mucilage of yam and its high solubility at high and low temperatures facilitate its easy dilution in several food matrices.

Suspensions with concentrations of 0.5 to 2% of lyophilized mucilage of yam show a flow behavior index higher than one, categorizing it as a dilatant fluid. The viscoamilogram demonstrates the low starch content in mucilage, indicating a setback of 11.43 mPa.s, proving thus the solid stability of this polymer.

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CONFLICT OF INTEREST

The authors of this study do not have conflict of interest to report.

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