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Research Article

Effect of the Yam Starch (*Dioscórea* spp.) and Pectin on the Rheological Properties of Stirred Yogurt

[1]Pérez Jorge A., [2]Andrade Ricardo D. and [2]Arteaga Margarita R.
[1]Master in Agro-Food Sciences, Universidad de Córdoba, Montería, Colombia
[2]Department Food Engineering, Universidad de Córdoba, Km 12 vía Cereté, Colombia

Abstract: The aim of study was to evaluate the effect of the temperature and concentration of yam starch and pectin on the rheological properties of yogurt. A stationary test was performed using an MCR 302 (Anton Paar) rheometer with concentric cylinder geometry, varying the strain gradient in an ascending (0-100/sec) and a descending (0-100/sec), at different temperatures (10, 20 and 30°C, respectively). Yogurts were made using two varieties of yam starch ("Espino" and "Criollo") and different concentrations of yam starches (0.1, 0.3 and 0.5% w/w, respectively) and pectin at 0.3% w/w was used as a commercial reference. The experimental data were fitted to the power law models, Herschel-Bulkley and Casson. The model that best represented the rheological data was the power law ($R^2 \geq 0.977$, MSE≤0.674). Yogurts with an addition of yam starch presented thixotropy and pseudoplastic behavior ($0<n<1$); However, when pectin was used at 30°C the behavior was dilating ($n = 1.23$). Yogurts with "Criollo" yam starch have higher consistency, while yogurt with an addition of "Espino" yam starch are more pseudoplastic and have less thixotropy.

Keywords: Consistency coefficient, flow behavior index, flow curves, hydrocolloids, rheological models

INTRODUCTION

Because of its position in the market and high consumption, yogurt constitutes on the most important fermented products of the market (Bakirci and Kavaz, 2008; Özer and Kirmaci, 2010). The whole yogurt produces a weak gel during incubation, which disintegrates in agitation processes resulting in a product with lower viscosity (Ramirez and Velez, 2013). It is for this reason that stabilizers or also called hydrocolloids appear as texture agents, but also intended to fulfill the functions of thickeners, gelling agents and suspending agents (Dickinson, 2003). Among the stabilizers used in the production of yogurt, the most used are gelatin, starches, vegetable gums and pectin (Lucey, 2002; Dickinson, 2003).

Yam starches have a special feature in comparison with other tubers, they have a certain crystallinity conferred by the amylose-amylopectin ratio present in the starch granule, this characteristic is reflected in the variation of the functional properties of the starch, for example. The temperature of gelation (Araujo *et al*., 2004; Rached *et al*., 2006), whereas in cassava starches, values between 49 and 73°C have been reported (Moorthy, 2002), which allows us to glimpse the differences in the behaviour that these starches can offer in food matrices (Tecante and Doublier, 1999).

The use of starches brings textural changes in yogurts, associated with an increase in the product viscosity, which depends on the type of starch used, for example, the use of 0.4% cassava starch increases the yogurt viscosity by 47% (Oroian *et al*., 2011) and using 1.5% modified cassava starch the viscosity increases by 95% in set yogurts (Cui *et al*., 2014). In addition to changes in viscosity, in general terms the inclusion of hydrocolloids (starch, gums and pectin) modifies rheological characteristics in yogurt, reporting changes in flow behavior index and pseudo plasticity of the product (Gaviria *et al*., 2010; Oroian *et al*., 2011; Behnia *et al*., 2013).

In this study, the individual effect of the starch of yam varieties "Criollo" (*Dioscórea rotundata*) and "Espino" (*Dioscórea alata*) and pectin on the rheological properties of stirred yogurt were evaluated.

MATERIALS AND METHODS

Yogurt elaboration: To produce the yogurt, the methodology proposed by Cárdenas *et al*. (2013) was followed. Using brand-name pasteurized milk, standardizing its non-fatty solids content to 12% and adding 5% sugar. To the homogenate product, was added gelled "Espino" yam starch (88°C/7 min) and "Criollo" yam starch (95°C/8 min) at concentrations of

Corresponding Author: Pérez Jorge A., Master in Agro-Food Sciences, Universidad de Cordoba, Km 12 vía Cereté, Colombia, Tel.: +57 301 677 1222

0.1, 0.3 and 0.5% w/w, respectively was added. For the control, gelled pectin was added at 80°C at 3% w/w. The mixture was inoculated with a lactic culture of *Streptococcus thermophilus*, *Lactobacillus delbruekii* subsp. Lactis. and *Lactobacillus delbruekii* subsp. *Bulgaricus* (Choozit MY 800 Danisco) at 42°C until reaching pH 4.5. The yogurt was then refrigerated at 4°C for 20 h.

Rheological behavior in shear flow: Flow curves were determined using an MCR 302 rheometer (Anton Paar, Austria) with a concentric cylinder geometry (SC4-21, 2.5 Cm in diameter) in a continuous ramp of the shear rate in ascending form of 0-100/sec and descending 100-0/sec. Measurements were made at 20 h of yogurt at different temperatures of 10, 20 and 30°C, respectively. The experimental data of the ascending and descending curves were fitted to the power law models Eq. (1), Herschel-Bulkley Eq. (2) and Casson Eq. (3):

$$\sigma = k(\gamma)^n \tag{1}$$

$$\sigma = \sigma_0 + k(\gamma)^n \tag{2}$$

$$\sigma^{0.5} = \sigma_o^{0.5} + k(\gamma)^{0.5} \tag{3}$$

where,

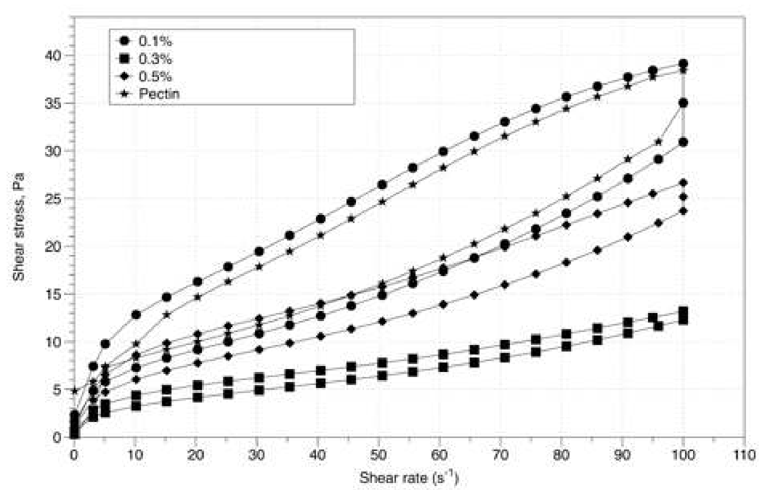
σ : Shear stress (Pa)
γ : Shear rate (/sec)
k : Consistency coefficient (Pas.s^n)
n : Flow behavior index (dimensionless)
σ_o : Yield stress (Pa)

Experiment design and data analysis: The experiment was conducted under a 2×3×3 factorial design, with the following factors: starch concentration at three levels (0.1, 0.3 and 0.5% w/w, respectively) and temperature at 3 levels (10, 20 and 30°C, respectively). For yogurts formulated with "Espino" and "Criollo" yam starches, yogurts with an addition of pectin at 0.3% w/w were also evaluated as a commercial reference treatment.

The selection of the best rheological model was determined by taking into account the coefficient of determination (R^2) and the Mean Squared Error (MSE). The analysis of the response variables, flow behaviour index, consistency coefficient and thixotropy was performed using the statistical software R 3.1.2, using an Analysis of Variance (ANOVA) and Tukey's mean comparison test ($p<0.05$). A test of Dunnett's tights ($p<0.05$) was used to establish the differences with the control treatment.

RESULTS AND DISCUSSION

Figure 1 and 2, the flow curves for yogurts formulated with "Espino" and "Criollo" yam starches at different temperatures (10, 20 and 30°C, respectively) are shown. There is no coincidence between upward and downward curves in these rheograms, this means that a bone hysteresis phenomenon (Time-dependent behavior) can be seen, this is usual in the production of agitated yogurts due to the breakage of the gel by agitation (Beal *et al*., 1999; Morell *et al*., 2015). On the other hand, all the treatments presented a non-Newtonian behavior, with a pseudo-plastic fluid characteristic. This behavior is related to the changes in the macromolecular organization. The shear rate increases, the randomly positioned chains of polymer molecules become aligned in the flow direction, resulting in less interaction among adjacent polymer chains (Koocheki *et al*., 2013). This behavior has been reported in yogurt with pineapple fiber (Sah *et al*., 2016) and yogurt with an addition of modified starch (Morell *et al*., 2015).



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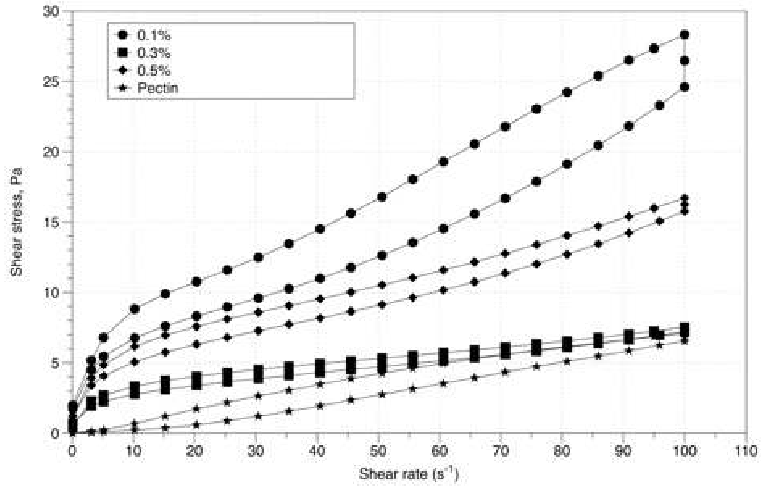

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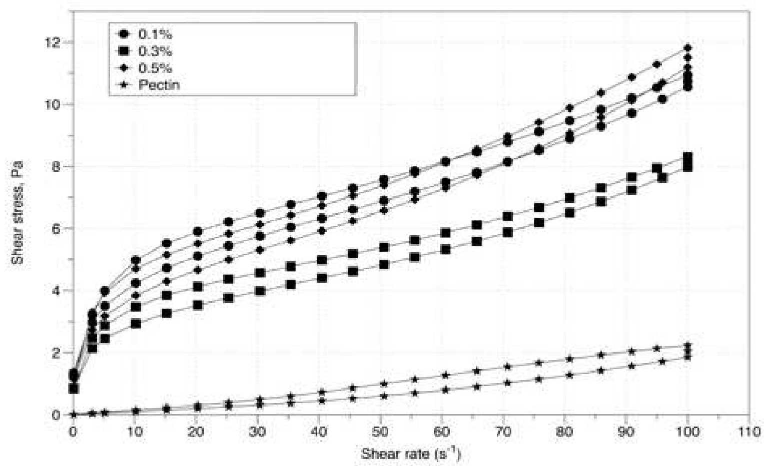

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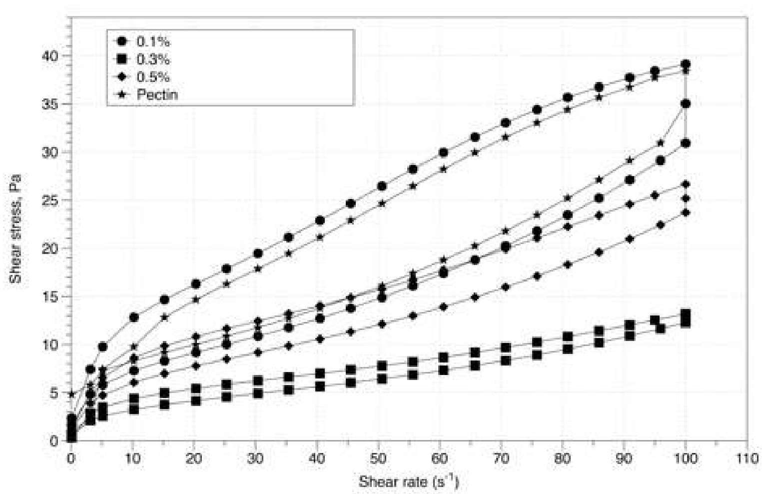
Fig. 1: Flow curves of yogurt with yam (*Dioscorea rotundata*) starch and pectin for different concentrations and temperature (a) 10°C, (b) 20°C, (c) 30°C



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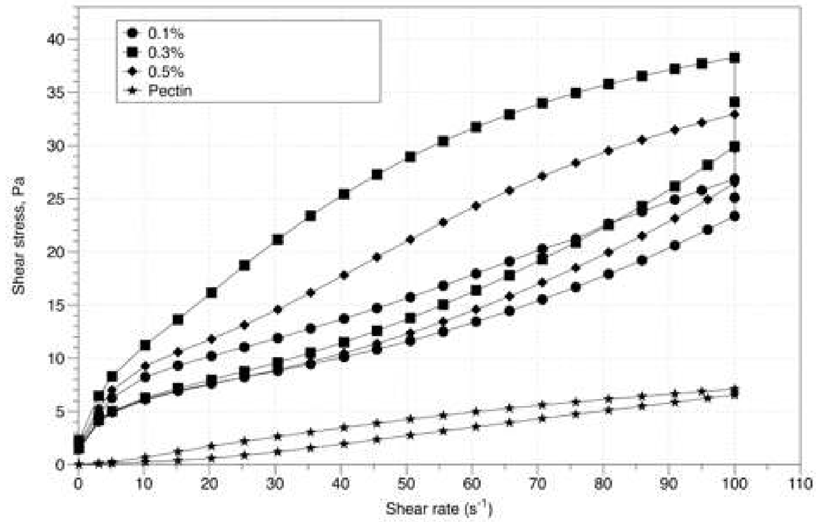

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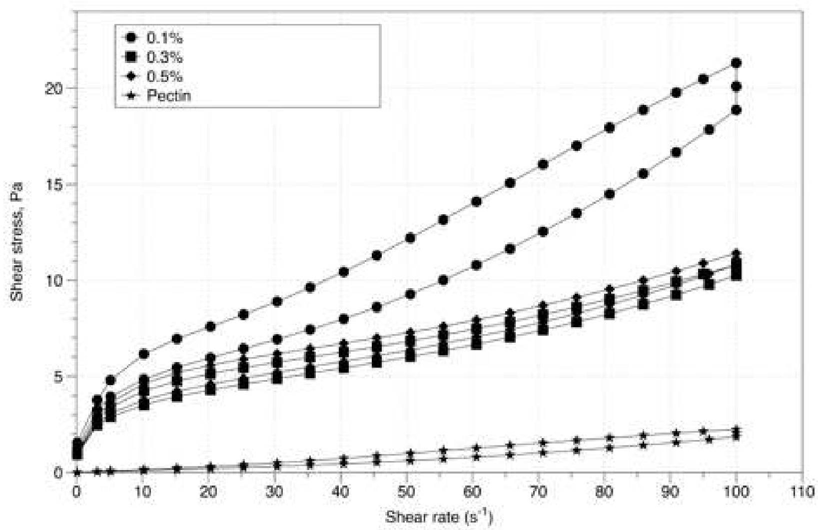

(c)

Fig. 2: Flow curves of yogurt with yam (*Dioscorea alata*) starch and pectin for different concentrations and temperature (a) 10°C, (b) 20°C, (c) 30°C

The model that best represented the rheological behavior of the yogurts with added stabilizers is the power law model, presenting values of R^2 between 93 and 99.1% and MSE between 0.030 and 1.118. The model of the power law is the most used in the rheological characterization of yogurts (Janhøj *et al*., 2008; Andrade *et al*., 2010; Oroian *et al*., 2011; Parra-Huertas *et al*., 2012; Cui *et al*., 2014).

Table 1 shows the rheological parameters of the power law model for yogurt with an addition of yam starch ("Espino" and "Criollo") with different starch concentrations and temperature. Moreover, the behavior of yogurt formulated with pectin (0.3% w/w) is shown.

All yogurts formulated with yam starch and pectin presented thixotropy. Yogurts with "Espino" yam starch presented thixotropy ranges from 8.643 to 38.445% in yogurts with "Criollo" yam starch ranging from 11.11 to 48.814%, while those formulated with pectin obtained a thixotropy range of 27.83 to 31.679%. Other studies report the presence of thixotropy in yogurts with gelatine (Gonçalvez *et al*., 2009), buffalo yogurts enriched with wheat bran (Andrade *et al*., 2010), yogurts added with pineapple fiber (Sah *et al*., 2016) and in yogurts with skim milk without addition of stabilizers (Wen *et al*., 2012). This is a commom characteristic in this type of products, during the

Table 1: Power law parameters for yogurt stirred at different yam starch concentrations and temperature

Hydrocolloids	w/w (%)	Temperature (°C)	n_{asc}	k_{asc} (Pa.s^n)	R^2	n_{desc}	k_{desc} (Pa.s^n)	R^2	Thixotropy, (%)
"Espino" yam starch	0.1	10	0.546	3.176	0.991	0.778	0.773	0.956	38.445
		20	0.602	1.693	0.974	0.672	1.001	0.949	21.975
		30	0.350	2.018	0.973	0.407	1.478	0.966	8.643
	0.3	10	0.527	1.062	0.964	0.664	0.517	0.959	15.900
		20	0.357	1.365	0.984	0.429	0.922	0.975	10.381
		30	0.386	1.267	0.957	0.455	0.880	0.951	9.603
	0.5	10	0.568	1.871	0.969	0.704	0.858	0.786	24.021
		20	0.463	1.824	0.970	0.539	1.189	0.960	12.081
		30	0.426	1.498	0.948	0.502	1.006	0.952	10.749
"Criollo" yam starch	0.1	10	0.613	2.448	0.989	0.856	0.562	0.957	38.736
		20	0.600	1.604	0.973	0.703	0.818	0.947	22.750
		30	0.643	1.047	0.972	0.729	0.592	0.948	20.484
	0.3	10	0.563	3.406	0.990	0.933	0.400	0.963	47.590
		20	0.529	3.535	0.992	0.872	0.493	0.963	44.316
		30	0.423	1.398	0.961	0.499	0.928	0.953	11.111
	0.5	10	0.529	4.201	0.987	0.906	0.461	0.962	48.814
		20	0.635	1.782	0.991	0.818	0.552	0.954	35.361
		30	0.428	1.492	0.956	0.512	0.942	0.948	12.274
Pectin	0.3	10	0.900	0.141	0.991	1.411	0.011	0.997	30.282
		20	0.864	0.137	0.993	1.363	0.012	0.997	27.830
		30	1.238	0.007	0.998	1.331	0.004	0.989	31.676

agitation or the application of another mechanical force the gel structure is broken, producing changes in the apparent vis the greater strength of the binding between starch and casein or whey proteins contained in the yogurt, giving a higher gel structure (Considine *et al.*, 2011; Cui *et al.*, 2014).

The analysis of variance shows that the starch concentration, the temperature and the interactions between the concentrations of starch * temperature, influence the thixotropy in yogurts with "Espino" and "Criollo" yam starches. In each of the starch concentrations evaluated (0.1, 0.3 and 0.5% w/w, respectively) as the temperature increases, the percentage of thixotropy decreases, but in a different percentage. In yogurts with an addition of 0.1% "Espino" yam starch, the increase in temperature causes a 77.51% decrease in thixotropy, while at concentrations of 0.3 and 0.5% this decrease is 39.60 and 55.25%, respectively. On the other hand, in the yogurt with an addition of 0.1% of "Criollo" yam starch, the increase of the temperature causes a decrease of the thixotropy of 47.11%, while at concentrations of 0.3 and 0.5% the decrease is of 76.65 and 74.85% respectively.

The flow behavior index for yogurt with addition of yam starch ("Espino" and "Criollo") presented values between 0.3 and 0.933 for flow curves in ascending and descending form, which confirms that the yogurts with addition of this hydrocolloid behave like a pseudo plastic fluid, this behavior has been reported in yogurts with addition of stabilizers such as cassava modified starch (Cui *et al.*, 2014), native cassava starch and gelatine (Gonçalvez *et al.*, 2009), agar, carrageen an (Oroian *et al.*, 2011), gums (Behnia *et al.*, 2013), caramel syrups (Ramírez-Sucre and Vélez-Ruiz, 2013) and buffalo milk yogurt added with wheat bran (Andrade *et al.*, 2010).

For yogurts made with pectin, flow behavior index at temperatures of 10 and 20°C is between 0.9 and 0.86, respectively, indicating that their behavior is pseudo plastic, while at 30°C flow behavior index was 1.237 indicating a dilatant behavior. Note that the values of this parameter are close to 1, characteristic of Newtonian fluids, similar to that reported in acidified milk with the addition of pectin and CMC (Janhøj *et al.*, 2008).

For all yogurts, independent of the stabilizer used (yam starches and pectin), the values of flow behavior index determined ascent form were smaller than those found in a descending way, whereby the yogurts lose pseudoplasticity over time, tending to a Newtonian behavior. This behavior has been reported in buffalo milk yogurts with an addition of wheat bran (Andrade *et al.*, 2010).

It should be noted that the values of the upward flow behavior index are similar to those reported for yogurt with modified starch, $0.49>n<0.56$ (Morel *et al.*, 2015), low-fat yogurt with addition of gum, $0.20<n<0.32$ (Behnia *et al.*, 2013), cranberry yogurt when different stabilizers are used: starch ($0.30<n<0.322$), agar-agar ($0.297<n<0.317$) and carrageenan ($0.305<n<0.329$) (Oroian *et al.*, 2011).

The analysis of variance indicates that yam starch concentration, temperature and interaction between them affects the flow behavior index of yogurt with "Espino" and "Criollo" yam starch in the ascent and descent tests. For yogurts with 0.1% of "Espino" yam starch, in ascent tests, a temperature increase decreases the flow behavior index by 35.89%, while at concentrations of 0.3 and 0.5% of yam starch, this elevation in temperature causes a decrease in the flow behavior index of 26.75 and 25%, respectively. In yogurts with 0.1% of "Criollo" yam starch, an increase in temperature produces a slight increase in the flow behavior index (4.66%), while at concentrations of 0.3 and 0.5% of yam starch, the flow behavior index decreases by 24.86 and 19.09%, respectively. Similar behavior is presented in the flow behavior index data obtained from the rheograms of the descent curves. An increase in temperature causes yogurts to augment their pseudoplasticity.

The consistency coefficients of yogurts with added yam starch from the two varieties were similar, however, these values were higher than those obtained when the commercial reference stabilizer (pectin) was used. This rheological parameter (k) is an indicator of the consistency degree of the products. Starches improve the rheological properties of yogurt due to the ability to bind water, high molecular weight and the capability to form casein-starch bridges. The ability to form gel induces an increased viscosity of the product, favoring the non-separation of serum in yogurt (Antonov *et al*., 1999; Oroian *et al*., 2011).

On the other hand, the values of the consistency coefficients of the ascent curves were higher than those determined in a descending manner, which shows that as time passes yogurts lose consistency. Similar results have been obtained in yogurt with modified starch addition, which presents values of k in ascent tests (5.6 to 18.2 $Pa.s^n$) higher than in descent (0.9 to 4.3 $Pa.s^n$) (Morell *et al*., 2015). The reduction in the coefficient of consistency is due to deformation of the yogurt with shear stress and is dependent on the application time (Morell *et al*., 2015).

The analysis of variance shows that, for the two types of yam starch, the starch concentration, temperature and interaction starch concentrations * temperature, had a significant influence on the consistency coefficient obtained in the test of ascent and descent. The consistency coefficient of the yogurt with "Espino" yam starch in the ascendant test showed that at yam starch concentrations of 0.1 and 0.5% w/w, the tendency of k is to decrease with increasing temperature, whereas to yogurts added with a yam starch of 0.3% w/w, the consistency coefficient increased by 16.17%.

For yogurts made with "Criollo" yam starch, the coefficients of consistency ascendant (k_{asc}) at any concentration of yam starch, tend to decrease with increasing temperature. However, for the 2 types of yam starch used in yogurt processing, the coefficients of consistency descendant (k_{desc}) increases with increasing temperature. It should be noted that the percentage increase in k_{desc} depends on the concentration and variety of the starch used.

CONCLUSION

Yogurts formulated with "Espino" and "Criollo" yam starches have a pseudo plastic and thixotropic behavior. The addition of yam starch makes the yogurt more pseudo plastic and consistent in comparison to the commercial reference stabilizer (pectin), which in addition causes yogurt to tend to behave like a Newtonian fluid. The concentration of yam starch and the temperature has an effect on flow behavior index, consistency coefficient and thixotropy of the yogurt. Yogurts with "Criollo" yam starch have a higher consistency, while yogurt with an addition of "Espino" yam starch are more pseudo plastic and have less thixotropy than the commercial reference stabilizer, which is favorable in the manufacture of this type of dairy products.

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CONFLICT OF INTEREST

The authors declare that this study does not present a conflict of interests.

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