



## Research article

Effect of yam (*Dioscorea spp.*) starch on the physicochemical, rheological, and sensory properties of yogurtJorge Pérez<sup>a</sup>, Margarita Arteaga<sup>b</sup>, Ricardo Andrade<sup>b,\*</sup>, Alba Durango<sup>b</sup>, Jairo Salcedo<sup>c</sup><sup>a</sup> Agri-Food, University of Córdoba, Montería, 230007, Colombia<sup>b</sup> Department of Food Engineering, University of Córdoba, Montería, 230007, Colombia<sup>c</sup> Department of Agroindustrial Engineering, University of Sucre, Sincelejo, 700001, Colombia

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## ABSTRACT

This study investigated the effect of the addition of starch from “hawthorn” yam (*Dioscorea rotundata*) and “creole” yam (*Dioscorea alata*) at different concentrations (0.1%, 0.3%, and 0.5% w/w) on the physicochemical and sensory properties of stirred-type yogurt. Pectin (0.3% w/w) was used as a reference stabilizer. Yogurt with yam starch presented 13.38% less syneresis than yogurts with pectin. At the sensory level, the most accepted treatment was yogurt with “creole” yam starch at 0.1% w/w. During 21 days of storage, yogurt with yam starch (“creole” and “hawthorn”) at 0.1% w/w showed a decrease in syneresis between 7% and 8%, while in those with pectin, syneresis remained practically constant in this period. Yogurt with yam starch was characterized as a pseudoplastic fluid, with a lactic acid bacterial count according to NTC 805. Yam starch can be used as stabilizer because it improves the physicochemical, sensory, and rheological characteristics of stirred-type yogurt. Especially the “creole” yam starch (0.1% w/w), which presents the best preference by consumers.

## 1. Introduction

Yogurt is a mass-consumed dairy product with great acceptability due to its benefits to human health and nutrition. It is produced by controlled fermentation of milk, by the combined actions of symbiotic cultures of *Streptococcus thermophilus* and *Lactobacillus delbrueckii spp. bulgaricus*, resulting in a product with creamy characteristics, typical aromas, and a slightly acidic taste (Andrade et al., 2010; Mendoza et al., 2007).

One of the most important attributes of yogurt is its texture, which defines the acceptance of the product and is related to viscosity. Under natural conditions, yogurt has a poor texture, which leads to syneresis or draining, which is manifested by the expulsion of serum towards the outside of the gel. This phenomenon has a negative influence on the physical and sensory properties of yogurt and is a factor in rejection by consumers. To improve this aspect, stabilizers or hydrocolloids are used (Cárdenas et al., 2013).

Among the most commonly used hydrocolloids in the preparation of yogurt are gelatin, vegetable gums, and pectins. However, the stabilizer most commonly used is high-methoxy pectin. The concentration of hydrocolloids plays an important role in the stability of yogurts, and it is also correlated with improved quality and sensory perception (Xu et al., 2019). The concentration of high-methoxy pectin required to ensure

stability in acid milk drinks is around 0.25 wt % (Willats et al., 2006). Each one of these stabilizers presents limitations to its use: in the case of gelatin, it solidifies at 25 °C, and its use causes problems in the refrigeration stage, while pectin reports stability problems, disadvantageous when forming gels at high temperatures, and the formation of granules in mixing (Mendoza et al., 2007). Therefore, it is important to advance in the search for new stabilizers that effectively control the phenomenon of syneresis. In addition, the concentration of the stabilizer used must be taken into account. Kumar and Mishra (2004) evaluated the effect of the addition of gelatin, pectin, and sodium alginate on the physical and sensory properties of yogurt, and report that sensory scores increased with the concentration of stabilizer up to 0.4%, but the addition of 0.6% resulted in lowered score in all yogurts.

Starch is widely used in the food industry because of its thickening, gelling, filling, binding, and stabilizing properties (Aguilar and Villalobos, 2013). The addition of starch to dairy-based products such as yogurt causes a change in consistency and texture (Lal et al., 2006). For example, corn starch (Pang et al., 2019; Wong et al., 2020), cassava starch (Agyemang et al., 2020), and potato starch (Altemimi, 2018), and water yam starch (Olufemi and John, 2016) are known to enhance the properties of yogurt. The addition of yam (*Dioscorea opposita* Thunb) powder has a positive effect on the texture, stability, and the consistency of the

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yogurt because of the availability of functional ingredients (Kim et al., 2011). The functionality of starches is related to their physicochemical (gelatinization and retrogradation) and functional properties (solubility, swelling, water absorption, and syneresis), in addition to the rheological behavior of their pastes and gels (Wang and White, 1994). These properties of starches depend on several factors: the botanical origin, the extraction process, and environmental conditions, among others. For example, for yam starch, gelling temperature values of 70.8 °C (Araujo et al., 2004) and 80 °C (Rached et al., 2006) are reported, and for cassava starches, ranges of 49 to 73 °C are reported, depending on the variety, genetic constitution and culture development environment (Moorthy, 2002). Also, yam contains a significant amount of starch ( $\leq 25\%$ ), make it suitable for pharmaceutical and food industry (Singh and Sharanagat, 2020). Therefore, this work aimed to evaluate the effect of yam starches (“hawthorn” and “creole”) on the physicochemical, rheological, and sensory properties of stirred-type yogurt.

## 2. Materials and methods

“Hawthorn” yam (*Dioscorea rotundata*) and “creole” yam (*Dioscorea alata*) from the public market in the city of Sincelejo (Sucre) and commercial UHT milk (3% fat, 3% protein, and 4.5% carbohydrate) were used. Yams were selected with a good physiological and microbiological condition. Freeze-dried concentrated lactic starter Choozit MY 800, Danisco Co. Ltd. (*Streptococcus thermophilus*, *Lactobacillus delbruekii* subsp. *Lactis*, and *Lactobacillus delbruekii* subsp. *bulgaricus*) was obtained from Cimpa s.a.s. (Colombia).

### 2.1. Physicochemical properties of yam starch

Yam starch was extracted according to the methodology reported by Lozano et al. (2018) using a system of mucilage separation and starch extraction on a pilot scale, in which phase separation occurs due to the injection of air and the subsequent generation of mucilage-laden bubbles, thus allowing native starch to be obtained. For yam starch characterization, the water solubility index, water absorption index, and swelling power, were determined according to the methodology proposed by Wang et al. (2010). A starch suspension (4% w/v) was heated at 60 °C, 70 °C, and 80 °C for 30 min in a water bath with shaking after every 5 min. After cooling to room temperature (25 °C), the suspension was centrifuged run at 4500 rpm for 15 min. The supernatant liquid from each tube was transferred into Petri-dish to be oven-dried at 70 °C for 18 h. The dried residue was then cooled in desiccators and weighed for soluble starch. The water solubility index, WSI (Eq. (1)), water absorption index, WAI (Eq. (2)), and swelling power, SP (Eq. (3)), were calculated as follows:

$$WSI = \frac{W_s}{W} \quad (1)$$

$$WAI = \frac{W_g}{W} \quad (2)$$

$$SP = \frac{W_g}{W - W_s} \quad (3)$$

where, Wg: weight of sediment (g), W: weight of dry solids in sample (g), and Ws: weight of dissolved solids in supernatant (g).

### 2.2. Pasting properties of yam starch

The pasting properties of yam starch suspensions were determined according to the methodology of Figueroa et al. (2016), using a rheometer (Anton Paar, MCR 302 Austria) with concentric cylinder geometry and a rapid starch analyzer (SAA24-2D/2V). A yam starch suspension (4% w/v) was freshly prepared just before running the test. The

temperature profile used was as follows: holding at 50 °C for 1 min; a heating-ramp from 50 to 95 °C at a rate of 6 °C/min; holding at 95 °C for 5 min; then cooling back to 50 °C at a rate of 6 °C/min, and finally holding at 50 °C for 2 min. Paddle speed was kept constant at 160 rpm, except for the initial 60 s when it was rotated at 960 rpm for suspension of sample. The parameters of the initial pasting temperature (PT), peak viscosity (PV), final viscosity (FV), breakdown viscosity (BV), and setback viscosity (SV) were obtained. The results were obtained using the Rheo Compass software (Anton Paar, version 1.12 Austria).

### 2.3. Set yogurt preparation

Yogurt was prepared according to the methodology proposed by Cárdenas et al. (2013), with some modifications.

Milk solids-not-fat was standardized to 12% by adding skim milk powder. The samples were stirred with a high dispersion homogenizer (Heidolph, Silent crusher M, Germany) starting at 8,500 rpm to remove the granules formed by the powdered milk, and then at 10,000 rpm for 30 s. The standardized milk was heated to 42 °C to facilitate the inclusion of stabilizers. For starches, a starch dispersion at 5% p/v was gelled. The heating conditions for “hawthorn” yam starch were 88 °C for 7 min, while for “creole” yam starch they were 95 °C for 8 min. In the preparation of yogurt, pectin was also used as a stabilizer (control or reference). Pectin at 5% p/v was heated to 80 °C until a gel point was observed. The stabilizers were added to the milk and homogenized until the gel granules formed at the time of addition were broken. At this point, the mixtures were inoculated with *Streptococcus thermophilus*, *Lactobacillus delbruekii* subsp. *Lactis*, and *Lactobacillus delbruekii* subsp. *bulgaricus*, and incubated at 42 °C until pH 4.5 was reached. Yogurts were then stirred at 8500 rpm for 2 min and stored at 4 °C for 24 h before evaluation. The concentrations of starch used in yogurt were 0.1, 0.3, and 0.5% w/w, and for the pectin a concentration of 0.3% w/w was used.

### 2.4. Physicochemical properties of stirred-type yogurt

The physicochemical properties of the yogurt were determined after 24 h of processing. pH was measured using a digital pH-meter (AOAC 945.27), Titratable acidity (as % lactic acid) was determined by the titration method (AOAC 947.05) using 0.1 M NaOH. The fat content was measured by the Geber method (AOAC 200.18), and total solids were determined by weight difference, drying in an oven at 70 °C (AOAC 990.16), during 24 h. The syneresis of yogurt was determined according to the centrifuge method described by Säker and Rodríguez (2012). 10 g of yoghurt sample was centrifuged at 5000 rpm for 20 min at 10 °C. After centrifugation, the clear supernatant was poured off, weighed and used to determine the percentage (w/w) of syneresis (Eq. (4)).

$$\text{Syneresis}(\%) = \frac{\text{Supernatant weight (g)}}{\text{Sample weight (g)}} \times 100 \quad (4)$$

### 2.5. Color parameters of yogurt

The color difference in the yogurt samples was determined using a ColorFlex EZ colorimeter (HunterLab, Virginia, USA) with reference to illuminant D65 and a viewing angle of 10°, calibrated with a standard plate (X = 97.83, Y = 81.58, Z = 91.51). Besides, the CIELab values (L, from black (0) to white (100); a, from green (-128) to red (127); and b, from blue (-128) to yellow (127)) were adopted to characterize the yogurt color. Eq. (5) describes the calculation of the color difference.

$$\Delta E = \sqrt{(L_m - L_c)^2 + (a_m - a_c)^2 + (b_m - b_c)^2} \quad (5)$$

where the subscript “m” stands for the sample of yogurt formulated with yam starch, and “c” stands for the control sample (yogurt formulated with pectin).

## 2.6. Preference test of stirred-type yogurt

A preference ranking test was conducted using an untrained consumer panel (50 panelists), and by asking the panelists to indicate the preferred sample by means of an order test. The test was conducted in two sessions. In the first session, yogurt samples with “hawthorn” yam starch and in the second, those with “creole” yam starch were tested; yogurt samples with pectin were included in both sessions. Samples were coded and 20 mL given to each assessor in individual random order in plastic tumblers. For data analysis, 1 point was given to the least preferred sample and 4 points to the most preferred. The rank sums for each sample were calculated and then, they were compared using the Friedman test ( $p < 0.05$ ).

The sensory evaluation was conducted according to established ethical guidelines, and informed consent obtained from the participants. These sensory tests do not require ethical approval in Colombia.

## 2.7. Properties of yogurt during storage

Physicochemical, rheological, and microbiological parameters were monitored during 21 days of storage for the treatments with the best physicochemical and sensory performance. These were determined every 7 days.

### 2.7.1. Physicochemical parameters

The physicochemical properties of syneresis, pH, and acidity were determined for the yogurts according to the methodology described above, during 21 days with measurements every 7 days.

### 2.7.2. Rheological characterization

A stationary test was performed on a rheometer (Anton Paar, MCR 302, Austria) with concentric cylinder geometry (SC4-21 2.5 cm diameter). The yogurt samples were subjected to a continuous ramp of the deformation gradient in an upward ( $0\text{--}100\text{ s}^{-1}$ ) and downward ( $100\text{--}0\text{ s}^{-1}$ ) manner. The test was performed at  $10\text{ }^{\circ}\text{C}$ , and the experimental data were adjusted to the power law.

### 2.7.3. Microbiological count

*Streptococcus thermophilus* and *Lactobacillus bulgaricus* were counted using specific growth agar. MRS (Merk) agar for *Lactobacillus growth* and M17 (Merk) agar for *Streptococcus growth*. Incubation was performed in anaerobic jars at  $37\text{ }^{\circ}\text{C}$  for 72 h. Quantification was performed by counting the number of colony-forming units per milliliter (CFU/ml).

## 2.8. Experimental design and data analysis

The experiment was conducted under a completely randomized design with a  $2 \times 3$  factorial arrangement, with the following factors: type of yam starch (“hawthorn” and “creole”) and starch concentration (0.1%, 0.3%, and 0.5% w/w). For data analysis, the software R 3.1.2 was used, employing analysis of variance (ANOVA), and in case of significant differences, the Tukey test was used ( $p < 0.05$ ).

## 3. Results and discussion

### 3.1. Physicochemical properties of yam starch

Table 1 shows the water solubility index, water absorption index, and swelling power results for “hawthorn” and “creole” yam starch. Solubility at  $60$  and  $70\text{ }^{\circ}\text{C}$  in both starches was low ( $0.01\text{--}0.016\text{ g water/g starch}$ ). However, when the temperature was increased to  $80\text{ }^{\circ}\text{C}$ , this parameter increased to about  $0.04\text{ g/g}$ . This behavior coincides with that reported for Chinese yam starch (Liu et al., 2020; Qian et al., 2019).

An increase in temperature causes an increase in water absorption index; however, this increase depends on the type of starch evaluated. For “hawthorn” yam starch the increase was 445%, while for “creole” yam starch it was only 130%, when the temperature is increased from  $60$  to  $80\text{ }^{\circ}\text{C}$ . The greatest difference occurs when the water adsorption index is determined at  $80\text{ }^{\circ}\text{C}$ . This is because the gelatinization temperature for “hawthorn” yam starch is  $73\text{ }^{\circ}\text{C}$ , while for “creole” yam starch it is  $80.2\text{ }^{\circ}\text{C}$ . The change in water solubility index, water absorption index, and swelling power with temperature is due to the gelatinization process, which implies a loss of molecular arrangement of the starch granule due to an increase in the system's kinetic energy, which allows water molecules to enter the starch granule (Pacheco and Techeira, 2009).

Creole yam starch presented lower values for the parameters water solubility index, water absorption index, and swelling power than hawthorn yam starch. These differences between the two types of yam starch may be due to the different levels of association forces within the granule, which depend on the amylose and amylopectin ratio, molecular weight, conformation, degree of polymerization of both fractions and degree of branching of the amylopectin (Chen et al., 2017; Naguleswaran et al., 2010). It should be noted that the amylose content of “creole” yam starch is  $25.01 \pm 0.03\%$ , while for “hawthorn” yam starch it is  $23.37 \pm 0.01\%$  (Salcedo et al., 2016). Amylose plays a key role in maintaining granule integrity by forming lipid complexes and facilitating amylopectin chain bonding.

The pasting profiles of “hawthorn” yam starch and “creole” yam starch are shown in Figure 1. The capacity of “hawthorn” yam starch to generate gels with a higher viscosity was noted. Similarly, the greater resistance of “creole” yam starch to thermal changes is shown as a product of the high degree of intramolecular order, which makes it difficult for water molecules to penetrate the starch granule (Beleia et al., 2006). In both starches, after the constant heating phase, an increase in viscosity is evident as a consequence of the phenomenon of retrogradation of the starch gel. In this stage, the polymers that are solubilized in the process are reassociated and form crystals accompanied by an increase in rigidity (Biliaderis, 1992).

Table 2 shows the pasting properties of yam starch suspensions. The pasting temperature (PT) of “hawthorn” yam starch ( $73.2\text{ }^{\circ}\text{C}$ ) is lower than that of “creole” yam starch ( $80.60\text{ }^{\circ}\text{C}$ ), which may be due to the difference in composition and molecular structure between the two starch species. For starches from different yam varieties, different pasting temperatures have been reported:  $86.8\text{ }^{\circ}\text{C}$  for the Chinese yam (Qian et al., 2019),  $86.7\text{ }^{\circ}\text{C}$  for white bitter yam (Oyeyinka et al., 2018),  $86.9\text{ }^{\circ}\text{C}$  for yellow bitter yam (Oyeyinka et al., 2018), and  $86.93\text{ }^{\circ}\text{C}$  for elephant foot yam (Suriya et al., 2019). The amylose content of “creole” yam

**Table 1.** Effect of the temperature on water solubility index (WSI), water absorption index (WAI), and swelling power (SP) of “hawthorn” and “creole” yam starches.

T ( $^{\circ}\text{C}$ )	WSI		WAI		SP	
	Hawthorn yam	Creole yam	Hawthorn yam	Creole yam	Hawthorn yam	Creole yam
60	$0.016 \pm 0.001^{\text{bA}}$	$0.010 \pm 0.001^{\text{bB}}$	$2.03 \pm 0.01^{\text{cA}}$	$1.91 \pm 0.01^{\text{bB}}$	$2.04 \pm 0.02^{\text{cA}}$	$1.92 \pm 0.01^{\text{bB}}$
70	$0.013 \pm 0.003^{\text{bA}}$	$0.012 \pm 0.003^{\text{bA}}$	$3.28 \pm 0.05^{\text{bA}}$	$1.90 \pm 0.01^{\text{bB}}$	$3.30 \pm 0.05^{\text{bA}}$	$1.91 \pm 0.01^{\text{bB}}$
80	$0.04 \pm 0.01^{\text{aA}}$	$0.04 \pm 0.03^{\text{aA}}$	$11.1 \pm 0.72^{\text{aA}}$	$4.4 \pm 0.3^{\text{aB}}$	$11.4 \pm 0.7^{\text{aA}}$	$4.5 \pm 0.3^{\text{aB}}$

\*Means with different lowercase letters in a column or the different capital letters in a row are significantly different ( $p < 0.05$ ) by the Tukey's test.

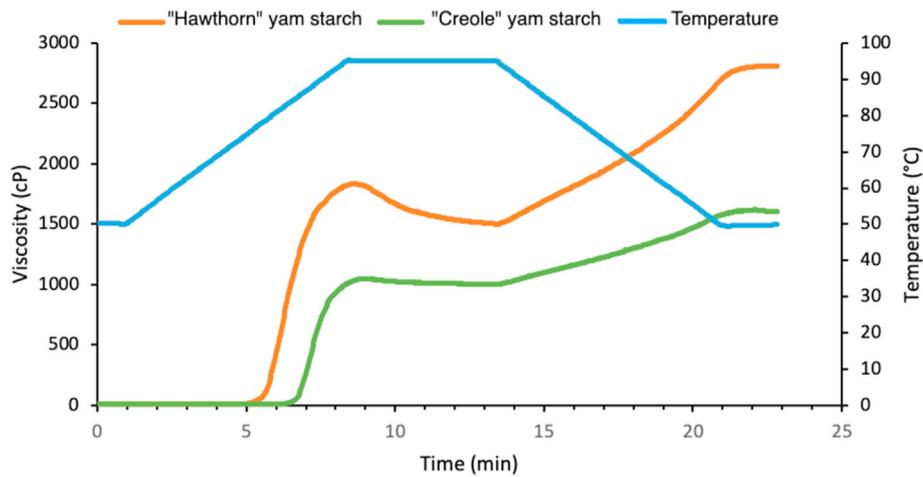


Figure 1. Viscosity profile comparison of “hawthorn” and “creole” yam starch.

starch is higher than that of “hawthorn” yam starch but lower than that of either white bitter yam starch (15%) (Oyeyinka et al., 2018) or bitter yellow yam starch (17%) (Oyeyinka et al., 2018). The higher amylose content in the starch granule requires a higher temperature to initiate the pasting process, as a result of the high intragranular order, which makes it difficult for water to enter the granule (Beleia et al., 2006).

The peak viscosity of “hawthorn” yam starch (1838 cP) is significantly higher than that of “creole” yam starch (1051 cP). This may be due to the amylose content, which prevents starches from swelling during sticking by forming a barrier around the starch granules. “hawthorn” yam starch reaches a higher viscosity at the end of the heating and cooling cycles (2807 cP) because its structure allows more water to penetrate the granule (Beleia et al., 2006). On the other hand, the “hawthorn” yam starch gel presents greater instability (breakdown); this characteristic is evidenced by the downward slope in the constant heating phase (90 °C), the gel is not able to maintain viscosity over time; this is a result of leaching of amylose from the starch granule, which does not allow the

three-dimensional network of the gel to be maintained (Salcedo et al., 2016).

### 3.2. Physicochemical properties of stirred-type yogurt

The results of the physicochemical properties of the yogurt formulations are shown in Table 3. The density, total solids, fat, and pH, are within the normal ranges for the yogurt.

The syneresis of yogurts formulated with “hawthorn” yam starch was in the range of 56%–58.4%, that of yogurts formulated with “creole” yam starch was in the range of 52.8%–57.6%, while yogurts with pectin obtained results for syneresis of 65%. This indicates that yam starches are better at controlling syneresis than the commercial stabilizer used (pectin). Other authors reported syneresis values between 62% and 73% for yogurt with added pectin (0.2–0.4%), between 36.39% and 45.01% for yogurt with 0.5–0.7% gelatin addition (Kiros et al., 2016), and between 47.36% for yogurt formulated using gelatin (0.25%), 18.27% for

Table 2. Effect of the botanical origin on pasting properties of yam starches.

Pasting properties	“Hawthorn” yam starch	“Creole” yam starch
Pasting temperature (PT), °C	73.2 ± 0.97 <sup>b</sup>	80.60 ± 0.08 <sup>a</sup>
Peak viscosity (PV), cP	1838 ± 54 <sup>a</sup>	1051 ± 39 <sup>b</sup>
Final viscosity (FV), cP	2807 ± 129 <sup>a</sup>	1606 ± 44 <sup>b</sup>
Breakdown (BD), cP	337 ± 1.5 <sup>a</sup>	28 ± 3.3 <sup>b</sup>
Setback (SB), cP	1305 ± 76 <sup>a</sup>	602 ± 43.5 <sup>b</sup>

\*Means with different lowercase letters in a row are significantly different (p < 0.05) by the Tukey's test.

Table 3. Effect of the addition of starch from “hawthorn” yam and “creole” yam at different concentrations on the physicochemical properties of stirred-type yogurt.

Physicochemical properties	Pectin	“Hawthorn” yam starch				“Creole” yam starch		
	0.3%	0.1%	0.3%	0.5%	0.1%	0.3%	0.5%	
Density (g/ml)	1.05 ± 0.01 <sup>a</sup>	1.05 ± 0.02 <sup>a</sup>	1.05 ± 0.01 <sup>a</sup>	1.04 ± 0.01 <sup>a</sup>	1.05 ± 0.02 <sup>a</sup>	1.05 ± 0.01 <sup>a</sup>	1.05 ± 0.01 <sup>a</sup>	
Total solids (%)	17.2 ± 0.31 <sup>d</sup>	19.0 ± 0.11 <sup>a</sup>	18.5 ± 0.64 <sup>abc</sup>	18.00 ± 0.02 <sup>c</sup>	18.6 ± 0.1 <sup>abc</sup>	18.90 ± 0.04 <sup>ab</sup>	18.20 ± 0.06 <sup>bc</sup>	
Fat (%)	2.50 ± 0.0 <sup>b</sup>	2.43 ± 0.05 <sup>b</sup>	2.43 ± 0.04 <sup>b</sup>	2.43 ± 0.05 <sup>b</sup>	2.65 ± 0.05 <sup>a</sup>	2.45 ± 0.05 <sup>b</sup>	2.20 ± 0.02 <sup>c</sup>	
Titrateable acidity (g/L)	0.98 ± 0.02 <sup>a</sup>	0.12 ± 0.01 <sup>b</sup>	0.12 ± 0.01 <sup>bc</sup>	0.11 ± 0.01 <sup>c</sup>	0.12 ± 0.01 <sup>bc</sup>	0.12 ± 0.01 <sup>bc</sup>	0.10 ± 0.01 <sup>bc</sup>	
pH	4.54 ± 0.01 <sup>a</sup>	4.50 ± 0.01 <sup>d</sup>	4.45 ± 0.01 <sup>e</sup>	4.52 ± 0.01 <sup>b</sup>	4.45 ± 0.01 <sup>f</sup>	4.43 ± 0.01 <sup>g</sup>	4.43 ± 0.01 <sup>g</sup>	
Syneresis (%)	65 ± 1.0 <sup>a</sup>	56 ± 1.1 <sup>c</sup>	58.4 ± 0.2 <sup>b</sup>	57.5 ± 0.6 <sup>bc</sup>	52.8 ± 0.2 <sup>d</sup>	56.0 ± 0.6 <sup>c</sup>	57.6 ± 0.1 <sup>bc</sup>	

\*Means with different lowercase letters in a row are significantly different (p < 0.05) by the Tukey's test.

yogurt using carboxymethyl cellulose (0.25%), and 65.4% for yogurt with 0.25% pectin addition (Cárdenas et al., 2013).

The analysis of variance indicates that the addition of starch has a significant effect on the syneresis of yogurt. As the concentration of yam starch increases, mainly from 0.1 to 0.3%, there is a tendency for syneresis in yogurt to increase. The same behavior was reported for yogurt with the addition of gelatin (Kiros et al., 2016). This increase in syneresis may be related to the fact that there is the agglomeration of starch in the network formed by casein and water, which is partially stabilized statically. When mechanical stress is applied, the casein network begins to lose integrity and expels the serum phase, which increases syneresis (Everett and McLeod, 2005).

The acidity of yogurt formulated with both yam starches was similar (0.10–0.12 g/L), while yogurt formulated with pectin had the highest acidity (0.98 g/L). Previous authors report ranges for acidity in yogurt from 0.45 to 1.6 g/L lactic acid (Kim et al., 2011). For formulations with yam starch, values below the reference ranges and those established in Resolution 2310 of the Codex Alimentarius (1986) and the Colombian Technical Standard - NTC 805 are evident. The low acidity is the result of the low release of amino acids and the low concentration of free H<sup>+</sup> groups in the food matrix.

Table 4 shows the results for the color parameters of stirred-type yogurt. For all treatments, the parameter L was approximately equal to 90, which is considered white and bright. These values are similar to those reported for yogurt using κ-carrageenan and corn starch as stabilizers (Skryplonek et al., 2019). Yogurts with yam starch have higher brightness than those with added pectin, which may be due to the difference in acidity. An increase in acidity causes a decrease in brightness (Cais-Sokolińska and Pikul, 2006). The different yogurts studied have negative values of parameter a\* and positive values of parameter b\*,

which indicates that the yogurts have green-yellow color characteristics. In yogurts with added pectin, this color was significantly more intense.

The value ΔE represents the change in color of yogurt treatments formulated with yam starches with respect to the reference color (yogurt formulated with pectin). This shows that the use of yam starch produces significant changes in the color of yogurt. However, due to the brighter color, the color of yogurts with added starches should be perceived as natural and attractive.

### 3.3. Preference test of stirred-type yogurt

Figure 2 shows the sum of the positions assigned by each of the consumer tasters in the sorting test. For yogurts formulated with yam starch, there is no significant difference between yogurts with “hawthorn” and “creole” yam starch. However, preference was inclined towards yogurts formulated with “creole” yam starch at a concentration of 0.1% w/w. On the other hand, yogurt with added pectin (reference stabilizer), was the less preferred treatment.

### 3.4. Characterization of yogurt during storage

The formulations with the best physicochemical and sensory performance were those in which “hawthorn” and “creole” yam starches were used, both at a concentration of 0.1% p/p. These treatments, as well as the one with pectin, were followed up during storage for 21 days.

#### 3.4.1. Physicochemical parameters of yogurt

Figure 3 shows the variation in the syneresis with storage time. In yogurts formulated with yam starch, syneresis shows a tendency to decrease with storage time up to 14 days. This decrease was 8.3% in

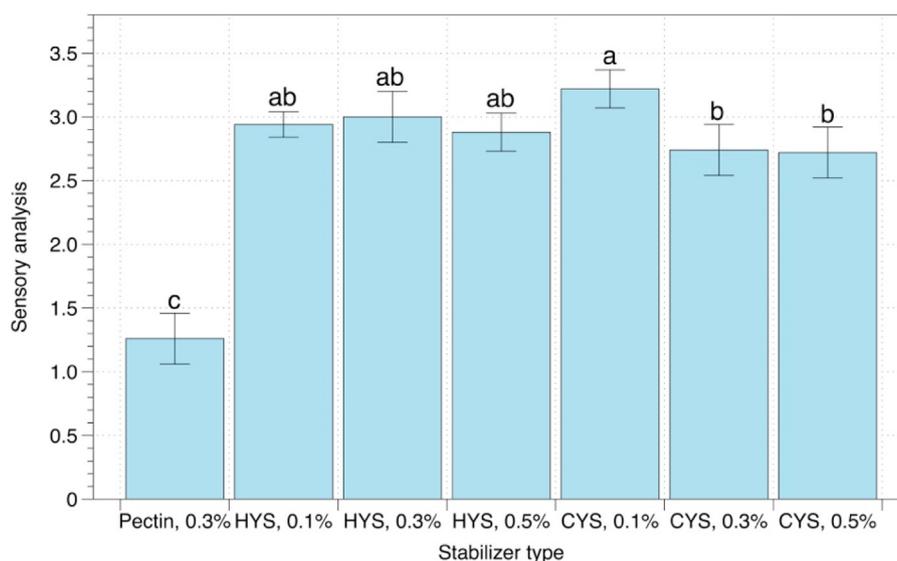


Figure 2. Results from the preference test of stirred-type yogurt. \* Means with different lowercase letters in a bars are significantly different (p < 0.05) by the Tukey's test.

Table 4. Effect of the addition of starch from “hawthorn” yam and “creole” yam at different concentrations on color parameters of stirred-type yogurt.

Color parameters	Pectin	“Hawthorn” yam starch			“Creole” yam starch		
	0.3%	0.1%	0.3%	0.5%	0.1%	0.3%	0.5%
L	86.8 ± 0.1 <sup>d</sup>	89.6 ± 0.1 <sup>a</sup>	89.7 ± 0.2 <sup>a</sup>	89.7 ± 0.1 <sup>a</sup>	88.4 ± 0.1 <sup>c</sup>	89.6 ± 0.1 <sup>b</sup>	89.7 ± 0.1 <sup>a</sup>
a	-0.54 ± 0.01 <sup>e</sup>	-0.01 ± 0.01 <sup>b</sup>	-0.03 ± 0.01 <sup>b</sup>	-0.32 ± 0.01 <sup>d</sup>	1.04 ± 0.02 <sup>a</sup>	-0.02 ± 0.01 <sup>b</sup>	-0.18 ± 0.01 <sup>c</sup>
b	15.0 ± 0.2 <sup>a</sup>	12.9 ± 0.1 <sup>b</sup>	12.9 ± 0.2 <sup>b</sup>	12.7 ± 0.1 <sup>c</sup>	12.1 ± 0.1 <sup>e</sup>	12.9 ± 0.1 <sup>b</sup>	12.7 ± 0.2 <sup>d</sup>
ΔE	0.0	3.58 ± 0.01 <sup>e</sup>	3.65 ± 0.04 <sup>d</sup>	3.74 ± 0.05 <sup>a</sup>	3.67 ± 0.02 <sup>c</sup>	3.55 ± 0.01 <sup>f</sup>	3.74 ± 0.02 <sup>b</sup>

\*Means with different lowercase letters in a row are significantly different (p < 0.05) by the Tukey's test.

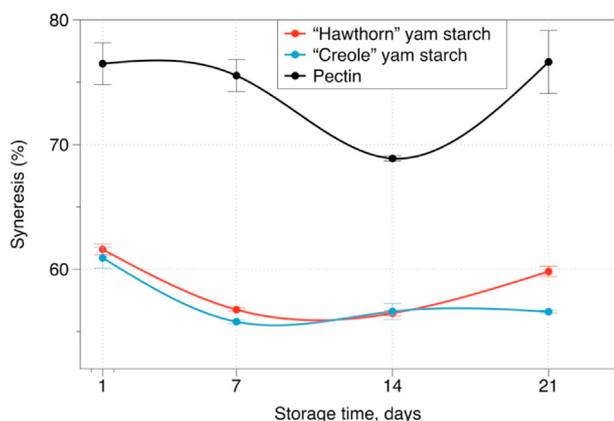


Figure 3. Effect of the stabilizer type on syneresis of stirred-type yogurts during storage.

yogurts with "hawthorn" yam starch and 7.11% for "creole" yam starch. On the other hand, syneresis in pectin-containing yogurts did not change significantly at the end of the storage period. This behavior is similar to that found in yogurt using cress seed mucilage and guar gum as stabilizers (Hassan et al., 2015). The decrease in the percentage of syneresis during storage 10 °C may be because the bonds between the particles of the gel are stronger or their number is greater. The particles may be more swollen and therefore connected over a larger area (Walstra et al., 1999). On the other hand, this behavior in the syneresis is contrary to what was reported in yogurts with native corn starch, which presented an increase of 11%, and in yogurts with modified cassava and corn starches where the increase in syneresis was 45.3% and 56.89%, respectively (Lobato et al., 2014). The above results confirm that yam starch has greater control over the draining of yogurt in storage.

Figure 4 shows the variation in the physicochemical parameters pH, and acidity with storage time. All yogurts showed a decrease in pH with storage time. At the end of the storage period (21 days), yogurts with "hawthorn" yam starch had a decrease of 6.52%, those with "creole" yam starch, 7.71%, and those with pectin, 7%. Other research reported a similar behavior: in low-fat yogurts the pH was 4.28 after 28 days of storage (Vital et al., 2015), and in stirred-type yogurts, it was 4.05 after 28 days of storage (Barkallah et al., 2017). The decrease in pH is attributable to the activity of microorganisms, which use residual carbohydrates and produce lactic acid, small amounts of CO<sub>2</sub>, and formic acid (Lee and Lucey 2010; Vital et al., 2015).

The increase in acidity is due to the production of lactic acid as the storage time increases. The significant increase in acidity in yogurts formulated with stabilizers occurs in the first 7 days of processing

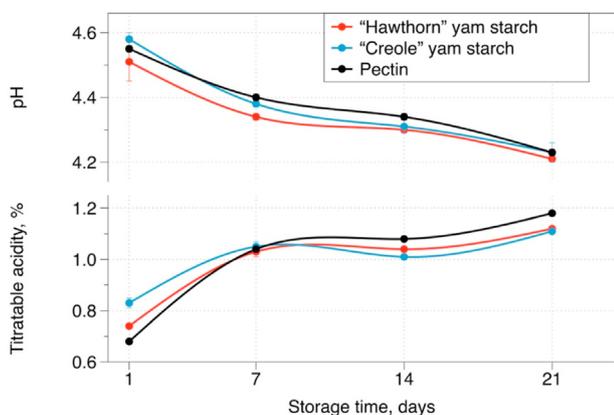


Figure 4. Effect of the stabilizer type on titratable acidity (%) and pH of stirred-type yogurts during storage.

(Figure 4); in yogurts with "hawthorn" yam starch, "creole" yam starch, and pectin, the increase in acidity was 27.6%, 20.9%, and 34.1%, respectively. From day 7, changes in acidity decreased. The observed behavior of the relationship between pH and acidity is common in the monitoring of these variables in yogurt production (Zourari et al., 1992).

### 3.4.2. Rheological behavior of yogurt during storage

Figure 5 shows the flow curves for yogurts formulated with "hawthorn" and "creole" yam starch. The rheograms show no coincidence between the upward and downward curves; that is, the phenomenon of hysteresis (dependence of behavior with time) is presented. This behavior is usual in stirred-type yogurts due to gel breakage by agitation (Beal et al., 1999; Morell et al., 2015; Pang et al., 2019).

The model that best represented the rheological behavior of yogurts with added stabilizers was the power-law model (R<sup>2</sup> between 93% and 99.1% and MSE between 0.030 and 1.118). This model is the most used in the rheological characterization of yogurts (Janhøj et al., 2008; Andrade et al., 2010; Oroian et al., 2011; Parra et al., 2012; Cui et al., 2014). Figure 6 shows the flow behavior index (n) of stirred-type yogurts during storage. For yogurts with added yam starch ("hawthorn" and "creole"), the flow behavior index is less than one, so the yogurt has the characteristics of a pseudoplastic fluid. This is related to changes in the macromolecular organization. As the shear rate increases, randomly positioned chains of polymer molecules align in the direction of the flow, resulting in less interaction between adjacent polymer chains (Koocheki et al., 2013). This behavior has been reported in yogurt with pineapple fiber (Sah et al., 2016) and yogurt with added modified cassava starch (Morell et al., 2015). In the yogurts with added pectin, the flow behavior index was close to one, mainly for the descending curve, tending to be a Newtonian fluid. The upward and downward flow behavior index for

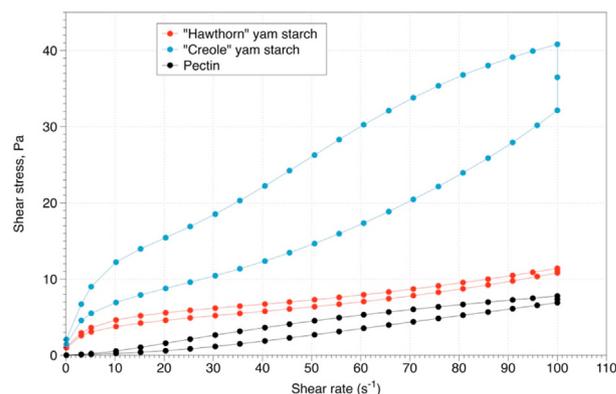


Figure 5. Rheological behaviors of yogurt with added stabilizers.

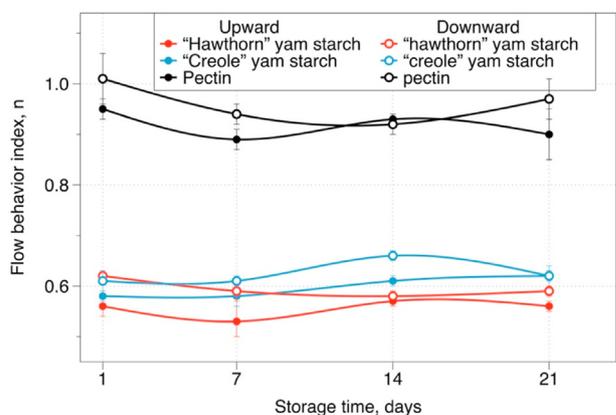
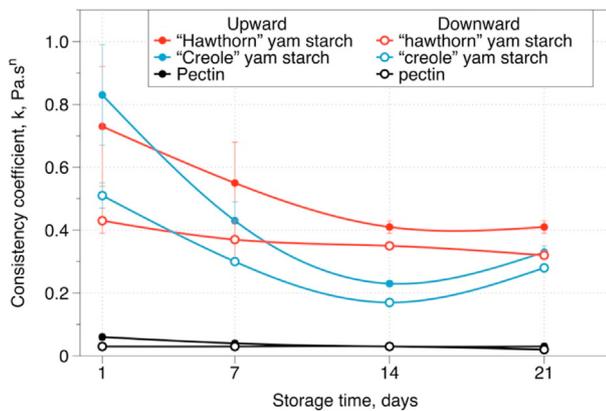
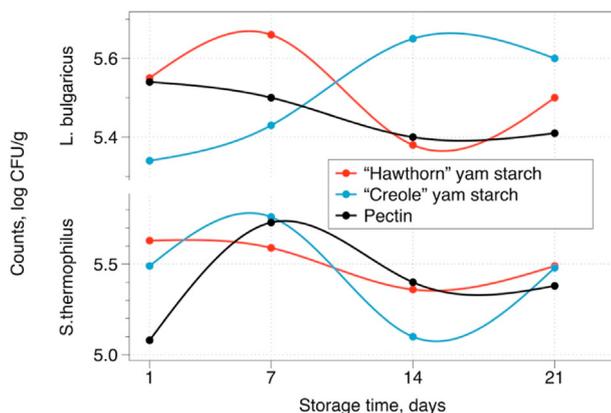


Figure 6. Effect of the stabilizer type on flow behavior index (n) of stirred-type yogurts during storage.



**Figure 7.** Effect of the stabilizer type on consistency coefficient ( $k$ ) of stirred-type yogurts during storage.



**Figure 8.** Effect of the stabilizer type on *S. thermophilus* and *L. bulgaricus* counts of stirred-type yogurts during storage.

yogurts with the different stabilizers remains almost constant with storage time. Yogurts with yam starch presented flow behavior index values between 0.53 and 0.66, which are similar to those reported for yogurt with modified starch (Morell et al., 2015).

Figure 7 shows the consistency coefficient ( $k$ ) of stirred-type yogurts during storage. The consistency coefficient of yogurts with yam starch (“hawthorn” and “creole”) is higher than that of the commercial reference stabilizer (Pectin), so yogurts with yam starch have a higher consistency. The consistency coefficient (rise and fall) for yogurts with yam starch decreases with storage time. This decrease is more pronounced when “creole” yam starch is used and for data in the descent curve. This denotes a loss of consistency of yogurt with hawthorn yam as time passes in storage. Several authors have reported changes in rheological parameters over the course of storage time. In yogurt with buffalo milk, a 49% decrease in the consistency coefficient and a 32.9% increase in the flow rate over a 21-day storage period have been reported (Andrade et al., 2010). However, in yogurts with added caramel and carrageenan at 4 weeks of storage, the flow rate decreases by 22% (Ramírez and Vélez, 2013). The changes in the flow rate and the loss of consistency of yogurts in storage are due to the loss of apparent viscosity, which leads to a loss of firmness and consistency of the protein matrix (Santillán et al., 2017).

### 3.4.3. Feasibility of yogurt microorganisms during storage

Figure 8 shows the viability count of *S. thermophilus* and *L. bulgaricus* in yogurts with yam starch (hawthorn and creole), and pectin throughout the storage time. Viability counts of *S. thermophilus* in yogurts with stabilizers were in the range of 5.34–5.66 log CFU/g, while for *L. bulgaricus* they were between 5.08 and 5.76 log CFU/g. These values were close to

the minimum (6 log CFU/g) required by the Colombian Technical Standard - NTC 805 in yogurts.

The addition of yam starch does not interfere with the viability of microorganisms; other investigations in yogurts formulated with yam starch (*Dioscorea opposita* Thunb) showed total viability values of 9.5 log CFU/ml (Kim et al., 2011), which are higher than those required by the standard. The viability of the microorganisms is a function of the formulation used in the preparation of the yogurt. In yogurts with buffalo milk, *S. thermophilus* and *L. bulgaricus* counts on the first day of storage of 9.4 and 6.44 log CFU/g, respectively (Akgun et al., 2016), and in low-fat yogurts supplemented with aqueous *Pleurotus ostreatus* extract showed *S. thermophilus* and *L. bulgaricus* counts of 8.72 and 8.81 log CFU/g, respectively (Vital et al., 2015).

In some yogurts with yam starch, there was an increase in lactic acid bacteria counts in the first days of storage, which may be due to continued metabolic activity for the consumption of lactose and other sugars produced in the biochemical process of lactic acid synthesis, in addition to the degradation of starch by enzymes released by lactic acid bacteria, which are metabolized into lactic acid (Abodjo et al., 2010; Kim et al., 2011).

## 4. Conclusions

Hawthorn yam starch has a greater capacity to absorb and retain water, which allows for higher viscosity gels, while Creole yam starch offers greater resistance and stability to heat treatment. The addition of yam starch improves the physicochemical characteristics of yogurt; it decreases syneresis, maintains an intense white color, and also presents a greater preference at the sensory level, compared to the commercial stabilizer (pectin). The physicochemical, rheological, and microbiological properties of yogurt change throughout the storage time. During 21 days of storage, yogurt with yam starch at 0.1% w/w showed a decrease in syneresis, while in those with pectin, syneresis remained practically constant in this period. In the first 7 days of storage, yogurts added with yam starch show an increase in pH and a decrease in acidity. Yogurt with yam starch presents thixotropy and pseudoplastic behavior.

## Declarations

### Author contribution statement

Jorge Pérez: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Margarita Arteaga: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ricardo Andrade: Analyzed and interpreted the data; Wrote the paper.

Alba Durango: Analyzed and interpreted the data.

Jairo Salcedo: Contributed reagents, materials, analysis tools or data.

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### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

## Additional information

No additional information is available for this paper.

## References

- Abodjo, C., Tagro, S., Olo, K., Akissi, F., Koffi, R., Koussemon, C., 2010. Biochemical and microbial changes during traditional spontaneous lactic acid fermentation process using two varieties of cassava for production of a "Alladjan" starter. *Int. Food Res. J.* 17 (3), 563–573.
- Aguilar, V., Villalobos, H., 2013. Harinas y almidones de yuca, ñame, camote y ñampí: propiedades funcionales y posibles aplicaciones en la industria alimentaria. *Tecnol. Marcha* 26 (1), 37–42.
- Agyemang, P.N., Akonor, P.T., Tortoe, C., Johnsona, P.-N.T., Manu-Aduening, J., 2020. Effect of the use of starches of three new Ghanaian cassava varieties as a thickener on the physicochemical, rheological and sensory properties of yoghurt. *Scient. Afr.* 9, e00521.
- Akgun, A., Yazici, F., Gulec, H., 2016. Effect of reduced fat content on the physicochemical and microbiological properties of buffalo milk yoghurt. *LWT - Food Sci. Technol.* 74 (2), 521–527.
- Altemimi, A., 2018. Extraction and optimization of potato starch and its application as a stabilizer in yogurt manufacturing. *Foods* 7 (2), 14.
- Andrade, R., Arteaga, M., Simanca, M., 2010. Efecto del salvado de trigo en el comportamiento reológico del yogurt de leche de búfala. *Inf. Tecnol.* 21 (5), 117–124.
- Araujo, C., Rincón, M., Padilla, F., 2004. Caracterización del almidón nativo de *Dioscorea bulbifera* L. *Arch. Latinoam. Nutr.* 54 (2), 241–245.
- Barkallah, M., Dammak, M., Louati, I., Hentati, F., Hadrich, B., Mechichi, T., Abdelkafi, S., 2017. Effect of *Spirulina platensis* fortification on physicochemical, textural, antioxidant and sensory properties of yogurt during fermentation and storage. *LWT - Food Sci. Technol.* 84, 223–330.
- Beal, C., Skokanova, J., Latrille, E., Martin, N., Corrieu, G., 1999. Combined effects of culture conditions and storage time on acidification and viscosity of stirred yogurt. *J. Dairy Sci.* 82 (4), 673–681.
- Beleia, A., Butarello, S., Silva, R., 2006. Modeling of starch gelatinization during cooking of cassava (*Manihot esculenta* Crantz). *LWT - Food Sci. Technol.* 39 (4), 400–405.
- Biliaderis, C., 1992. Structures and phase transitions of starch in food systems. *Food Technol.* 46 (6), 98–109.
- Cais-Sokolíńska, D., Pikul, J., 2006. Use of colour measurement to evaluate yoghurt quality during storage. *Ital. J. Food Sci.* 18 (1), 63–71.
- Cárdenas, A., Alvites, H., Valladares, G., Obregón, J., Vásquez, V., 2013. Optimización mediante diseño de mezclas de sinéresis y textura sensorial de yogurt natural batido utilizando tres tipos de hidrocoloides. *Agroindust. Sci.* 3 (1), 35–40.
- Chen, J.L., Tang, L., Shi, P.H., Yang, B.H., Sun, T., Cao, W.X., Zhu, Y., 2017. Effects of short-term high temperature on grain quality and starch granules of rice (*Oryza sativa* L.) at post-anthesis stage. *Protoplasma* 254 (29), 935–943.
- Cui, B., Lu, Y.M., Tan, C.P., Wang, G.Q., Li, G.H., 2014. Effect of cross-linked acetylated starch content on the structure and stability of set yoghurt. *Food Hydrocol.* 35 (1), 576–582.
- Everett, W., McLeod, E., 2005. Interactions of polysaccharide stabilisers with casein aggregates in stirred skim-milk yoghurt. *Int. Dairy J.* 15 (11), 1175–1183.
- Figuroa, J., Salcedo, J., Rodríguez, M., 2016. Acetilación de almidón nativo de batata (*Ipomeas batata* L.). *Vitae* 23 (1), S174–S179.
- Hassan, L.K., Haggag, H.F., ElKalyoubi, M.H., Abd El-Aziz, M., El-Sayed, M.M., Sayed, A.F., 2015. Physico-chemical properties of yoghurt containing cross seed mucilage or guar gum. *Ann. Agric. Sci.* 60 (1), 21–28.
- Janhøj, T., Frøst, M., Ipsen, R., 2008. Sensory and rheological characterization of acidified milk drinks. *Food Hydrocol.* 22 (5), 798–806.
- Kim, S., Lee, S., Palanivel, G., Kwak, H., 2011. Effect of *Dioscorea opposita* Thunb (yam) supplementation on physicochemical and sensory characteristics of yogurt. *J. Dairy Sci.* 94 (4), 1705–1712.
- Kiros, E., Seifu, E., Bultosa, G., Solomon, W.K., 2016. Effect of carrot juice and stabilizer on the physicochemical and microbiological properties of yoghurt. *LWT - Food Sci. Technol.* 69, 191–196.
- Koocheki, A., Taherian, A., Bostan, A., 2013. Studies on the steady shear flow behavior and functional properties of *Lepidium perfoliatum* seed gum. *Food Res. Int.* 50 (1), 446–456.
- Kumar, P., Mishra, H.N., 2004. Mango soy fortified set yoghurt: effect of stabilizer addition on physicochemical, sensory and textural properties. *Food Chem.* 87, 501–507.
- Lal, S., O'Connor, C., Eyres, L., 2006. Application of emulsifiers/stabilizers in dairy products of high rheology. *Adv. Colloid Interface Sci.* 433–437.
- Lee, W., Lucey, J., 2010. Formation and physical properties of yogurt. *Asian-Australas. J. Anim. Sci.* 23 (9), 1127–1136.
- Liu, X.X., Liu, H.M., Fan, L.Y., Qin, G.Y., Wang, X.D., 2020. Effect of various drying pretreatments on the structural and functional properties of starch isolated from Chinese yam (*Dioscorea opposita* Thunb.). *Int. J. Biol. Macromol.* 153, 1299–1309.
- Lobato, C., Ramirez, C., Vernon, E., Álvarez, J., 2014. Impact of native and chemically modified starches addition as fat replacers in the viscoelasticity of reduced-fat stirred yogurt. *J. Food Eng.* 131 (3), 110–115.
- Lozano, E.J., Andrade, R.D., Salcedo, J., 2018. Functional and rheological properties of yam (*Dioscorea rotundata*) mucilage. *Adv. J. Food Sci. Technol.* 16 (SPL), 134–142.
- Mendoza, R., Trujillo, Y., Duran, D., 2007. Evaluación del almidón de ñame espinoso (*Dioscorea rotundata*) como estabilizante en la elaboración de yogurt entero tipo batido. *Rev. Facul. Ciencias Bás.* 5 (2), 97–105.
- Moorthy, S., 2002. Physicochemical and functional properties of tropical tuber starches: a review. *Starch Staerke* 54 (12), 559–592.
- Morell, P., Hernando, I., Llorca, E., Fiszman, S., 2015. Yogurts with an increased protein content and physically modified starch: rheological, structural, oral digestion and sensory properties related to enhanced satiating capacity. *Food Res. Int.* 70, 64–73.
- Naguleswaran, S., Vasanthan, T., Hoover, R., Liu, Q., 2010. Structure and physicochemical properties of palmyrah (*Borassus flabellifer* L.) seed-shoot starch grown in Sri Lanka. *Food Chem.* 118 (3), 634–640.
- Olufemi, A.O., John, O.S., 2016. Physico-chemical, functional and pasting properties of native and chemically modified water yam (*Dioscorea alata*) starch and production of water yam starch-based yoghurt. *Starch Stärke* 68 (7–8), 719–726.
- Oroian, M.A., Gutt, S., Gutt, G., 2011. Influence of hydrocolloids on the rheological behavior of blueberries yogurt. *Ann. DAAAM & Proc.* 1031–1032.
- Oyeyinka, S.M., Adeleke, O.F., Dauda, A.O., Abiodun, O.A., Kayode, R.M.O., Adejuyitan, J.A., 2018. Flour composition and physicochemical properties of white and yellow bitter yam (*Dioscorea dumetorum*) starches. *Ind. Crop. Prod.* 120, 135–139.
- Pacheco, de Delahaye E., Techeira, N., 2009. Propiedades químicas y funcionales del almidón nativo y modificado de ñame (*Dioscorea alata*). *Interciencia* 34 (4), 280–285.
- Pang, Z., Xu, R., Luo, T., Che, X., Bansal, N., Liu, X., 2019. Physicochemical properties of modified starch under yogurt manufacturing conditions and its relation to the properties of yogurt. *J. Food Eng.* 245, 11–17.
- Parra, R., Riveros, J., García, Montañez, C., 2012. Evaluación fisicoquímica, sensorial y reológica de yogurt con carambolo (*Averroha carambola*) y stevia (*Reboudiana bertoni*). *Vitae* 19 (1), 258–260.
- Qian, S.Y., Tang, M.Q., Gao, Q., Wang, X.W., Zhang, J.W., Tanokura, M., Xue, Y., 2019. Effects of different modification methods on the physicochemical and rheological properties of Chinese yam (*Dioscorea opposita* Thunb.) starch. *Lebensm. Wiss. Technol.* 116, 108513.
- Rached, B., Viscarrondo, C., Rincón, A., Padilla, F., 2006. Evaluación de harinas y almidones de mapuey (*Dioscorea trifida*) variedades blanco y morado. *Arch. Latinoam. Nutr.* 54 (4), 375–383.
- Ramírez, M., Vélez, J., 2013. Physicochemical, rheological and stability characterization of a caramel flavored yogurt. *LWT - Food Sci. Technol.* 51 (1), 233–241.
- Sah, B., Vasiljevic, T., McKechnie, S., Donkor, O., 2016. Physicochemical, textural and rheological properties of probiotic yogurt fortified with fibre-rich pineapple peel powder during refrigerated storage. *LWT - Food Sci. Technol.* 65 (1), 978–986.
- Säker, W., Rodríguez, A., 2012. Influencia del cultivo láctico, gelatina y sacarosa sobre la viscosidad, sinéresis y características sensoriales en leche fermentada. *Pueblo Cont.* 23 (1), 125–136.
- Salcedo, J., Hernández, J., Fernández, A., 2016. Effect of the acetylation process on native starches of yam (*Dioscorea* spp.). *Revista Facultad Nacional de Agronomía. Medellín* 69 (2), 7997–8006.
- Santillán, E., Méndez, M., Vélez, J., 2017. Fortification of yogurt with nano and micro sized calcium, iron and zinc, effect on the physicochemical and rheological properties. *LWT - Food Sci. Technol.* 80, 462–469.
- Singh, R., Sharanagat, V.S., 2020. Physico-functional and structural characterization of ultrasonic-assisted chemically modified elephant foot yam starch. *Int. J. Biol. Macromol.* 14, 1061–1069.
- Skrypek, K., Henriques, M., Gomes, D., Viegas, J., Fonseca, C., Pereira, C., Dmytrów, I., Mitoniewicz-Malek, A., 2019. Characteristics of lactose-free frozen yogurt with κ-carrageenan and corn starch as stabilizers. *J. Dairy Sci.* 102 (9), 7838–7848.
- Suriya, M., Reddy, C.K., Haripriya, S., 2019. Functional and thermal behaviors of heat-moisture treated elephant foot yam starch. *Int. J. Biol. Macromol.* 137, 783–789.
- Vital, A., Goto, P., Hanai, L., Gomes, S., de Abreu, B., Nakamura, C., Matumoto, P., 2015. Microbiological, functional and rheological properties of low fat yogurt supplemented with *Pleurotus ostreatus* aqueous extract. *LWT - Food Sci. Technol.* 64 (2), 1028–1035.
- Walstra, P., Geurts, T.J., Noomen, A., Jellema, A., Van Boekel, M.A.J.S., 1999. Dairy technology: principles of milk properties and processes. Marcel Dekker, Inc., New York, USA.
- Wang, L., White, P., 1994. Structure and properties of amylose, amylopectin and intermediate materials of oat starches. *Cereal Chem.* 71 (5), 263–268.
- Wang, L., Xie, B., Shi, J., Xue, S., Deng, Q., Wei, Y., Tian, B., 2010. Physicochemical properties and structure of starches from Chinese rice cultivars. *Food Hydrocol.* 24 (2), 208–216.
- Willats, W.G.T., Knox, J.P., Mikkelsen, J.D., 2006. Pectin: new insights into an old polymer are starting to gel. *Trends Food Sci. Technol.* 17 (3), 97–104.
- Wong, S.S., Wicklund, R., Bridges, J., Whaley, J., Koh, Y.B., 2020. Starch swelling behavior and texture development in stirred yogurt. *Food Hydrocol.* 98, 105274.
- Xu, K., Guo, M., Du, J., Zhang, Z., 2019. Okra polysaccharide: effect on the texture and microstructure of set yoghurt as a new natural stabilizer. *Int. J. Biol. Macromol.* 133, 117–126.
- Zourari, A., Accolas, J., Desmazeaud, M., 1992. Metabolism and biochemical characteristics of yogurt bacteria. A review. *Lait* 72 (1), 1–34.