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Research Article

The Effect of the Addition of Starch and Flour from Yam in the Physiochemical and Techno-Functional Properties of Low Fat Sausages

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Abstract: The objective of this study was to evaluate the effect of the addition of starch and flour from yam in the physiochemical and techno-functional properties of low fat sausages. A factorial arrangement of 3×5 was applied with factors: Fatty mimetic (flour, native starch and pregelatinized starch) and substitution of fat (0, 10, 20, 30 and 40%, respectively) to sausages, evaluating their physicochemical and techno-functional properties. The results showed that the humidity, the ashes and the water retention of the sausages increased by increasing the percentage of fat substitution, while the fat content and the calories decreased. No significant differences were observed ($p \geq 0.05$) in pH and protein content. The rancidity values of all the sausages increased with the refrigerated storage time, being higher in the sausage control. In addition, the addition of flour and starches increased ($p \leq 0.05$) stability of the emulsion and the performance of sausages. The substitution of 10 and 20% of fat/flour, native starch and pregelatinized of yam are the most recommended in the production of sausages as they improve the stability of the emulsion, water retention, yield and generate a lower rancidity for 30 days of refrigerated storage.

Keywords: Emulsion, mimetic of fat, rancidity, stability, water retention, yield

INTRODUCTION

One of the main ingredients in the production of meat emulsions is fat, which is used in proportions of 20 to 30% of the final weight of the product and can be obtained from sources of animal or plant origin (Sousa *et al*., 2017). The emulsions of fine pasta such as sausages are characterized by having a high fat content, because hard pork fat is usually used in its formulation (Ventanas *et al*., 2010). This type of fat plays an important role in the development of emulsion, cooking performance, in water retention capacity and sensory characteristics, In addition, fats are an important source of energy, provide essential fatty acids and are the vehicle of fat-soluble vitamins (Lee *et al*., 2006), but provide a large amount of saturated fatty acids, which have been associated with the development of cardiovascular and various types of obesity (Ozvural and Vural, 2008; Vural *et al*., 2004), which has generated a growing demand for low-fat product consumption.

This demand has motivated the chemical and food industry to develop new and innovative products that are similar to fatty materials, but whose consumption constitutes a low caloric contribution, or ideally no contribution, without the consumer renouncing the chemical and physical characteristics that make the fat substances practically inalienable (Valenzuela and Sanhueza, 2008). Different alternatives have been raised to replace the fat used in different foodstuffs such as structured lipids, substitutes and fatty mimetic. Within these have been highlighted the fatty mimetic, because with its use is able to lower the energy tenor in direct proportion to the fat they replace, these simulate fats without possessing any of its components or nutritional characteristics and can only replace a fraction of these without notoriously altering the behavior and organoleptic characteristics of the product to which they have been incorporated (Singhal *et al*., 1991).

In the market there are a variety of fatty mimetics (Lucca and Tepper, 1994; Valenzuela and Sanhueza, 2008), as mimetics based on modified carbohydrates featured in Maltrim M-040, a maltodextrin obtained by controlled hydrolysis of starch, N-OIL, dextrin obtained from cassava, Paselli SA-2 prepared from the enzymatic modification of potato starch, among others and mimetics based on modified proteins such as Simplesse obtained from milk protein or egg white. On the other hand, several studies show the possibility of

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developing low-fat meat products based on carbohydrates as native starches, modified starches and starch-rich flours, for example, rice starch combined with gum has been used in the production of Cantonese-style Chinese sausages low in fat, improving performance and water retention (Feng *et al*., 2013). With the use of modified starches of cassava, the fat in sausages has been reduced to between 48.12 and 48.78%, obtaining a greater stability of the emulsions and increased water retention capacity (Luo and Xu, 2011), by replacing fat in meat products by flours such as chickpea, pea, plantain and oats, yields and water retention have also improved (Pietrasik and Janz, 2010; García *et al*., 2012a; Araya-Quesada *et al*., 2014; Bastos *et al*., 2014).

On the other hand, the need has emerged to explore new alternatives and sources of obtaining starch, due to the growing demand for its low cost, constituting the cultivation of roots and tropical tubers an option to be rich sources of starch (Alves *et al*., 2002; Cobana and Antezana, 2007).

A tuber that has been highlighted by its high starch content between a 83.3 and a 90% is yam (Alvis *et al*., 2008), which also contains phosphorus, potassium, vitamins A and C (Alvis *et al*., 2008; Montes *et al*., 2008), riboflavin, niacin, ascorbic acid, pyridoxine, carotene and possesses most of the essential amino acids (Santos, 2002), characteristics that promotes it in the food industry. In addition, it has been reported that its addition to low-fat Chinese sausages has decreased oxidative rancidity possibly by the antioxidant properties of Yam (Tan *et al*., 2007).

Despite the kindness offered by the yam and that Colombia in recent years has been highlighted among the American countries as the main producer (FAOSTAT, 2016), this is still considered an orphan crop, since there are few research efforts carried out both worldwide and in Colombia. This tuber is being used only for consumption in fresh mainly in homes of the Caribbean region, where the largest production is found is that it is a substitute for potato and cassava (Pinzón, 2014). For this reason, this research was carried out a physicochemical and techno-functional characterization of the flour, the native starch and three modified starches of yam. Selecting among the modified starches the best techno-functional properties contribute to being used as mimetic of fat.

The objective of the research was to study the effect of the addition of native starch, modified starch and yam flour to the physiochemical and techno-functional properties of low-fat sausages, with the aim of obtaining a low-calorie producst, improving the techno-functional and physiochemical properties.

MATERIALS AND METHODS

Raw materials: The yam (*Dioscorea rotundata*) tubers used in this study were provided by local producers in the city of Sincelejo (Colombia). Beef and hard pork fat were acquired at a local supermarket in the city of Sincelejo (Colombia) and the other additives and ingredients used for the production of sausages were provided by the marketer of inputs TECNAS®.

Obtaining of yam starch and flour: The yam starch and flour were produced in Planta de Operaciones Unitarias de la Universidad de Sucre (Colombia). The native yam starch was obtained, according to the methodological proposal by Salcedo *et al*. (2014), through a continuous bubbling process in a pilot prototype designed for the obtaining of starch and recovery of its mucilage.

From the NS obtained were produced modified starches. The Pregelatinized Starch (PS) of yam was obtained following the methodology proposed by Barragán-Viloria *et al*. (2016) with some modifications, in a batch reactor. A 10% (w/v) starch/water suspension was prepared, which was kept under continuous stirring and heating at 81°C for 10 min at 300 rpm. After this time, 0.5 mL of ethanol was added per gram of starch while stirring for 1 h, followed by methanol, equivalent to one-third of the water in the suspension, with continuous stirring for 5 h. Finally, the samples were dried in a convective oven at 40°C for 24 h and ground until passing through a 100 mesh sieve.

For the modification process of Acetylated Starch (AS), we used 3.0 mL acetic anhydride, added drop by drop to a 4.5% starch suspension, previously agitated for 60 min at 30°C. The PH was maintained between 8.0 to 8.4 using a solution of NaOH 3.0%. After the reaction time, the PH of the suspension was adjusted to 4.5 with HCL 0.4 n, then the starch was washed, dried at 40°C and reduced in size to pass through a sieve mesh 100 (Salcedo Mendoza *et al*., 2016a).

Enzymatic Starch (ES) was obtained by adding 315 μL the enzyme (commercial α-amylase) to an aqueous solution (120 ML) containing 20 g/L of starch. This solution was maintained in agitation at a PH of 5.5 (Citrate buffer solution 0.1 mol/L) for 20 min. After this time the reducing sugars (Miller, 1959) were determined to calculate the percentage of Dextrose (DE) and the reaction was stopped using hydrochloric acid (2 mol/L) to decrease the PH to 1.5 for 5 min and then using sodium hydroxide (2 mol/L) to increase the PH to 6. The starch obtained was left to settle, the supernatant was removed, dried in a convective oven at 40°C for 24 h and was reduced in size to pass through a sieve mesh 100. The enzymatic activity was determined following the methodology proposed by Matute *et al*. (2012).

To obtain the Flour (F) of yam, the plant material was washed with potable water to remove the soil, then they were disinfected with a solution of sodium hypochlorite (200 ppm) for 10 min by immersion, rinsed, peeled and chopped. The pieces obtained were immersed in a solution of 0.1% citric acid and dried by convection at 50°C for 12 h. Finally, they were subjected to a process of reduction of size to mesh 100 (Pérez and Pacheco de Delahaye, 2005).

Physiochemical characterization of yam starch and flour:

Proximal composition and Ph: The flour and starches obtained were analyzed the moisture content (method 925.10), crude protein (method 920.87), crude fat (method 920.85), ash (method 923.03), crude fibre (method 920.86) and the pH (method 943.02) was determined according to the official methods described by the AOAC (2012).

Starch content: The starch content was determined by enzymatic hydrolysis following the procedure of Bello (1995). Forty-two mL of distilled water and 20 μL of α-amylase solution were added to 200 mg of sample. Subsequently, the mixture was heated in a water bath at a temperature between 80-90°C for 15 min, with constant agitation. It was allowed to cool and the dextrinificación of the starch was confirmed with an assay of lugol negative. Acetic acid was then added until a pH of 4.8 was obtained. Subsequently, 300 μL of amyloglucosidase solution was added and brought to a thermostated bath at a temperature of 60°C for 30 min with constant stirring. The hydrolyzed sample was cooled to room temperature and 2 drops of 2N NaOH solution were added to neutralize. The sample was taken to a volume of 125 mL by adding distilled water and the concentration of Reducing Sugars (RS) was determined using the method of Miller (1959).

Amylose content: The amylose content of the starch samples (100 mg) was analyzed using the standardized iodine colorimetry method, in accordance with the ISO 6647-1 (2007). It was used as the standard for the amylose calibration curve of potato coming from Sigma Aldrich (St. Luis, MI, USA). The absorbance of the samples measured at 620 mm using a spectrophotometer (Thermo-Scientific Evolution 60S, USA).

Techno-functional characterization of yam starch and flour:

Water Retention Capacity (WRC): Method 88.04 of the AACC (2012) was followed. In a pre-weighed 10 mL specimen, 1 g of sample was added and 10 mL of distilled water was added, gently shaken to homogenize. Then it was kept at room temperature for 24 h. Subsequently, the supernatant was removed with a 5 mL pipette, the remaining water was drained with absorbent paper. Finally, the specimen was weighed with the precipitate. WRC was expressed as the grams of water retained per gram of solid.

Water Absorption Capacity (WAC): Into a pre-weighed centrifuge tube, 1 g of sample was deposited and 10 mL of distilled water was added, gently agitated to homogenize, allowed to stand and then centrifuged at 3500 rpm for 15 min. The supernatant liquid was decanted and the tube with the precipitate drained by inverting it at a 45° angle for 10 min and then being weighed (Abbey and Ibeh, 1988). The WAC was expressed as the grams of water retained per gram of solid.

Determination of the resistance to the freeze-thaw cycle: The starch and flour suspensions (at 2% w/V) were subjected to heating at a temperature of 90°C with constant agitation for 15 min. A sample of 10 g of gel, deposited in polypropylene centrifuge tubes, was stored at -5°C for 22 h. Subsequently, the frozen samples were placed in a water bath at 30°C for 90 min and centrifuged at 4000 rpm for 15 min. The amount of water released (supernatant fluid) was determined. The same samples were frozen again at -5°C for 22 h, after removing the residual supernatant. The procedure was repeated for three cycles, recording the weighting of the amount of water released in each (Crosbie, 1991; Sánchez-Hernández *et al*., 2002).

The syneresis was calculated as the liquid quantity that is separated from the gel, due to the centrifugation related to the total mass of the gel that was centrifuged in Eq. (1):

$$\%\text{Syneresis} = \frac{\text{liberated liquid mass}}{\text{Sample weight}} \text{ x } 100 \qquad (1)$$

Cold and hot pasta behavior (viscoamilograma): To determine the viscosity profile of the starch dispersions and flour, the technique proposed by AACC (2000) was employed; using a rheometer (Anton Paar, MCR 302, Austria). Two grams of dry-based sample was dissolved in 25 mL of distilled water in an aluminized sample hold, stirring until the suspension was homogenized. The temperature at 50°C was maintained for one minute, then elevated to 95°C at 7.5 min, remained at 95°C for 5 min, it was immediately chilled at 50°C at 7.5 min and finally remained at 50°C for 2 min. The spindle speed (Anton Paar, ST24-2d/2v, Austria) was 960 rpm during the first 10 sec, allowing the suspension to disperse evenly and then reduced to 160 rpm for the remainder of the experiment (Montoya *et al*., 2012). The parameters evaluated were the initial temperature of the paste, maximum viscosity, stability (breakdown = maximum viscosity-viscosity at 95°C for 5 min) and settling (setback = final viscosity-maximum viscosity).

Formulation and processing of sausages: Sausages were made on the basis of the formula proposed by Paternina *et al*. (2016a) with some modifications based on the Colombian technical standard for meat products (NTC 1325, 2008). Five formulations were developed, where the percentages of all the ingredients were kept constant and the fat substitutions were varied by fatty mimetic (flour, (native starch and modified starch) in a weight/weight ratio, selecting between the modified starches to formulate the sausages which presented the

Table 1: Formulation of sausages with percentages of fat substitution

	Formulation (%)				
Ingredient	0	10	20	30	40
Beef	60.00	60.00	60.00	60.00	60.00
Pig fat	20.00	18.00	16.00	14.00	12.00
Mimetic fat	0.00	2.00	4.00	6.00	8.00
Ice	20.00	20.00	20.00	20.00	20.00
Healing salt[1]	1.50	1.50	1.50	1.50	1.50
Erythorbate	0.03	0.03	0.03	0.03	0.03
Phosphate	0.20	0.20	0.20	0.20	0.20
Universal seasoning	1.00	1.00	1.00	1.00	1.00
Mixture of spices[2]	0.71	0.71	0.71	0.71	0.71

[1]: 6% of sodium nitrate and 94% of sodium chloride; [2]: Mixed powdered spices: onion 0.3%, garlic 0.3%, pepper 0.01%, nutmeg 0.1%

highest value of WAC and WRC and the lowest values of syneresis, initial temperature of the paste and stability. The percentage of fat substituted in the formulations was 0, 10, 20, 30 and 40%, respectively as shown in Table 1. The percentages of fat to be substituted in the meat emulsion, they were established by the determination of the fat content of commercial sausages which included in their formula fatty pork fat, stipulating the maximum value to be replaced when obtaining with the addition of some of the mimetic fatty values of hardness equal to the formulation control.

Beef meat with a temperature of 4°C and PH between 5.8 and 6.4 was used for sausage production. The meat and the hard pork fat were adequate and diced in the form of cubes, then cured with salt curing (nitrate to 6%) and were made a fine milling. The mixture of meat and additives was made in a cutter (javar with capacity for 5 L), adding the ingredients according to the following order: meat, ice, phosphate, erythorbate, condiments, spices, ice, fat, ice and fatty mimetic. The emulsion obtained was sausage in synthetic casing (caliber 19), portions of 12 cm were obtained and scalded by immersion at 72°C for 30 min, until the internal temperature of the product (70°C), the samples were finally cooled at room temperature, vacuum packed, encoded and stored in refrigeration at 4°C.

Physiochemical characterization of sausage:

Proximal composition, pH and calories: The moisture content of the sausages was analyzed (method 950.46), crude protein (method 981.10), crude fat (method 960.39) and ash (method 920,153). According to the official methods described by AOAC (2012), the pH was determined in accordance with the method Choi *et al.* (2010) and total calorie (Kcal) values were calculated according to the Atwater factor.

Oxidative rancidity (TBA): The TBA of the samples was determined according to the methodology reported by Zipser and Watts (1962), evaluating the rancidity on days 1, 10, 20 and 30, respectively of the stored products. Ten grams of the sample was added to 49 mL of distilled water at 50°C and 1 mL of sulfanilamide 0.5% in HCI at 20% (V/V) and homogenized for 2 min. Subsequently, the mixture was added in a 500 mL Erlenmeyer with 47.5 mL of distilled water at 50°C, 2.5 mL of HCl solution and 2 drops of antifoam; It was distilled until obtaining a distillate of 50 mL of which 5 mL were taken and placed in a test tube, then 5 mL of BTA solution was added. Finally, it was taken to a water bath at a temperature of 80°C for 30 min, cooled and measured absorbance at 532 nm using a spectrophotometer (Thermo Scientific, Evolution 60s, USA). The values of TBA were expressed as mg Malonaldehído/Kg of a sample.

Techno-functional characterization of sausages:

Emulsion stability: For this purpose, 5 g of meat emulsion was weighed and they were placed in tubes, which were centrifuged for 5 min at 1134 G at 5°C, then heated in a water bath until reaching an internal temperature of 75°C. The tubes were then cooled in an ice bath at 4°C to facilitate the separation of fat and water (exudate). The Total Released Fluid (TRF) was expressed as a percentage relative to the weight of the sample and the Fat content Released (FR) was determined by the difference in the total liquid released after drying in an oven at 105°C for 16 H according to Eq. (2), (3) and (4):

$$\text{TRF} = (\text{weight of tube plus sample}) - (\text{weight of tube} + \text{sample after exudation}) \quad (2)$$

$$\%\text{TRF} = \frac{\text{TRF}}{\text{weight of sample}} \text{ x } 100 \quad (3)$$

$$\%\text{FR} = \frac{(\text{Weight of crucible plus dry exuded substance}) - (\text{weight of crucible container})}{\text{TRF}} \text{ x } 100 \quad (4)$$

Cooking yields: Sausage weights were recorded before and after cooking for 5 replicates/treatment (Naveena *et al.*, 2006).

Water Retention Capacity (WRC): Was performed using the pressure method on filter paper for quantitative analysis. Water retention capacity was calculated as a percentage of water issued according to Eq. (5) (González *et al.*, 2007):

$$\%\text{WRC} = \frac{\begin{pmatrix}\text{final weight of filter paper} - \\ \text{initial weight of filter paper}\end{pmatrix}}{\text{sample weight}} \text{x}100 \quad (5)$$

Statistical analysis: A multifactorial categorical design was used for the statistical analysis of the physicochemical and techno functional properties of the sausages, with Fatty Mimetic (FM) in 3 levels (F, NS and PS, respectively) and fat substitution in 5 levels (0, 10, 20, 30 and 40%, respectively) and for oxidative rancidity in addition to the mentioned factors, the effect of days at 4 levels (1, 10, 20 and 30 days, respectively) was evaluated. To determine any effect of the

Table 2: Physiochemical composition[1] of yam starches and flour

Parameter	NS	PS	AS	ES	Flour
Humidity (%)	10.24±0.1000b[2]	9.17±0.0300c	10.19±0.050b	10.59±0.0200a	10.24±0.10b
Ash (%)	0.15±0.0100d	0.19±0.0100c	0.14±0.005d	0.41±0.0050b	2.57±0.01a
Protein (%)	0.68±0.0007b	0.40±0.0003e	0.60±0.001d	0.67±0.0005c	3.23±0.00a
Fat (%)	0.06±0.0100b	0.06±0.0100b	0.07±0.020b	0.05±0.0100b	0.84±0.01a
Fiber (%)	ND[3]	ND	ND	ND	1.59±0.01
Amylose (%)	23.37±0.2600b	24.33±0.1500a	24.18±0.430ba	25.05±0.5600a	19.61±0.22c
Starch (%)	99.64±0.2500a	97.76±0.0700b	98.68±0.120ba	99.08±0.7400a	89.30±0.20c
pH	7.14±0.0100a	6.85±0.0200b	6.32±0.010d	6.73±0.0100c	6.16±0.01e

[1]: Values expressed in dry state; [2]: Different letters in each row denote significant statistical differences ($p \leq 0.05$), conforming with the Tukey test; [3]: ND: None detected

independent variables on the dependent variables, an Analysis of Variance (ANOVA) ($\alpha = 0.05$) was applied. To compare the obtained results a test of multiple ranges of comparison of means of Tukey was used. In all cases, three replicates were performed for each treatment and the data were analyzed with the aid of the statistical package R 3.2.1 free version.

RESULTS AND DISCUSSION

Physiochemical characterization of yam starch and flour: Table 2 shows the results of physiochemical characterization of starches and yam flour. As for the humidity, the PS presented the lowest value and the ES the largest, resulting statistically different ($p \leq 0.05$) from the other samples, whereas between the flour, the NS and the AS there were no significant differences ($p \geq 0.05$). The differences presented could be attributed to the different processes of obtaining these samples and to differences in the moisture content before being subjected to the drying process (Pérez and Pacheco de Delahaye, 2005; Techeira *et al*., 2014). However, the values obtained were <12%, the percentage in which it is possible to predict that this type of products will have a great stability in time (Pérez and Pacheco de Delahaye, 2005) and were found within the range reported for yam flours of the species *Dioscorea opposita* subjected to different methods of drying (9.11 to 11.78%) (Chen *et al*., 2017) and within the reported for native starches extracted from different plant species such as cassava, sweet potato, sweet potato and sago with ranges between 8.99 to 10.50% (Hernández-Medina *et al*., 2008).

In terms of ash content, significant statistical differences ($p \leq 0.05$) were presented between the samples, with the exception of the AS, those who obtained the lowest values; the flour presented the highest value, since it is possible to present a higher content of minerals and inorganic salts (Pérez and Pacheco de Delahaye, 2005) and was within the range reported by Techeira *et al*. (2014) for yam flour of the variety *Dioscorea alata* (2.01 to 2.83%) and that of the starches except for the enzyme within the reported by Pérez *et al*. (2013) for 5 Wild yam genotypes (between 0.1 and 0.3%).

In relation to the protein content, it can be observed that there were statistically significant differences ($p \leq 0.05$) between the samples. The AN with respect to the modified had the highest value, which could be due to the extraction of the proteins called integrals during the processes of modification, since these are covalently joined to the complex Amylose-amylopectin (Thomas and Atwell, 1999). The values obtained were higher than those reported by Huang *et al*. (2016) for native and modified yam starches of the species *Dioscorea opposita* (between 0.12 to 0.31%) and by Alvis *et al*. (2008) for *Dioscorea alata* (between 0.10 and 0.49%); The flour was found within the range reported for yam flours of the species *Dioscorea opposita* (0.16 to 5.29%) (Chen *et al*., 2017).

The starches did not present significant differences ($p \geq 0.05$) in the fat content and were within the range reported by Techeira (2008) in native starch and pregelatinized of yam of the species *Dioscorea alata* (005 to 0.06%) and by Alvis *et al*. (2008) for 4 varieties of the same species (0.00 to 0.06%). For its part, the fat content of the flour was greater than that of the starches and was superior to the reported for yam flours, sweet and cassava flours with ranges between 0.25 to 0.68% (Techeira *et al*., 2014). However, it is noteworthy that all the results obtained were low, since these are flours and starches obtained from roots and tubers, which by their nature show a lower amount of fat than cereal flours such as maize (1.3%) and wheat (1.5-2%) (Torres and Guerra, 2003) and Rice starch (0.38-0.56%) (Gani *et al*., 2017).

In the analyzed starches no fiber was detected in its composition, results consistent with those reported by Alvis *et al*. (2008) for four varieties of yams. The percentage of fiber found in the flour was within the range reported by Abiodun and Akinoso (2014) in yam flour of the species *Dioscorea dumetorum* (1.58 to 3.35%).

In terms of the content of amylose, the modified starches showed no statistically significant differences ($p \geq 0.05$) among them, but when compared with the pregelatinized and enzymatic starches, they presented higher values. This could be due to the production of a greater number of long chains generated in the amylopectin product of the applied modification, which when reacting with the iodine could be detected as amylose (Polesi and Sarmento, 2011). Similar behavior has been observed when comparing native and acetylated starches of Yam and Yucca (Mbougueng *et al*., 2012; Salcedo Mendoza *et al*., 2016a) and Pregelatinized (Techeira, 2008). The obtained results were found within reported by Salcedo Mendoza *et al*. (2016a) and Salcedo-Mendoza *et al*. (2016b) for native starches and acetylated of yam of the species *Dioscorea alata*, (23.37 to 25.51%); Jayakody *et al*. (2007) for *Dioscorea esculenta* and *alata* (19.98 to 29.29%) and in those reported by Benavent-Gil and Rosell (2017) for native starch and enzymatically modified maize (23.47 to 28.95%).

For its part, yam flour presented the lowest value in terms of the content of amylose and was statistically different ($p \leq 0.05$) with respect to starches. Values higher than that obtained in this study were reported by Techeira *et al*. (2014) for yam flours (37.00 to 37.22%), sweet potato (29.43 to 37.00%) and cassava (28.25 to 31.28%), while Chen *et al*. (2017), reported lower values for yam flour of the species *Dioscorea opposita* (9.40 to 11.78%). These differences could be explained by the fact of being of different species, the conditions of growth of the crops, by the method of obtaining or by the methodology used in the determination of amylose (Jayakody *et al*., 2005).

In terms of starch content, the flour presented the lowest value and was statistically different ($p \leq 0.05$) with respect to starches because its proximal composition is greater in proportion to other components. The native, acetylated and enzymatic starches did not present significant differences ($p \geq 0.05$) between them, while the PS was different ($p \leq 0.05$) when compared with the native and the enzymatic. However, the starch content determined in all the samples was elevated indicating a high purity of the starches obtained and were superior to those reported by Techeira (2008) for native starch (94.67%) and modified starches of yam (between 95.64 and 98.27%).

Among the most important chemical components in root and tuber flours is starch, as it is responsible for most of the functional properties that determine its use in different food products. The proportion of starch found in the flour under study was higher than those reported by Chen *et al*. (2017) in yam flour of the variety *Dioscorea opposita* (51.61 to 67.92%) and by Techeira *et al*. (2014) for yams (62.65 to 69.59%), sweet potato (42.27 to 65.59%) and cassava (72.37 to 77.49%), this product being of great importance as a high energy value food ingredient and as a possible alternative source of commercial starch (Techeira, 2008).

The values obtained for PHs showed statistically significant differences ($p \leq 0.05$) among all the samples evaluated. The differences presented can be associated with the PHs managed in each modification. The results obtained were within the range reported by Techeira (2008) for starches and yam flour of the species *Dioscorea alata* (5.91 to 7.31).

Techno-functional characterization of starches and yam flour: In Table 3, the values obtained from the techno-functional properties of the starches and the yam flour are shown. The values obtained from WRC and WAC in the modified starches were greater with respect to NS, resulting in statistically different ($p \leq 0.05$). The increase of these properties in starch when subjected to a modification process could be associated with the breakdown of the intragranular forces of the amorphous region, which leads to the beginning of the splitting of the regions with double helix which causes a disorganization in the structure of the granule, thus facilitating the entry of water to the granule (Rincón *et al*., 2007). This same behavior was reported by Huang *et al*. (2016) and Falade and Ayetigbo (2015) when comparing the native yam starch with the modified ones. However, the major WAC and WRC were obtained with the PS.

Table 3: Techno-functional characterization of starches and yam flour

Sample	WRC (%)	WAC (g/g)	Syneresis (%)
NS	82.26±0.75e[1]	1.04±0.04e	33.30±0.26c
PS	373.53±1.16a	2.59±0.02a	2.26±0.18d
AS	90.62±0.30d	1.15±0.02d	32.55±0.38c
ES	105.22±0.58c	1.23±0.01c	53.04±1.46[a]
F	216.09±1.75b	1.53±0.01b	44.93±1.01b

[1]: Different letters in each row denote significant statistical differences ($p \leq 0.05$), conforming with the Tukey test

The results obtained from WAC for the modified were superior to those reported by Falade and Ayetigbo (2015) in native and modified yam starches of the *Dioscorea rotundata* species, *alata*, *cayenensis* and *domentorum* (0.63 to 1.04 g water/g starch). They were in the range reported by Chen and Zhang (2012) in native and modified maize starch (1.04 to 1.83 g water/g starch) except for pregelatinized starch. While the WRC values of the native, acetylated and enzymatic starches were inferior to those found by Huang *et al*. (2016) in native and modified yam starches of the species *Dioscorea opposita* (103.83 to 241.92%).

The values of WRC and WAC of flour were higher than those obtained with native, acetylated and enzymatic starches, probably due to their higher content of proteins interacting with water (Aguilera Gutiérrez, 2009). Also, the WRC of the flour was superior to that reported by Chen *et al*. (2017) for yam flour of the species *Dioscorea opposita* subjected to different drying methods (90.39 to 207.95%), while the WAC was lower than that reported for quinchoncho flour subjected to different processing (2.70 to 3.85 g water/g (Araya-Quesada *et al*., 2014) and similar to those reported for fine and coarse banana flour (1.54 and 1.58 g water/g flour, respectively) (Araya-Quesada *et al*., 2014).

The PS presented the lowest syneresis and the highest ES, being statistically significant ($p \leq 0.05$) with respect to the other samples, whereas the NS and the AS did not present significant statistical differences between them. The syneresis occurs mainly due to the reorganization of the amylose, as well as the reversible crystallization of the amylopectin external short chains at a given time. It was evidenced a greater stability to

Table 4: Behavior of the viscosity in yam starch and flour suspensions during heating and cooling cycles

Sample	Initial temperature of the paste (°C)	Max. viscosity (cP)	Stability (breakdown)	Settlement (setback)
NS	80.00±0.14c[1]	3210.50±53.03a	761.50±44.54a	2059.00±57.98a
PS	70.75±0.21d	1285.50±105.35c	0.00±0.00e	901.00±33.94c
AS	80.20±0.14c	2418.90±55.15b	402.90±25.45c	1909.40±37.05b
ES	82.55±0.21a	1190.50±13.43c	559.40±2.97b	21.05±4.59e
F	81.55±0.21b	1272.00±8.48c	260.50±7.78d	189.50±3.53d

Max.: Maximum; [1]: Different letters in each row denote significant statistical differences ($p \leq 0.05$), conforming with the Tukey test

the thermal treatments with the PS given its lower syneresis, probably the modification generated changes in the structure of the amylopectin, in the amorphous regions and possible reduction of the crystallinity of this structure, evidenced by the decrease of the initial temperature of the paste; these changes could affect the reorganization of the amylose and amylopectin molecules generating a lower syneresis (Carrascal, 2013). A similar behavior was evidenced when comparing pregelatinized maize starch with native (Hedayati *et al.*, 2016), where the percentage of syneresis obtained during the third cycle (between 5 and 20%) was higher than that obtained in this study for the PS of yam.

On the contrary, the enzymatic hydrolysis generated a greater synerisis of the ES with respect to NS, although the latter obtained the lowest settlement value, possibly by the rupture of large amylopectin molecules that are reflected as amylose, these molecules can absorb water and when they are frozen, the degraded molecules are re-associated by expelling larger amounts of water (Atichokudomchai *et al.*, 2002). Therefore, the process of enzymatic hydrolysis must be carried out above the initial temperature of the paste of the NS so that the amylose can be leached affecting its reorganization. This behavior was similar to that reported in enzymatically modified millet starch when compared to the native (Dey and Sit, 2017).

It should be pointed out that the percentage of syneresis obtained for the NS during the accumulation of the 3 freezing cycles-defrosting, it was inferior to the reported for native yam starches of the varieties *Dioscorea alata* and *esculenta* (45.7 and 48.1%, respectively), cassava (38.9%), sweet potato (69%) and maize (69.5%) for the third cycle (Srichuwong *et al.*, 2012). The obtained with the flour was inferior to the one found for rice flour (46.4%) (Meng *et al.*, 2014).

Behaviour of cold and hot pasta (viscoamilograma): Table 4 and Fig. 1 shows the viscosity behavior in suspensions of starches and yam flour during heating-cooling cycles. Significant differences were found in the initial pastification temperature of the studied samples ($p \leq 0.05$). The PS presented a low pulp formation temperature with respect to the other samples, possibly due to loss of crystallinity, weakening of intermolecular amylose-amylopectin bonds and the bonding capacity produced by the modification to which it was submitted (Garzón, 2006). A similar behavior was observed in pregelatinized

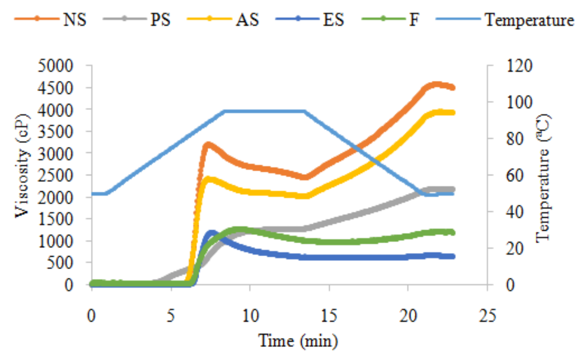


Fig. 1: Viscoamilograma of yam starch and flour

cassava starches when compared to the native (Oginni *et al.*, 2015; Barragán-Viloria *et al.*, 2016).

On the contrary, the ES presented a higher temperature of pasta formation, possibly by the action of the enzyme on the amorphous structure of the amylopectin which would be the section that less resistance would present to the enzymatic attack, so the disintegration of the amorphous section would contribute to the increase of the crystallinity and thus to the temperature of gelatinization. This same behavior was observed in enzyme yam starches of the species *Dioscorea trifid* (Montes *et al.*, 2008).

The AS showed no significant differences ($p \geq 0.05$) at the initial temperature of the paste when compared to NS. The initial temperature of the paste of the NS was similar to that reported by Salcedo Mendoza *et al.* (2016a) for yam starch of the species *Dioscorea rotundata* (79.60°C) and lower than that of *Dioscorea alata* (82.40°C), while the AS was superior to that reported by the same author in acetylated starch of yam of the species *Dioscorea rotundata* (77.20 to 78.60°C) and was found within the range of *Dioscorea alata* (80.10 to 81.20°C).

The initial temperature of the paste of the yam flour was greater than that of the starches: native, pregelatinized and acetylated, possibly because of its higher lipid and protein content, which form a complex with amylose, that tends to repress the swelling and solubilization of the granules in need of high temperatures to break the amylose-lipid-protein structure and solubilize the fraction of Amylose (Pacheco de Delahaye and Techeira, 2009). In turn, the result obtained for the flour in study was greater than that reported in flours of different species of Dioscoreáceas, such as those obtained by Abiodun and

Akinoso (2014) in the species *Dioscorea dumetorum* (48.61 to 49.11°C), Techeira (2008) in *Dioscorea alata* (77.9°C) and Bou Rached *et al.* (2006), in *Dioscorea trifid* (75 to 78°C). Differences in the initial temperature values of the paste between one species and another could be attributed to the differences in the composition and molecular structure that each granule possesses (Beleia *et al.*, 2006) and the higher the value, the starches would initiate the process of water absorption, swelling and gelling at a higher temperature and would need a longer cooking time (Techeira, 2008).

As for the maximum viscosity, the NS showed the highest value and was statistically significant ($p \leq 0.05$) with respect to the other samples. The decrease in the maximum viscosity of the modified starches with respect to the native could be associated with the processes of fragmentation and disintegration of the intragranular structure, occurring during the processes of modification to which they were subjected. This partial degradation probably caused a loss of the integrity of the granules, which resulted in lower viscosity values (Choi and Kerr, 2004; Sandhu *et al.*, 2008). Similar behavior was reported by Salcedo Mendoza *et al.* (2016a) for acetylated starch of yam and by Techeira (2008) in the pregelatinized starch of yam.

Significant differences s($p \leq 0.05$) were found in the stability of the studied samples, obtaining the AN the highest value and the lowest AP. If the breakdown value is high, it indicates that the swollen granules will be less resistant to mechanical disintegration and the starch or flour suspension will be less stable during the cooking process (Lawal, 2004). On the basis of this, the results obtained show an increase in the stability of the starches modified during cooking, with respect to the native. This could be related to a more organized structure of modified starches, giving them a greater resistance to deformation efforts. Similar behavior is reported in pregelatinized starches of rice, maize and yam (Adedokun and Itiola, 2010) and in acetylated of yam, cassava and sweet potato (Figueroa Flórez *et al.*, 2016; Salcedo Mendoza *et al.*, 2016a; Salcedo-Mendoza *et al.*, 2016b) as compared to the natives.

Rivas–González *et al.* (2009) report a constant period of viscosity during the heating phase associated with excellent gel stability. Behavior that was observed in the suspensions of PS and in the yam flour, emphasizing that the pregelatinizado had a greater stability. However, starches modified by acetylation and enzymatic hydrolysis tend to be less stable, probably because of their structural configuration, which makes them more fragile and susceptible to rupture by thermal and mechanical forces (Bou *et al.*, 2006).

As for the settlement, the NS presented the highest value and was statistically significant ($p \leq 0.05$) with respect to the other samples. The settlement or "setback", is an index used to express the tendency of the starches to retrograde. Consequently, the greater the value of this index, the greater the tendency of the components of the starch paste to retrograde, the product of the increase in the viscosity of the suspension during the cooling. In this sense, the one from the yam showed a greater tendency to the retrogradation compared to the modified starches and to the flour, product of the greater increase of its viscosity during the cooling (Adedokun and Itiola, 2010). A similar behavior was evidenced by Techeira (2008), when comparing the setback of the native yam starch with respect to the flour and the modified starches; By contrast, Salcedo Mendoza *et al.* (2016a) and Figueroa Flórez *et al.* (2016), when comparing native and acetylated starches of yam and sweet potato respectively, reported larger settlements with modified starches, associating this behavior with restoring hydrogen bonds that produce an increase in the viscosity of the starch suspension at the end of the cooling period.

Furthermore, it was found that among the modified starches the ES showed better settlement properties, obtaining the lower values of setback, followed by the PS and the AS, possibly due to the incorporation of hydroxyl groups to the molecules of the pregelatinized and enzymatic starches, which allows the reassociation under a new crystalline order when the cooling of the suspensions occurs gelatinizadas (Adedokun and Itiola, 2010; Figueroa Flórez *et al.*, 2016). However, the gels formed from the PS and AS show greater elasticity, generating a lesser syneresis gradation phenomenon (Robyt *et al.*, 1996).

Taking into account that for the development of emulsions of fine pasta whose process of scalding occurs at temperatures between 70 and 75°C, starches with low gelling temperatures are desirable to enable greater water absorption (Torres, 2012) and it should be guaranteed that the starch granules to be used in meat products are stable against continued heating, under mechanical stress and being subjected to freeze thaw cycles to contribute to the stability of products at low temperatures (Lawal, 2004), the PS was selected among the modified to be used as fatty mimetic in the production of sausages to present the highest values of WRC and WAC and the lowest values of syneresis, initial temperature of the paste and stability, being statistically different ($p \leq 0.05$), when compared to acetylated and enzymatic starches (Table 3 and 4).

Physicochemical characterization of the sausages: In Table 5, the results obtained from the physio-chemical characterization of sausages are shown, noting that there were no significant differences ($p \geq 0.05$) in the interaction of the factors FM and fat substitution for the variables humidity, ash, fat, protein, pH and calories. As for the humidity, the main effect of the factors was statistically significant ($p \leq 0.05$). As the percentage of fat substitution increased by the fatty mimetic increased

Table 5: Physiochemical composition of sausage

		Fat substitution (%)			
FM	Control[1]	10	20	30	40
Humidity (%)					
F	64.77±0.16NS[2]	64.92±0.43NS	65.48±0.33NS	65.72±0.17NS	65.82±0.31NS
NS	64.67±0.19NS	64.61±0.34NS	64.90±0.12NS	65.36±0.19NS	65.48±0.10NS
PS	64.66±0.09NS	64.75±0.07NS	65.42±0.08NS	65.49±0.19NS	66.01±0.11NS
Ash (%)					
F	2.62±0.09NS	2.68±0.05NS	2.81±0.06NS	2.89±0.06NS	2.92±0.01NS
NS	2.59±0.15NS	2.72±0.07NS	2.61±0.06NS	2.59±0.05NS	2.78±0.09NS
PS	2.61±0.13NS	2.65±0.05NS	2.72±0.01NS	2.66±0.09NS	2.78±0.10NS
Fat (%)					
F	20.79±1.14NS	18.00±1.77NS	16.45±1.12NS	14.22±1.13NS	13.12±0.95NS
NS	19.55±1.02NS	18.07±1.54NS	16.77±1.56NS	13.61±0.84NS	12.00±1.07NS
PS	20.15±1.20NS	18.60±0.91NS	16.67±1.00NS	14.32±1.80NS	12.83±1.04NS
Protein (%)					
F	13.23±0.50NS	13.07±0.28NS	13.82±0.13NS	13.75±0.15NS	14.28±0.88NS
NS	13.32±0.33NS	13.06±0.49NS	13.23±0.57NS	13.52±0.54NS	13.19±0.37NS
PS	13.31±0.21NS	12.62±0.62NS	13.70±0.99NS	12.99±0.59NS	13.50±0.93NS
pH					
F	6.37±0.01NS	6.39±0.02NS	6.39±0.03NS	6.40±0.01NS	6.38±0.03NS
NS	6.38±0.02NS	6.38±0.02NS	6.38±0.02NS	6.40±0.01NS	6.40±0.03NS
PS	6.37±0.01NS	6.39±0.01NS	6.38±0.02NS	6.36±0.01NS	6.37±0.01NS
Calorías (Kcal)					
F	240.15±9.78NS	222.66±7.83NS	209.05±5.48NS	196.66±4.98NS	190.67±5.31NS
NS	230.23±7.56NS	221.93±8.14NS	216.16±7.36NS	198.10±4.63NS	187.55±5.41NS
PS	235.56±9.59NS	223.40±4.40NS	211.05±5.57NS	198.97±8.66NS	188.96±5.26NS

[1]Control: 0% fat substituion; [2]NS: Not significant

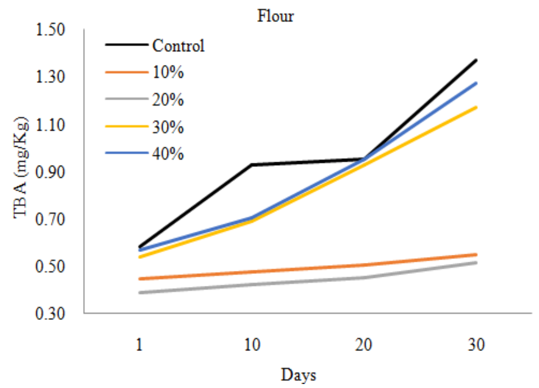
the humidity of the sausages obtaining the highest values with the addition of flour and PS, this could be due to the greater WRC and WAC determined in these and their ability to form complexes with water and proteins improving water retention in products (Choe *et al*., 2013). Increases in humidity values, also have been evidenced by Luo and Xu (2011), in sausages where modified starches of yucca were used as fatty mimetic with ranges between 56.36 and 65.87%, similar to those obtained in this study; In the same way Ramírez-Camargo *et al*. (2016) reported increases in sausage moisture when using mixtures of fibres and cassava starch as fat substitutes with values between 61.1 and 64.8%; For its part, García-Reyes (2015) obtained higher moisture values (71 and 75%) in low-fat chicken sausages formulated with pea fiber and potato starch than those found in this study.

There were also differences between the main effects ($p \leq 0.05$) for the ash content. By substituting 40%, the fat by the fatty mimetic increased the ash content of the sausages with respect to the other treatments, although it was statistically equal to replace 30%, resulting in the flour added as mimetic fatty different from the native and pregelatinized starch, possibly associated with the greater ash content determined for this one with respect to the other mimetic and the purity of the starches. A similar behavior was reported by Feng *et al*. (2013), who reported that the ash content of the control sample without fat reduction was less than that of the sausages substituted in fat arguing that this result could be attributed to the contribution of ashes of the substitutes, obtaining ranks between 2.71 to 2.89%, similar to the results obtained in this study; Similarly, De Oliveira Faria *et al*. (2015) reported that substituting 50% for pork fat in Bologna-type sausages by pig skin gels formulated with different concentrations of amorphous cellulose showed increases in the ash content of 3.63 to 4.90%.

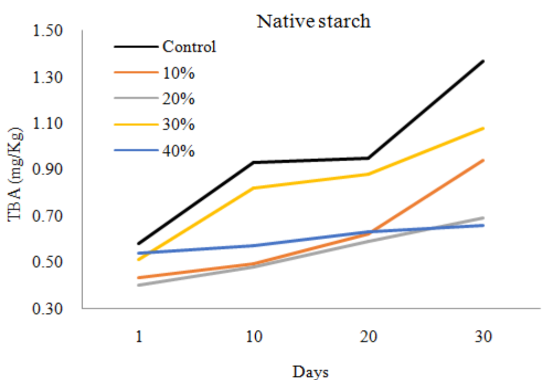
The effect of fatty mimetic was not significant ($p \geq 0.05$) in the fat content and calories of sausages. Similar results were found by Feng *et al*. (2013), who reported that Cantonese-style Chinese sausages did not undergo significant changes in fat content by adding different mixtures of rice starch and gum. Likewise, Luo and Xu (2011) reported that the addition of enzymatic starch and a dual cassava starch as fat substitutes did not affect the fat content and calories of sausages.

However, the substitution proved to be significant ($p \leq 0.05$) in the variation of fatty content and calories of sausages. As for the fat content, substituting 30 and 40% by the mimetic, no significant differences ($p \geq 0.05$) were observed among each other. In the same way, when replacing 10 and 20% no differences were observed, but if they were different from the control formulation, achieving reductions in the content of fat in sausages between 9.62 and 37.25% with respect to the control formulation.

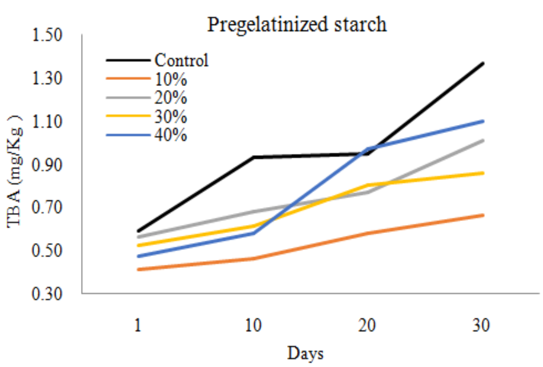
On the other hand, the values of the calorie of the sausages were reduced by increasing the percentages of fat substitution, resulting statistically different from the sausage control. The reduction of the calories with respect to the control oscillated between 5.38 and 19.66%. Reductions in product energy by lowering fat levels in meat products has also been evidenced by other authors. Luo and Xu (2011) showed that by replacing 50% the fat by modified starches of cassava in sausages the fat was reduced between 48.12 and



(a)



(b)



(c)

Fig. 2: Oxidative rancidity of sausages

49.29% and the calories between 27.97 and 29.76% with respect to the control. Likewise, Liu *et al*. (2008), obtained a reduction in energy of 29.7 and 52.2% in sausages when fat was reduced from 49.9 to 84% by replacing the fat with potato enzymatic starch. On the other hand, Choe *et al*. (2013) by reducing pork fat in frankfurter sausages by 50% by a mixture of pork skin and wheat fiber, obtained 32% fewer calories and Pacheco Pérez *et al*. (2011), achieved a 32.34% reduction in the fat content of sausages by using a fat extender made with pork dorsal bacon and a mixture of sodium alginate and calcium carbonate.

The main effect of the factors was not significant ($p \geq 0.05$) on the average protein and pH values of the sausages. Similar results were reported by García *et al*. (2012a) in low fat burgers including pea flour and by Araya-Quesada *et al*. (2014) in chicken emulsions where green plantain flour was evaluated as a fat substitute; associating this behavior to the low protein content present in the starches and in the flour. The protein values (Table 5) were similar to the ranges reported by Luo and Xu (2011) (13.98 to 14.41%) and Choe *et al*. (2013) (12.60 to 13.79%) in sausages where modified cassava starches and a mixture of pork skin with wheat fiber were used, respectively, as mimetic fatty, but were inferior to those found by García *et al*. (2012b) (18.59 to 19.87%), however, the proposed formulations complied with the established, for this parameter, in NTC 1325 (2008). The pH's were within the range reported by Feng *et al*. (2013) in Cantonese-style sausages using rice starch and mixtures of starch with gum as substitutes for fat (6.32 to 6.48) and were inferior to those found by Choe *et al*. (2013) (6.43 to 6.45), but higher than those observed by Araya-Quesada *et al*. (2014) (6.07 to 6.10).

In terms of oxidative rancidity, the interaction between factors FM, substitution of fat and days generated statistically significant changes ($p \leq 0.05$). In Fig. 2 the oxidative rancidity values of the sausages are shown, noting that these in all the samples increased with the refrigerated storage time (4°C), possibly because of the oxidation of the lipids in the sausages. Increases in rancidity values of meat products substituted in fat during storage have also been reported by other investigators (Tan *et al*., 2007; Meneses *et al*., 2011; Triki *et al*., 2013).

The values obtained from Rancidity were lower than the range reported by Tan *et al*. (2007) for 21 days of refrigerated Chinese sausage storage where fat is replaced by yam (2.37 a 4.18 mg malonaldehido/Kg sample), but higher than those reported by Feng *et al*. (2013) in sausages substituted in fat with rice starch and mixtures of that starch with rubber during three weeks of refrigerated storage (0.2 to 0.5 mg of malonaldehido/Kg of sample), emphasizing that by substituting 10 and 20% the fat by flour the values Obtained are similar to those reported in this range. However, as reported by Chow (1992), the rancidity of all the evaluated samples does not exceed the unacceptable range by the consumers, he argues that the maximum tolerable limit of rancidity is 2 mg of malonaldehyde/kg.

For its part, Sheard *et al*. (2000) indicate that consumers could perceive rancidity at concentrations greater than 0.5 mg of sample malonaldehido/kg, while other researchers (Ockerman and Kuo, 1982), point to the value of 1 mg/kg as a limit for the perception of rancidity by part of consumers. According to this, it is probable that in the sausages where the fat was replaced by FM the consumers do not perceive rancidity in the

Table 6: Techno-functional characterization of sausages

		Fat substitution (%)			
FM	Control[1]	10	20	30	40
TRF (%)					
F	4.49±0.44Aa[2]	4.36±0.08abA	3.73±0.39bA	2.52±0.12cB	2.16±0.27cA
NS	4.49±0.44aA	4.42±0.09aA	3.27±0.14bcAB	3.40±0.24bA	2.67±0.39cA
PS	4.50±0.24aA	3.54±0.12bB	2.81±0.23cB	2.72±0.54cB	2.52±0.13cA
FR (%)					
F	2.89±0.04aA	1.93±0.09bA	1.85±0.10bcA	1.69±0.08cdA	1.55±0.04dA
NS	2.85±0.07aA	1.68±0.09bB	1.56±0.09bAB	1.33±0.08cB	1.24±0.08cB
PS	2.83±0.06aA	1.54±0.07bB	1.25±0.02cC	0.67±0.10dC	0.65±0.02dC
Yield (%)					
F	95.87±0.25dA	98.42±0.51cB	98.84±0.21bcB	99.70±0.53abA	99.88±0.20aA
NS	95.81±0.20cA	97.84±0.25bB	98.52±0.56bAB	99.62±0.66aA	99.78±0.39aA
PS	95.83±0.40bA	99.65±0.36aA	99.78±0.38aA	99.83±0.30aA	99.76±0.42aA
WRC (%)					
F	13.10±0.44NS[3]	13.31±0.92NS	14.79±0.64NS	14.71±0.69NS	16.23±0.76NS
NS	13.27±0.24NS	12.23±0.89NS	14.28±0.54NS	15.49±0.42NS	16.33±0.72NS
PS	13.15±0.50NS	13.51±0.73NS	13.94±0.75NS	15.67±0.70NS	16.45±0.88NS

[1]Control: 0% fat substitution; [2]: Stockings with different letters in rows (lowercase, comparison between fat substitution) and columns (uppercase, comparison between FM indicate significant differences ($p \leq 0.05$), conforms with the Tukey test; [3]NS: Not significant

product until the 30 days of refrigerated storage, except for those produced with substitutions of 30 and 40% when using the flour and the PS, as they exceed 1 mg of malonaldehido/Kg of sample. It was also observed that in the formulations where the fat was replaced by the mimetic the rancidity was lower than in the formula control, except for the formulations where 40% of the fat was replaced by flour and PS at 20 days of storage. The increase in the rancidity of the sausage control can be due to the higher fat content that could generate a greater amount of oxidation products.

On the other hand, it was observed that by substituting 30 and 40% of the fat with the flour in the different days of storage, the rancidity values increased with respect to the substitutions of 10 and 20%. In the same way, with the NS on days 1 and 10 the higher values of rancidity are generated with the substitutions of 30 and 40%, while in the 20 and 30 the higher values are presented with the replacement of 30%. However, on days 1 and 10 of storage, when replacing 40% the fat per PS rancidity is <20 and 30%, but in the 20 and 30 is greater the rancidity generated with the substitution of 40%. Possibly this behavior is associated with the humidity of the product, since the greater substitution of fat by FM, the higher the water retained in the sausages, which could accelerate the oxidative rancidity, since the humidity tends to catalyze the reactions of Rancidity (Barreiro and Sandoval, 2006). Contrary results were reported by Tan *et al*. (2007) when evaluating Chinese sausages formulated with different fat/yam ratios (20/0, 15/5, 10/10 and 5/15%, respectively), observing low values of TBA in samples with higher fat replacement/yam, arguing that this behavior could be due to antioxidant properties of yam. For its part, Jang and Lee (2014) reported that by adding different percentages of yam starch (*Dioscorea japonica*) to a Frankfurt sausage, the values of TBA during the 1st week of storage were higher in samples containing starch of yam and in the rest of the weeks were lower in the samples with higher concentrations of yam, associating this behavior to the possible presence of tocopherol and vitamin C in the starch which could contribute to antioxidant activity.

On the other hand, it was shown that by substituting 10% the fat during the first 10 days of refrigerated storage, the flour and NS (native starch) generated a greater rancidity in the sausages than the PS, however, at 20 and 30 days it was less with the flour. When replacing 20% the fat, the sausages showed less rancidity during the whole time of storage by adding the flour as FM, however, by substituting 30 and 40% this tended to generate greater rancidity that the starches during the 30 days of storage cooled. This behavior could be related to the ability of starches and flour to absorb and retain water, as well as its behavior to thaw cycles (syneresis). The PS and the flour had higher values of WRC and WAC than the NS, but the flour presented the greatest syneresis, being probable, that this being added in greater quantity has generated a greater release of water during the refrigerated storage product of the Reorganization of starch molecules (Pongsawatmanit and Srijunthongsiri, 2008), by generating greater moisture in the product may have accelerated the reactions of rancidity (Barreiro and Sandoval, 2006), while using the PS, although it has embedded a greater amount of water than the flour the umlaut was much lower and the one despite the fact that the syneresis was greater than that of the PS, it probably generated less water release because of the reduced capacity to absorb water.

Techno-functional characterization of sausages: Table 6 shows the results of the techno-functional characterization of sausages. The interaction between the factors FM and substitution of fat used in the elaboration of the sausages generated statistically significant changes ($p \leq 0.05$) in the stability of the emulsions. By substituting 20, 30 and 40% the flour fat and NS decreased the percentage of TRF with respect to the formulation control, whereas in all formulations where the fat was replaced by PS decreased the TRF value with respect to the control. As the percentage of fat substitution per FM was increased, the FR was reduced, with the substitution of 40% of the fat per flour, NS and PS reductions of 46.37, 56.49 and 77.03%, respectively, with respect to the control formulation. The greater stability achieved with the replacement of the fat by the mimetic can be due to the contribution of its techno-functional properties like the WRC and WAC, achieving stabilizing the emulsion of water, fat and protein by the formation of a gel matrix more rigid that avoids the exudation of water and fat (Flores *et al*., 2007).

An improvement in the stability of low-fat meat products has also been demonstrated by the use of pregelatinized, solubilized, dispersed starches and retrograded maize and potatoes, modified cassava starches and rice starch mixes with gum (Aktas and Genccelep, 2006; Luo and Xu, 2011; Feng *et al*., 2013).

Significant differences ($p \leq 0.05$) between FM with the exception of the control were shown for each fat substitution. In particular, lower losses of water were obtained with the flour and the PS due to the greater WRC and WAC of these mimetics. However, with the addition of the starches the exudation of fat significantly decreased, being less with the PS, which may be due to the formation of a dense network of molecules of fatty globules restricted by the mixture of polysaccharides and proteins (Shand, 2000). Similar behavior has been evidenced by the use of maize and potato pregelatinizados starches achieving greater stability in Bologna-type sausage emulsions when compared with solubilized, dispersed and retrograded starches from Same varieties with percentages of water released from 0.69 to 2.37% and fat released from 0.08 to 0.30% (Aktas and Genccelep, 2006), in the same way, with the use of modified cassava starches has achieved greater stability in the emulsions with respect to the control reflected in the percentages of a Freed 0.78 to 2.98% and freed fat from 007 to 0.22% (Luo and Xu, 2011), inferior values to those found in this study, possibly with modified starch from cassava, maize and potato greater retention of water is obtained during the scalding of the products in creeped by its low temperature of Pastificación (Techeira, 2008). However, the stability values obtained in this study are within the ranks reported by De Oliveira Faria *et al*. (2015) in bologna sausages substituted in fat by the combination of pig skin with amorphous cellulose (water released from 1.03 to 7.03% and of fat released from 0.15 to 1.62%) and by Choe *et al*. (2013) in emulsions of fine pasta, where fat is replaced by a mixture of pig skin and wheat fiber (water released from 0.58 to 5.60% and fat released from 0.15 to 0.47%).

The interaction between study factors also generated statistically significant changes ($p \leq 0.05$) in sausage output. For all the fatty mimetic, there were significant differences ($p \leq 0.05$) between the fat substitutions studied except for the control, noting that their additions increased the yield with respect to the formulation control, possibly by the greater amount of water retained by increasing the weight of the finished product (Flores *et al*., 2007). By substituting 30 and 40%, the fat per flour and AN are given the highest yields. By replacing it by PS, there were no differences between the substitutions where it was added. When comparing the yield between FM, there were significant differences ($p \leq 0.05$) only in the 10 and 20% fat substitutions, generating the PS the highest values, which may be due to its higher WRC and WAC. Several studies report an improvement in the yield of low-fat meat products by including starches and flours as fat analogues (Pietrasik and Janz, 2010; Luo and Xu, 2011; García *et al*., 2012a; Araya-Quesada *et al*., 2014; Bastos *et al*., 2014). However, the yields obtained in this study were similar to those reported by Araya-Quesada *et al*. (2014) (greater than 99%), when using plantain flour in chicken emulsions and were superior to those reported by Feng *et al*. (2013) (84.76 to 86.20%) in sausages substituted with rice starch and mixtures of this with rubber.

For its part, the interaction between the factors FM and substitution of fat did not generate statistically significant changes ($p \geq 0.05$) in the WRC of the sausages. However, the substitution of fat exerted a significant effect ($p \leq 0.05$) on the WRC of the sausages, whereas the main effect of the factor FM did not influence this property. As the percentage of fat substitution increased by the mimetic increased the WRC of the sausages being greater by substituting 40% the fat, which could be due, in the capacity of the starches and the flour to absorb and retain water, allowing the greater additions of the fatty mimetic during the process of elaboration of the emulsions, to bind and to retain greater quantity of water in the products (Luo and Xu, 2011).

The values of WRC of the sausages were inferior to those reported by Correa and González (2015) for an emulsion of fine pasta (23.41-30.44%) formulated with 12% of fat and 5% of a mixture of native starches of yucca and yam. These differences could be due to a greater capacity of absorption of water from the cassava starch during the process of scalding of the products, since this has a lower temperature of pastificación (42.2°C) (Paternina *et al*., 2016b) that the one found for the starches and flour in study, so the cassava starch would initiate the process of water absorption, swelling and gelling at a lower temperature (Techeira, 2008).

CONCLUSION

The yam PS was the one that presented the best techno-functional properties required for a fatty mimetic because it was characterized by its high capacity to absorb and retain water, greater stability of its gels to cycles of freezing and thawing and lower initial temperature of the paste. The addition of flour NS and PS of hawthorn yam as a fat memetics in sausages, allow in addition to reducing the fat content, to modify the energetic value in the final product, constituting an alternative for the formulation of healthy meat sausages. Likewise, the decrease of fat with the consequences increase of flour, NS and PS of hawthorn yam in the formulation of sausages improves the stability, the yields and the capacity of water retention of the meat emulsions. However, for the development of low-fat sausages, it is recommended to replace up to 20% fat per flour NS and PS when generating lower values of rancidity indicating a lower oxidation of lipids.

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