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Research Article

Lintnerized Yam Starches (*Dioscorea alata* cv. Diamante 22) for Food Industry

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Abstract: This study evaluated the effect of acid concentration and reaction time in the lintnerization process on the physicochemical, structural and rheological properties of native yam starch (*Dioscorea alata* cv. Diamante 22). The lintnerization process involves chemical modification with hydrochloric acid to produce starch for the food, paper and textile industries. The acid hydrolysis of yam starch produced low dextrose equivalents (D.E 4.7%) and yields between 83 and 96%, as well. Slight changes to the granule surface, which mainly affected the amorphous part of the granule and reflected in the increased crystallinity, reducing the Water Absorption Capacity (WAC) and swelling (SP). For to the native starch, otherwise, when moderate acid hydrolysis is applied. A yield between 83 and 96%, slight changes on the granular surface (exo-corosión superficial). A reduction was observed in the initial gelatinization temperature from 82.1 to 77.6°C and maximum viscosity (1790 to 1656 MPa.s) when subjected to severe lintnerization treatments. The lintnerization process improved the stability of the starches during heating and decreased their tendency to retrograde, resulting a gel of stable consistency, suitable for the processed food industry.

Keywords: Amylaceous, hydrolysis, modified starch, retrogradation, starchy, tubers

INTRODUCTION

Yam is the third most important tropical tuber crop in the world, after Cassava (*Manihot esculenta* Crantz) and potato (*Ipomoea batatas*). In Colombia, the cultivation of the *Dioscorea alata* and *Dioscorea rotundata* species is of great socio-economic importance in the Caribbean region, with a production of 277850 t/ha in 2015. The criollo yam (*Dioscorea alata*) has a high starch content, representing 73-85% of its weight in dry matter, cataloged as an excellent energy source. The starch granules are composed of amylose and amylopectin chains, which depending on their composition and structural arrangement, confer unique physicochemical and functional properties characteristic of each species (Shunjun *et al*., 2006a; Shunjun *et al*., 2006b).

The amylose content in *Dioscorea alata* starches oscillates between 21.17 and 29.37% (Karam *et al*., 2006; Alvis *et al*., 2008). Native starches of *Dioscorea* species present specific characteristics such as stability of suspensions to thermal stresses, the absence of a peak of a maximum viscosity during heating, good water retention capacity and high gelatinization temperature (Shunjun *et al*., 2006a; Shunjun *et al*., 2006b; Alvis *et al*., 2008). Which emphasize its use in the industry as a stabilizer, filler agents, film-formers, texture improver, gelling agent and thickener (Singh *et al*., 2003).

However, native yam starches present limitations when they are subjected to extreme mechanical, thermal or chemical stresses, as well as showing a high tendency toward retrogradation and syneresis. These barriers overcome specific industrial applications through the chemical, physical or enzymatic modification of the starch granule (Falade and Ayetigbo, 2015). The lintnerization process involves chemical modification using acid, which is performed to produce starches for the food, paper and textile industries (Lawal *et al*., 2005). According to the World Health Organization (WHO), the maximum theoretical quantity of chemical agent permitted in the production of lintnerized starches for the food industry is 8% w/w (Cereda and Vilpoux, 2003). The hydrolysis occurs initially in the amorphous regions of the granules remaining the crystalline region relatively intact, producing linear chains, which affect the phenomenon of retrogradation and the formation of resistant starch. The acid hydrolysis process comprises treating a starch suspension with a mineral acid, at a temperature below that of gelatinization for a specified time (Sandhu *et al*., 2007). The lintnerization process produces to changes in the morphological and structural properties of the starch, affecting thermal and functional properties such as transition temperature, enthalpy of gelatinization,

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viscoelastic properties of starch and resistant starches formation (Thomas and Atwell, 1999). The solubility and the resistance of the gel increase concerning the native starch and the starch loss due to the conversion to glucose (Lawal *et al*., 2005; Sandhu *et al*., 2007; Lawal, 2004; Shujun *et al*., 2007a; Dutta *et al*., 2011). In previous studies, the effect of acid treatment on native yam starches has been evaluated, with changes in the size and shape of the starch granules, the degree of crystallinity, increase in solubility and water absorption capacity, obtaining a stable gel and increased gelatinization temperature (Falade and Ayetigbo, 2015; Shujun *et al*., 2007a; Shujun *et al*., 2007b).

The present study evaluated the effect of low acid concentrations and reaction time in the lintnerization process on the physicochemical, structural and rheological properties of native yam starch *Dioscorea alata* cv. Diamond 22 that could facilitate its use in the food industry.

MATERIALS AND METHODS

Raw materials: The vegetable material used in the research corresponds to the variety of yam *Dioscorea alata* cv. Diamante 22, which was provided by local farmers in the city of Sincelejo). The Yam starch was obtained from the Unitary Operations Plant of the University of Sucre (Colombia), by a bubbling equipment redesigned by Salcedo *et al*. (2014). The moisture, ash, protein, dry matter and starch content, were determined by the methods proposed in AOAC (2000, 2004).

Starch modification process: A homogeneous dispersion of 100 g (d.b.) of starch was prepared in 250 mL of water and agitated at 100 rpm for 10 min. After this, 2, 4 and 6 g of HCl (0.2, 0.42 and 0.63 M, respectively), were added to the dispersion and a constant agitation at 100 rpm was maintained, with the reaction time varying from 4 to 10 h. The modification process was carried out at a temperature of 35°C. adjusting the suspension to a pH of 6.0 with a 2.0 M NaOH solution. The starch obtained was washed with distilled water, subjected to convective drying at 50°C for 20-24 h, pulverized and sieved in 100 mesh (ASTM Standard).

Yield and degree of hydrolysis: The yield of modified starch was calculated using the ratio: Lintnerized starch (g) /native starch (g). The reducing sugars were determined using the DNS (3, 5-dinitrosalicyclic acid) method described by Miller (1959). The degree of hydrolysis was expressed as Dextrose Equivalents (DE).

Scanning Electron Microscopy (SEM): The samples were analyzed by Scanning Electron Microscopy (SEM, JSM 5910LV, Japan) according to the method proposed by Lawal (2004). The dehydrated yam starch samples were placed in a vacuum evaporator and covered with 9 mm-carbon tapes and a gold-palladium coating, to 15 KV and 30 mA.

Infrared analysis (FTIR): Infrared spectra of native and modified starches were acquired using a Fourier Transform Infrared Spectrometer (Thermo Scientific, Nicolet IS50 FTIR, USA) in the region from 4000 to 500/cm. The analysis was conducted with the software Thermo Scientific OMNIC The crystals were obtained by mixing 20 mg of starch with KBr at a ratio of 1: 5 (starch: KBr). Thirty-two readings were collected at a resolution of 4/cm (Wang *et al*., 2014).

X-ray diffraction: X-ray diffraction patterns were recorded with a diffractometer (Panalytical, X'Pert Pro MPD). Operating at 1.8 kW, 40. The diffractograms were acquired over a 2θ range of 4-45°, with a step size of 0.013°, a step time of 59 sec, a divergence grating of 1° wide, a dispersion grating of 1°, a 10 mm mask and a solar grating of 0.07 rad. The proposed method by Nara and Komiya (1983) was used to determine the material's Crystallinity Degree (CD). This method estimates the ratio of absorption peak areas (due to crystalline regions) to the total sample area throughout integration (Frost *et al*., 2009). The Degree of Crystallinity (CD) was calculated using Eq. (1):

$$\text{Degree of Crystallinity (\%)} = \left(\frac{A_C}{A_C + A_A}\right) * 100 \qquad (1)$$

where,

A_C : The crystalline areas of the absorption peaks

A_A : The amorphous area of the diffractograms

The CD of the starch samples was quantitatively determined with the program Origin 8.0®, trial version. (Origin Lab Corporation, USA).

Pasting properties: Various pasting parameters of starches such as maximum viscosity, pasting final temperature, viscosity, final viscosity at 95°C, final viscosity at 50°C, breakdown and setback were determined using an MCR 302 Rheometer (Smart Starch 131 Analyser; Anton Paar, Austria). The method described by Nasrin and Anal (2013) with some modifications was used to determine the viscosity profiles of the starch dispersions. Starch suspensions (4% w/w) were prepared to assess the viscosity profiles of the starches using a 23 min of standard test, which involved: initial equilibrium at 50°C for 1 min, heating from 50 to 95°C over 7.5 min., maintained at 95°C for 5 min., cooled 95 to 50°C over 7.5 min. And finally at 50°C for 2 min. The spindle speed (Anton Paar, ST24-2D/2V, Austria) was kept at 960 rpm for the first 10 sec to keep the suspension dispersed and reduced to 160 rpm for the rest of the procedure. The results obtained from the test were processed using the software RheoCompass 1.12. (Mendoza *et al*., 2016).

Freeze-Thaw Stability (FTS): Native and modified yam starches suspension (2% w/w) were heated in water bath at 90°C for 15 min, cooled to room temperature and storage at -20°C during 24 h, followed by 1.5 h in a water bath at 30°C. These samples were centrifuged at 2800× g for 15 min and the amount of water separated the freeze-thaw cycle was determined. Then the samples were frozen again at -20°C and the same procedure was repeated. Measurements were carried out during three freeze-thaw cycles. The syneresis was calculated as the ratio between the weights of the separated liquid from the gel and the gel collected after centrifugation (Dutta *et al*., 2011).

Water Absorption Capacity (WAC) and Oil Absorption Capacity (OAC), Solubility Index (SI) and Swelling Power (SP) and Emulsifying Capacity (CE): The WAC and OAC were determined according to the method of Mweta *et al*. (2011), the SI and SP by the methodology proposed by Wang *et al.* (2014). The CE was determined by method proposed by Koksel *et al*. (2008) with slight modifications; 1 g of sample was dispersed in 25 mL of distilled water, mixed with 25 mL of vegetable oil and homogenized for 1 min at 10000 rpm in an Ultraturrax (Heidolph, Silent Crusher M, US). The emulsion is poured into two centrifuge tubes (25 mL/tube) and centrifuged at 4000 rpm for 10 min. The emulsifying capacity is determined from the ratio, emulsified layer volume and total volume occupied in the tube.

Experimental design: A central rotational design with of axial points was established. Table 1 Shows the experimental factors and levels established in this study. The results were statistically analyzed using analysis of variance, lack of fit testing, determination of regression coefficients and comprehensive study of the effects of these process parameters and their interactions with statistical software (R). Experimental data were fitted to the second order model Eq. (2):

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X_i^2 + \sum_{i=j=1} \beta_{ij} X_i X_j \quad (2)$$

where,

β_0, β_i, β_{ii} and β_{ij} : Regression coefficients for the intercept, linear interaction terms and quadratic, respectively

X : The independent variable

RESULTS AND DISCUSSION

The proximate analysis of the diamante 22 yam starch variety found the following contents: protein 0.326±0.015%, crude fiber 0.156±0.015%, ash 0.14±0.0%, dry matter 84.58±0.51% and starch content in dry base 97.8%.

Yield and degree of hydrolysis: Table 2 presents the results for yield and degree of hydrolysis in lintnerized yam starches (diamond 22). The acid concentration and reaction time did not significantly influence ($p>0.05$) the yield of starch obtained through the lintnerization process.

Table 1: Factors analyzed and coding of established levels

Factor	Symbol	Low	Medium	High
Coding		-1	0	+1
Concentration (% p/p, g HCl/g starch)	X_1	2	4	6
Reaction time (h)	X_2	6	8	10

Table 2: Behavior of the yield and degree of hydrolysis in the lintnerized yam starches (*Dioscorea alata* cv. Diamante 22)

Treatment	Concentration (% p/p)	Time (h)	Yield (%)	DE (%)
AL1	-1.0	-1.0	88.07	3.34
AL2	-1.4	0.0	83.24	2.65
AL3	1.0	-1.0	96.35	5.75
AL4	0.0	-1.4	90.86	3.07
AL5	0.0	0.0	95.22	4.03
AL6	0.0	0.0	95.67	4.45
AL7	0.0	1.4	91.66	4.05
AL8	-1.0	1.0	96.21	3.04
AL9	1.4	0.0	96.13	4.80
AL10	1.0	1.0	90.41	4.73

Prepared by researchers

Table 3: Effects of the regression model for starch yield and degree of hydrolysis

Regression coefficients	Yield	DE (%)
β_0	95.44	4.29
β_1	0.41	-
β_2	2.58	0.89*
β_{12}	-3.52	-0.18
β_{11}	-1.52	-
β_{22}	-2.31	-0.02
R^2	0.75	0.76
Last to fit (value p)	0.06	0.52

*: Factors with significant effect $p<0.05$; β_0: Constant; β_1: Time; β_2: Concentration; Prepared by researchers

The mathematical model used to describe the behavior of starch yield produced a regression coefficient of 75.78% (Table 3). The lack of fit test allows inferring that the selected model is adequate to describe its behavior ($p>0.05$). The lintnerized starches presented a yield between 83 and 96%. Similar results have been reported in the production of lintnerized starches of sweet potato and yam (Shujun *et al*., 2007b; Olorunsola *et al*., 2011) and starches hydrolyzed with citric acid (Falade and Ayetigbo, 2015).

The acid concentration played a significant role ($p<0.05$) in increasing the (DE) during the lintnerization process. However, no significant differences were found with concerning to the reaction time. Kim *et al*. (2012), this indicates that the type and concentration of acid are essential in demarcating the state of degradation and the percentage of yield in the production of lintnerized starches. Similar behavior reported Wang and Copeland (2012), who found that the hydrolysis process was directly related to the capacity of the acid to degrade the amorphous or

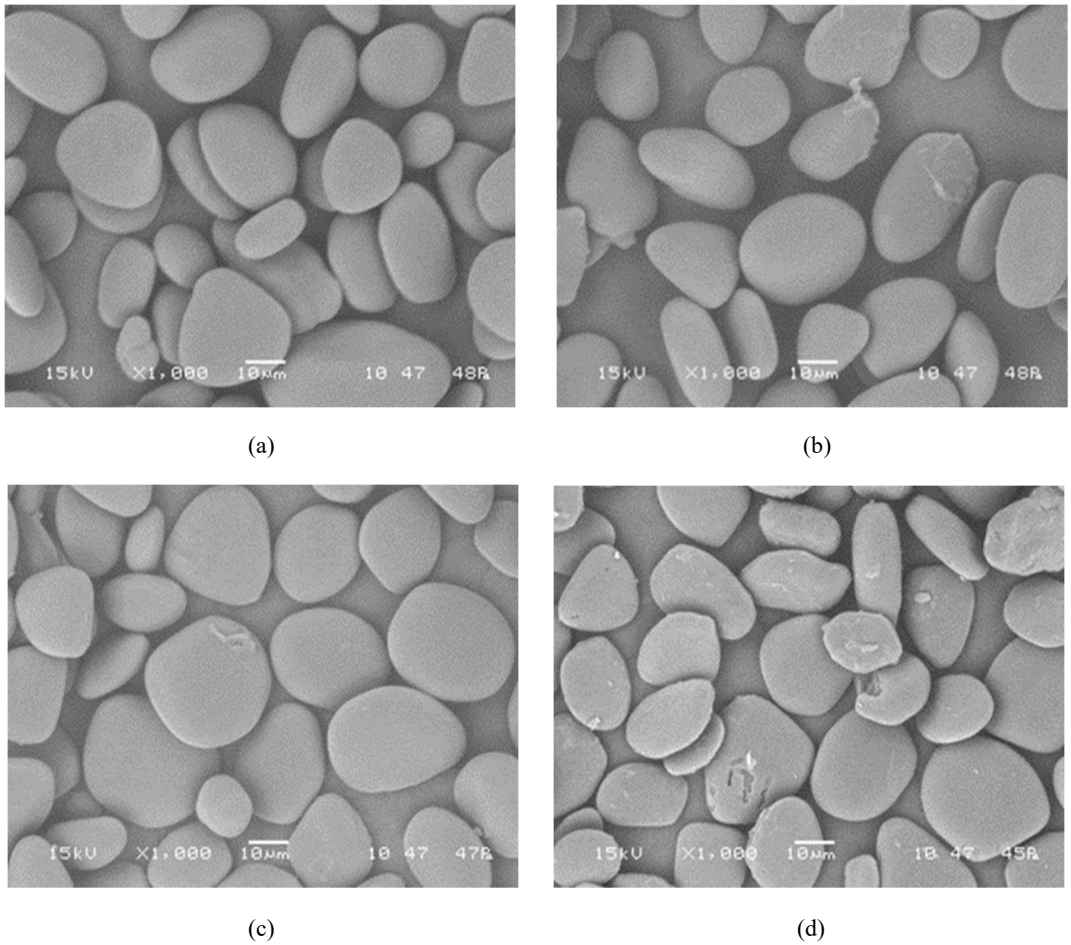

Fig. 1: Microphotographs of native and lintnerized yam starches of *Dioscorea alata* (cv. Diamante 22) (a) Native starch (b) Lintnerized treatment AL1, (c) Lintnerized treatment AL5, (d) Lintnerized treatment AL10
Prepared by researchers

disorganized zones of the granule, thus partially destroying the structure and increasing the degree of conversion and content of glucosidic compounds (DE).

Microphotography of SEM: The microphotographs of the native and lintnerized starch of yams showed that native starch granules are ovoid, elliptical, round and in some cases irregular shaped (Fig. 1a). The images showed that acid hydrolysis produced slight changes on the granular surface of the lintnerized yam starch (exo-corrosion), which may have been caused by the release and association of short amylose chains during the hydrolysis process (Fig. 1b and 1c). Shujun *et al*. (2007a) described slight alterations in the smooth surface of modified yam starch after two days of acid hydrolysis. Atichokudomchai *et al*. (2000) in lintnerized cassava starches reported this same behavior after 12 h of reaction.

The extent of degradation became more visible as treatment time increased. The surfaces appeared to be less smooth and with evidence of notches, fissures or pores. However, the native morphology of the granules did not show significant changes corresponding to the treatment time (Fig. 1d). Aparicio-Saguilan *et al*. (2015) note that acid treatment time is an essential factor in the degradation of amorphous regions, affecting the shape and crystallinity of the starch granules. Falade and Ayetigbo (2015) observed fissures or pronounced edges caused by the hydrolysis process of the lateral chains on the granular layer, which altered the surface structure of the lintnerized yam starch. Previous studies have reported more severe alterations in the surface of the starch granule caused by the attack of hydrogen ions during long hydrolysis times (Sandhu *et al*., 2007; Shujun *et al*., 2007a; Dutta *et al*., 2011).

Spectroscopy Infrared (FTIR): FTIR spectroscopy was used to verify the chemical structure of starch molecules after lintnerization, Fig. 2 shows the native starch FTIRs and the lintnerized starches corresponding to treatments AL1, AL 5 and AL. 10. The 1010 and 1097/cm Bands, presented an increase in the absorbance of the lintnerized starches, which indicates increased tension due to the stretching of the C-O in the

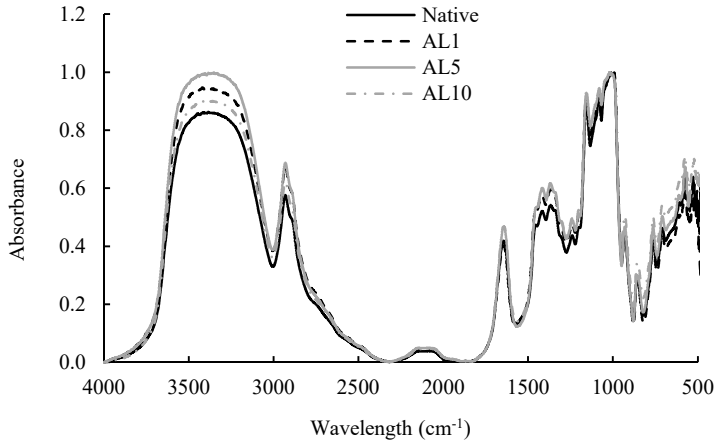

Fig. 2: FT-IR spectra of native starch and lintnerized yam starches of *Dioscorea alata* (cv. Diamante 22)
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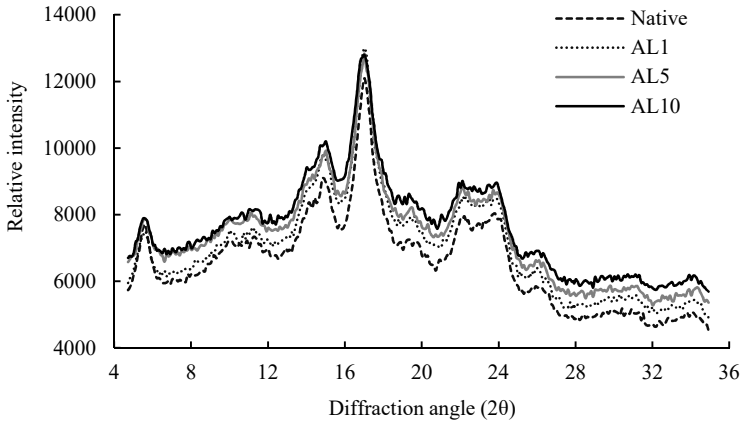

Fig. 3: X-ray diffractograms in native starch and lintnerized yam starches of *Dioscorea alata* (cv. Diamante 22)
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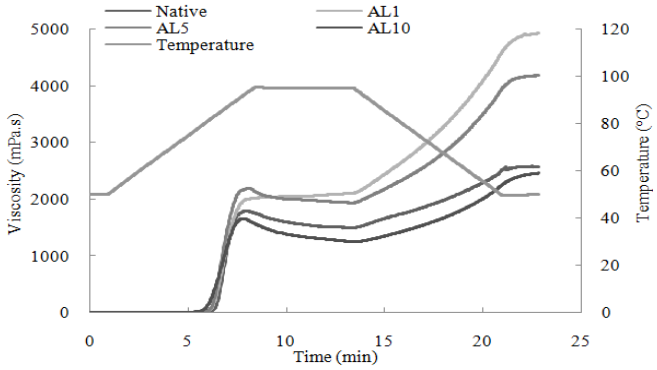

Fig. 4: Viscoamylograms of native and lintnerized yam starches of *Dioscorea alata* (cv. Diamante 22)
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C-O-H bond. 1241, 1371, 1451, 1528, 1638 and 1743 /cm, respectively bands were more pronounced in the lintnerized starches, carbonyl or carboxyl conjugate groups and C-O vibrations can be assigned (Thygesen *et al*., 2003; Nuopponen *et al*., 2006). Smits *et al*. (1988) reported that the band at 1047/cm is related to the ordered region of the starch while the signal at 1022/cm is related to the disordered regions. Based on this and using a reference line drawn between 1060 and 976/cm, the absorbance ratio 1047/1022 was calculated, the result showed an absorbance ratio of 0.963 for the native starch and 0.973 for the starch from sample AL

Table 4: Some physical characteristics and viscoamylograms of suspensions of native and modified starches of *Dioscorea alata* (cv. Diamante 22)

Treatments	CG	Amylose (%)	A	B	C	D	E	F	Syneresis (%)
Native	0.470±0.11	25.56±0.16	82.1	1790	1757	2469	778	289	3.95±0.19
AL1	0.488±0.09	25.53±0.08	80.1	2100	2100	4922	2762	5	3.78±0.09
AL5	0.494±0.15	25.49±0.13	79.6	2183	1933	4177	1961	250	2.76±0.11
AL10	0.512±0.06	24.45±0.23	77.6	1656	1246	2457	748	410	0.00±0.14

A: Gelatinization temperature (°C); B: Máximum viscosity (mPa.s); C: Viscosity to 95°C (mPa.s); D: Final viscosity (mPa.s); E: Setback (mPa.s); F: Breakdown (mPa.s); CG: Crystallinity grade; Prepared by researchers

Table 5: Functional properties of native starch and lintnerized starches of yam of *Dioscorea alata* (cv. Diamante 22)

Treatment	WAC (%)	OAC (g/g)	SI (%)	SP (%)	EC
1	64.379	0.730	0.913	1.757	0.127
2	66.808	0.853	0.720	1.937	0.115
3	81.032	0.815	1.050	1.890	0.197
4	67.289	0.725	0.802	1.787	0.183
5	79.489	0.851	1.031	2.013	0.127
6	85.591	0.895	1.088	2.007	0.064
7	81.229	0.868	0.608	1.965	0.054
8	79.910	0.818	0.674	2.003	0.038
9	87.850	0.933	0.707	2.079	0.201
10	96.096	0.893	0.744	2.293	0.124
Native	106.010	0.743	0.982	2.056	0.146

10. Furthermore, for the short hydrolysis times and the low acid concentrations used in this investigation, a 1.22% increase in absorbency was observed in band while no significant change was seen in absorbency in band 1022. That can be explained by a reordering of the crystalline structure. These findings stand in contrast to those of Sevenou *et al*. (2002), for long times of hydrolysis and higher concentrations of acid.

Crystallinity: Figure 3 shows the X-ray diffraction patterns of native and lintnerized yam starches. The diffractograms of the native and lintnerized starches displayed peaks at angles (2θ) of 5.7; 15.1; 17.2; 22; And 23.9, which corresponded to B-type and A-type X-ray diffraction patterns (Lawal, 2004; Shujun *et al*., 2007b). These starches can be classified as type C., which is a pattern that they retained after lintnerization. The degree of crystallinity of the modified starches was higher than that of the native starch (Table 4) and increased as the modification was extended, with the highest degree occurring for treatment AL 10. It was also possible to observe a reduction in the amylose content and an increase in crystallinity, attributed to preferential hydrolysis of the amorphous region of the starch. Since acid catalysis (lintnerization) is not selective and can indiscriminately attack the amylose, amorphous regions of the amylopectin, which can result in a decrease in the amylose content in lintnerized starches.

Starch behavior during heating and cooling (viscoamilogram): Figure 4 and Table 4 show the results of the viscoamylograms of native starch suspensions and treatments AL1, AL5 and AL10. The starches exhibited a decrease in the initial gelatinization temperature, increased crystallinity and a decrease in the amylose content when subjected to more rigorous lintnerization treatments. This final result stands in contrast to the findings of Varavinit *et al.* (2003) and Otegbayo *et al*. (2013), who found that the presence of amylose reduced the pasting temperature of the crystalline region and the energy needed to initiate gelatinization. The gelatinization temperature is considered a parameter of the crystalline perfection. The gelatinization temperature is considered a parameter of crystalline perfection. One interpretation of this behavior could be that when the polysaccharide chains located in the amorphous granular regions hydrolyze, lintnerization generates relatively enriched preparations in crystalline fractions, which could be linked to the starch diffraction pattern.

The treatments with a higher concentration of acid (AL 10), presented increases in DE values and decreased in the maximum viscosity and final viscosity relative to the native starch. The opposite was true for the starches from treatments with low and medium acid concentrations (AL 1 and AL. 5), due to increased rupturing of the intermolecular hydrogen bridges in the amorphous region. The difference of the viscosity at 50°C with respect to the maximum viscosity is denominated "setback." Treatments AL 1 and AL 5 presented higher setback values than the native starch or treatment AL 10, which indicates a higher tendency to retrograde (Singh *et al*., 2003). This should be taken into account when incorporating this starch into products that need to be chilled. The phenomenon of retrogradation, in this case, is related to the reordering of the hydrogen bonds in the amylose, which is the component of the starch that reaches its crystallization limit in short times. For all of the treatments, the viscosity continued to increase until cooling was completed. Treatments AL1 and AL5 had a better capacity to withstand deformation of the heated paste, which is an important factor in processes in which it is

necessary to maintain the decomposition speed of the viscosity.

Stability to thaw: The treatments with acid presented a significantly lower ($p<0.05$) percentage of syneresis, displaying greater stability to the freeze-thaw cycle than native starch (Table 4). Iheagwara (2013) has reported similar results for lintnerized sweet potato starches; the authors attribute the decrease in syneresis to improved solubility resulting from increased availability of hydrophilic sites. It is also likely that the amylose content influenced the syneresis of the starches under study. The starches underwent structural changes during storage that was mainly facilitated by the interaction between the leached amylose components during the gelatinization process (Otegbayo *et al*., 2013).

Water Adsorption (WAC) and Oil Absorption Capacity (OAC), Solubility Index (SI) and Swelling Power (SP) and Emulsifying Capacity (EC): Table 5 describes the results for WAC, SI, SP and emulsifying capacity. The lintnerization of yam starches had a significant effect ($p<0.05$) on the WAC, OAC and emulsifying capacity, in relation to the concentration and reaction time. However, the factors of reaction time and acid concentration did not significantly influence ($p>0.05$) the behavior of the solubility index. The WAC of the modified yam starches oscillated between 64.38 and 96.10%; these values are similar to those reported by Atichokudomchai *et al*. (2000) for lintnerized yam starches obtained from the *D. alata*, *D. dumetorum* and *D. rotundata* yam species. However, the starches subjected to acid hydrolysis process showed lower WAC than native starches of *D. alata*, *Ipomea batatas*, *Colocasia esculenta* and corn (Falade and Ayetigbo, 2015; Sandhu *et al*., 2007; Mweta *et al*., 2011; Olorunsola *et al*., 2011). This result is probably due to the weakening of the associative forces among the polymeric chains of the granule and the reduction of the amorphous region of the starch granule, leading to low water absorption (Sandhu *et al*., 2007; Lawal, 2004).

The lower WAC of the modified starches relative to native starch is linked to a loss in amorphous material, which is reflected in an increase in the crystalline region, as represented in the infrared analysis of the starches and the increased degree of crystallinity. However, as the rigor of the acid treatment increased, the WAC decreased, which was seen in a decrease in the final viscosity and setback. This behavior can be explained as a result of the rupture of the intermolecular hydrogen bonds of the amorphous zones of the amylose, which produced progressive and irreversible water absorption (Lii *et al*., 1995).

The OAC of the modified starches was between 73.02 and 93.29%, reaching a peak value for the period between 8 and 9 h of reaction time. These results are lower than those reported by Falade and Ayetigbo (2015) in *D. rotundata* and *D. cayenensis* yam starches. The acid hydrolysis process reduced the oil absorption capacity of the modified starches relative to the native starches. This behavior has been observed in hydrolyzed yam starches, lintnerized acha (*Digitariathys exilis*) starches and corn starches (Falade and Ayetigbo, 2015; Lawal *et al*., 2005; Olu-Owolabi *et al*., 2014). This reduction could result from an increase in the crystallinity of the starch, which impedes the access of oil in the starch granules, or from a decrease in the density of the lipophilic groups on the surface of the granules (Olu-Owolabi *et al*., 2014).

The Solubility Index (SI) was not statistically significant ($p>0.05$) for the factors of reaction time and acid concentration. The solubility index of the lintnerized yam starches varied between 0.608 and 1.09 soluble g/sample g. Similar studies have found the same behavior with starches of malanga (*Xanthosoma sagittifolium*), sago (*Metroxylon sagu*), acha (*Digitaria exilis*) and plantain (*Musa paradisiaca* L). These changes are small compared to those resulting from prolonged treatments with acids, where a partial depolymerization of the starch chains occurs, which produces short or oligomeric chains of starch that are soluble during heating (Lawal, 2004; Nasrin and Anal, 2013; Aparicio-Saguilan *et al*., 2015; Olu *et al*., 2014; Abdorreza *et al*., 2012). Aparicio-Saguilan *et al*. (2015) found that the acid hydrolysis process in starches increased the number of hydroxyl groups, leading to increased solubility in water. Sandhu *et al*. (2007) reported a significant increase in the SI in corn varieties treated with hydrochloric acid.

The SP of the starches lintnerized for short reaction times decreased relative to that of the native starches. However, the SP in the lintnerized starches presented a significant increase ($p<0.05$) as a function of reaction time. Abdorreza *et al*. (2012), found that the leaching of the granule constituents increased with the hydrolysis time, particularly with regard to the amylose content, which directly influenced the capacity of the granule to retain water and swell. The swelling power of the modified yam starched oscillated between 1.756 and 2.293. Similar results have been obtained for lintnerized starches of malanga, corn, sweet potato, sago, acha and plantain (Sandhu *et al*., 2007; Lawal, 2004; Olorunsola *et al*., 2011; Aparicio-Saguilan *et al*., 2015; Abdorreza *et al*., 2012). In theory, during acid hydrolysis in starches, linear fractions of hydroxyl groups of low molecular weight increase; these can retain water molecules through hydrogen bonds and the SP should thus increase (Nasrin and Anal, 2013). The structure of the amylopectin plays an essential role in the swelling of the starch granule and the water retention capacity (Tester and Morrison, 1990). Once the structure of the amylopectin is altered, it cannot reconstitute itself in a network and the destroyed chains cannot dissolve and

trap water (Wang and Copeland, 2012). John *et al*. (2002) also reported a decrease in the SP and an increase in the solubility of arrowroot starch, indicating an increase in the proportion of soluble dextrins of short lengths and medium chains after 8 h of hydrolysis with hydrochloric acid.

About to emulsifying capacity, the reaction time and the reagent concentration had a significant effect on the quantity of emulsion formed ($p<0.05$). The emulsifying capacity varied between 3.8 and 20.05%. These values are lower than those reported by Falade and Ayetigbo (2015) in modified starches of diverse yam species produced through hydrolysis with hydrochloric acid. They reported that these differences among species could be caused by the protein content characteristic of each species, which contributed to the emulsifying properties of the starch. The lintnerization process produced an increase in the emulsifying capacity of the modified starches relative to the native starches. Similar results were reported for yam species (*D. rotundata* and *D. cayenensis*) treated with hydrochloric acid for 192 h (Falade and Ayetigbo, 2015). Koksel *et al*. (2008), found a significant increase in the quantity of emulsion formed by linternized corn starches. Hydrolyzed starches can be expected to present a higher capacity to remain in the oil-water interface, thus increasing the stability of the emulsion and decreasing the separation between phases.

CONCLUSION

The lintnerized yam starches of the diamante 22 variety presented low Dextrose Equivalents (D.E. 4.7%), which primarily affected the amorphous part of the granule, resulting in an increase in crystallinity, which reduced the Water Absorption Capacity (WAC) and Swelling Power (SP) relative to the native starch. The opposite occurred when more strong acid hydrolysis was applied. Furthermore, the increase in crystallinity generated greater stability to refrigeration, decreasing starch retrogradation.

The increase in crystallinity affected the stability of the gel, reflecting in a decrease in the final viscosity and setback. These results suggest the possibility of using this starch in food systems or formulations that require the rapid development of viscosity and gel with a stable consistency, such as refrigerated or frozen products or, given their high gelatinization temperature, for canned products and foods resistant to cooking.

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CONFLICT OF INTEREST

There is no "Conflict of interest" of the authors, with the results of the investigation.

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