Use of flour from cormels of *Xanthosoma sagittifolium* (L.) Schott and *Colocasia esculenta* (L.) Schott to develop pastes foods: physico-chemical, functional and nutritional characterization

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Abstract

The corms of cocoyams, specifically *Colocasia esculenta* (L.) Schott and *Xanthosoma sagittifolium* (L.) Schott are usually consumed as pastes. Nevertheless, the secondary corms, also named cormels, are not fully exploited. In this study, the chemical composition and functional properties of cormels from different botanical sources were evaluated, and the digestibility of the resulting pastes investigated. *Colocasia* spp. flour contained significantly higher protein (10.32% vs 9.65%), ash (5.65% vs 5.05%) and oxalates (0.32% vs 0.22%) content, and exhibited lower Amylab gel strength (773 g vs 1040 g) than *Xanthosoma* spp. flour. In the resulting pastes, micrographs revealed that starch gelatinization depended on cocoyam variety. Indeed, the very tight and closed microstructure of pastes containing *Colocasia* spp. flour led them to better stability during storage with lower syneresis. Lower protein digestibility was obtained in *Colocasia* spp. gels (67.56% vs 70.91%), but they showed faster (higher *k*) *in vitro* starch hydrolysis (0.0140 vs 0.0050) with lower estimated glycemic index (61.29 vs 65.84) than *Xanthosoma* spp. gels. The present findings offer ways to develop cocoyam based foods by using cormels, enhancing the applicability of cocoyams.

Key words: cocoyam; cormels; physico-chemical properties; starch; paste; digestibility.

1. Introduction

The consumption of foods containing root crops like edible aroids is quite common in many tropical and sub-tropical countries. Till the last decade, scarce scientific information was available about them, but lately, the increasing knowledge about their nutritional benefits has attracted much expectation. Cocoyams, particularly, *Colocasia esculenta* (L.) Schott (*Colocasia* spp. or taro) and *Xanthosoma sagittifolium* (L.) Schott (*Xanthosoma* spp. or tannia) are subsistence crops in South Pacific Island countries and in the Caribbean and West Africa, respectively (Owusu-Darko, Paterson, & Omenyo, 2014). The underground tubers so-called corms and cormels (secondary corms) can be used as such, although in *Colocasia* spp., corms are the part commonly utilized for human consumption (Njintang, Parker, Moates, Mbofung, Smith & Waldron, 2006), while *Xanthosoma* spp. cormels are eaten after boiling or roasting and its corms are used for vegetative propagation (Owusu-Darko, Paterson, & Omenyo, 2014). Cocoyam tubers contain naturally occurring compounds such as fiber, minerals, vitamins, phenolic compounds, and mucilage (Mwenye, Labuschagne, Herselman, & Benesi, 2011; Ndabikunze, Talwana, Mongi, Issa-Zacharia, Serem, Palapala, et al., 2011). Nutritional benefits, like highly digestible starch with intermediate glycemic index (Simsek & El, 2015) and the reduction of postprandial levels of blood glucose (Handajani, Harini, Yuliningsih, Afianatuzzahra, Hasanah, & Widiyani, 2018) have been reported. Despite the importance of these aroids as emergency crops, their high moisture content (>70%) is responsible for a rapid deterioration after harvest, with the consequent losses (Falade & Okafor, 2015). Because of that, the production of flours from those tubers becomes an attractive alternative for extending storage stability and enhancing applicability ends (Kaushal, Kumar, & Sharma, 2015). Among flour applications reported in the scientific literature, taro flour has been used as a texturizing agent (added up to 4% total weight) in a milk pudding, owing to its thickening properties and nutritional content (Hendek, Atasoy, & Akın, 2019). Flours from *Colocasia* spp.

corms have also been utilized to partially replace (up to 30%) wheat flour in bread doughs, but only 10% replacement could be accomplished without affecting the functionality and viscoelastic properties of the bread dough (Aboubakar, Njintang, Scher, & Mbofung, 2008). Cocoyam flours, being of tuber origin, can be employed for producing gluten-free fermented breads, in fact, flour from *Colocasia* spp. cormels have been used for that purpose obtaining gluten free breads with improved digestibility patterns (Calle, Benavent, & Rosell, 2020). Precooked flours of *Colocasia* spp. corms are used for preparing paste food by reconstitution, although the optimization of the cooking conditions is advisable (Aboubakar, Njintang, Scher, & Mbofung, 2009). This type of precooked flours of *Colocasia* spp. corms has been also useful for preparing weaning foods by blending up to 10% taro flour with variable amounts of *Digitaria exilis* and *Cyperus esculentus* flours (Onuoha, Chibuzo, & Badau, 2014).

Therefore, scientific literature has mainly focused on *Colocasia* genera and the use of corms as edible parts (Kaushal, Kumar, & Sharma, 2015), despite other genera such a *Xanthosoma* might offer alternative flours. In fact, Falade and Okafor (2013) characterized the flours obtained from the corms of five cocoyams (*Xanthosoma* spp. and *Colocasia* spp.) showing the cultivars variability regarding the physico-chemical properties of the flours. Nevertheless, the authors stated that despite morphological differences in the corms between those species, their flour properties resembled those of other roots or tubers crops. Likewise, precooked flours of *Xanthosoma* spp. and *Colocasia* spp. have been studied for producing a traditional food paste in Cameroon (*achu*), confirming the use of *Xanthosoma* spp. for partial replacement of *Colocasia* spp. (Kaushal, Kumar, & Sharma, 2015; Markusse, Marcel, Aboubakar, Nicolas, Joël, and Moses, 2018). In addition, although most studies have been carried out with cocoyam corms, the use of secondary corms or cormels could be an extra commodity for human consumption. Nevertheless, Calle, Benavent-Gil, Garzón, and Rosell (2019) reported significant differences between *Xanthosoma* spp. starches isolated from corms and cormels in terms of granule

morphology, hydration properties, and pasting performance. Because of that, some additional knowledge about cormels flours from both cocoyam species it is necessary to extend their application.

Cormels flours from *Xanthosoma* spp. could have the same use as those from *Colocasia* spp., which are the most extended ones, despite differences in corms and cormels already reported. For this purpose, flours from cormels of *Xanthosoma* spp. and *Colocasia* spp. were characterized regarding their functional and morphological structure. Also, their use in paste food was evaluated assessing the *in vitro* starch and protein digestibility.

2. Material and methods

2.1. Materials

Fresh cormels from *Xanthosoma* spp. MX-2007 and *Colocasia* spp. MC-2012 were collected in the National Institute of Tropical Food Research Farms in Cuba. Flours were obtained as described by Calle, Benavent, and Rosell (2020) and then sieved, collecting the fraction under the 0.300 mm sieve to get homogeneous fractions with similar particle size distributions. Two different batches were performed to obtain flours. All reagents were of analytical grade and used without further purification.

2.2. Chemical composition of flours

Standard methods (AACC, 1999; AOAC, 1990) were applied to determine the compositional analysis of cocoyam flours referred to as moisture (AACCI Method 44–15.02), protein content (AOAC method 992.23), fat content (AACC Method 30–25.01), ash content (AACC Method 08–01.01) and crude fiber content (AOAC Method 973.18). The calcium oxalate content of samples was analyzed following the method described by Kumoro, Putri, Budiyati, Retnowati, and Ratnawati (2014) with slight modifications. Briefly, a mixture of flour (2 g), water (195 mL), and 12 M HCl (5 mL) was heated and digested at 100 °C for 1 h under constant stirring. After cooling, the solution was trimmed up to 250 mL and then filtered (Whatman No.4 filter

paper). The pH of sample portions (125 mL) was increased to 4 - 4.5. with a concentrated NH_4OH solution and then heated at 90 °C, cooled down, and filtered to remove the precipitate containing ferrous ion. The filtrate was heated again at 90 °C and 10 mL of 5 % CaCl_2 solution was added while stirring. Samples were kept overnight at 4 °C and then centrifuges for 6 min at 3000x g. The precipitate was dissolved with 10 mL water/ H_2SO_4 (80/20). The solution was kept at 80-90 °C during its titration with 0.05 M standardized KMnO_4 . The oxalate content was quantified considering that 1 mL of 0.05 M KMnO_4 solution = 0.00225g oxalate. The sample was analyzed in duplicate and data expressed as a percentage of oxalate.

2.3. Particle size distribution and hydration properties

The particle size distribution of the flours was assessed with a Malvern Mastersizer equipment (Model 2000; Malvern Instruments Limited, Worcestershire, U.K.). The refractive and absorption indexes were 1.36. Particle size distribution parameters included volume-weighted mean particle diameter ($D [4,3]$) and $d (0.9)$, $d (0.5)$ and $d (0.1)$, which represent 90%, 50%, and 10% of sample volume with particle size below the size indicated, respectively. The polydispersity index (PDI) was also calculated as:

$$PDI = (d (0.9) - d (0.1))/d (0.5) \quad \text{Eq. 1}$$

The measurement was carried out in three replicates.

Water binding capacity (WBC) and water holding capacity (WHC) were analyzed according to the method described by Calle, Benavent-Gil, Garzón, and Rosell (2019). Results were expressed as grams of water retained per gram of solid.

2.4. Differential scanning calorimetry (DSC)

The thermal properties of *Xanthosoma* spp. and *Colocasia* spp. flours were examined by differential scanning calorimetry using a DSC 7 (Perkin–Elmer Instruments, Norwalk, CT, USA) instrument. Flours were accurately weighed (10 mg) in triplicate into stainless steel pans. Starch gelatinization was studied at 1:3 (w/w) (flour d.m.: water) ratio. Hermetically sealed pans were

equilibrated at room temperature before heating from 30 to 120 °C at 10 °C min⁻¹ under the nitrogen atmosphere. An empty capsule was used as a reference. Thermal transition temperatures and enthalpy were determined.

2.5. *Viscosity force of the flours*

The viscosity of the gels was measured using the Amylab FN device (Villeneuve-la-Garenne, France). Amylab was used in its testogram mode to record the apparent viscosity of flours (Garzon, & Rosell, 2020). Cocoyam flour (7.0 g ± 0.1 g, corrected according to the specific moisture content) and distilled water (25 mL) were agitated for 90 s while heating up to 100 °C. The force required for a stirrer to pass through the gel was recorded, following the 90s Testogram protocol and the parameters evaluated were: Onset₉₀ (time at which the force begins to increase, s) and A1₉₀ (peak force, g).

2.6. *Paste production and characterization*

Preliminary tests were carried out to define the best flour suspension to resemble the common consumption texture of the paste food. The paste was prepared with 87.7% water and 12.3% flour. Formulas were prepared by heating the suspension for 15 min at 100 °C. The resulting pastes were placed in a glass petri plate then cooled at room temperature before analysis. Three replicates were performed for each sample. Paste color was measured with a Minolta colorimeter (Chromameter CR-400/410 Konica Minolta, Japan) using a CIE-*L** *a** *b** scale, after standardization with a white calibration plate (*L**= 96.9, *a**= -0.04, *b**= 1.84). Parameters indicated: *L** lightness, *a** hue on a green (-) to red (+) axis, and *b** hue on a blue (-) to yellow (+) axis. AACC methods 02-31.01 and 02-52.01 were used to analyze the pH and total titratable acidity (TTA) of the gels, respectively.

The viscosity profile was analyzed in duplicate with a Rapid Visco Analyzer (RVA) 4-SA (Newport Scientific, Warriewood, Australia). To this end, flour (3.5 g ± 0.1 g, corrected according to the specific moisture content) and distilled water (25 mL) suspensions were

equilibrated at 50 °C for 1 min under continuous stirring (160 rpm) and then heated to 95 °C. After an isothermal step at 95 °C for 10 min, samples were cooled to 50 °C and held at this temperature for 2 min. Parameters identified from the plots included: peak viscosity (maximum viscosity during heating), final viscosity (after cooling), breakdown viscosity (the difference between peak viscosity and minimum viscosity of hot paste), setback (the difference between cold and minimum hot paste viscosities).

Syneresis of pastes was recorded during 9 days of storage at 4 °C following the method described by Ribotta, Colombo, León, and Añón (2007), with minor modifications. Briefly, pastes (prepared as described previously) (~1.0 g) were placed into Eppendorf tubes while they were hot and stored. Samples were tempered at 25 °C for 2 h, and centrifuge at 3000 x g for 10 min at 25 °C. The free water was separated, weighed, and expressed as percentage of the total water present in the gel. Measurements were the mean of four repetitions for each duplicated gel prepared in different days.

2.7. *Scanning electron microscopy (SEM)*

Morphology of the flours and freeze-dried pastes were observed using a SEM (S-4800, Hitachi, Ibaraki, Japan). Samples were mounted on specimen holders followed by coating with gold in a vacuum evaporator (JEE 400, JEOL, Tokyo, Japan). All micrographs were recorded at an accelerating voltage of 10 kV. The image analysis to assess the granule size and the microstructure analysis of the pastes was carried out using the methodologies described by Benavent-Gil and Rosell (2017a) and Benavent-Gil, Román, Gómez, and Rosell (2019), respectively.

2.8. *In vitro starch digestibility and estimated glycemic index*

Digestibility of pastes was evaluated following the method described by Benavent-Gil and Rosell (2017b). Briefly, 100 mg of sample was suspended in 4 mL of 0.1 M sodium maleate buffer (pH 6.9) containing porcine pancreatic α -amylase (0.2 U/mL) (Type VI-B, ≥ 10 units/mg

solid, Sigma Chemical, St. Louis, USA). Incubation was performed in a shaking water bath at 37 °C for three hours. Aliquots of 200 µL were taken and 200 µL ethanol (96%) were added to stop the enzymatic hydrolysis. Then, the sample was centrifuged for 5 min at 10,000 × g and 4 °C. The pellet was washed with 50% ethanol (200 µL) and supernatants were pooled together and kept at 4 °C for further glucose determination. The results were expressed in the amount of glucose released (mg/100 mg). Glucose was quantified in samples using a glucose oxidase–peroxidase kit (GOPOD, Megazyme, Dublin, Ireland). The absorbance was measured using an Epoch microplate reader (Biotek Instruments, Winooski, USA) at 510 nm. Starch was calculated as glucose (mg) × 0.9. Experimental data were fitted to the equation reported by Goñi, García-Alonso, and Saura-Calixto (1997) equation:

$$C = C_{\infty} (1 - e^{-kt}) \quad \text{Eq. 2}$$

Where C represents the concentration at t time, C_{∞} the equilibrium concentration or maximum hydrolysis extent, k the kinetic constant, and t the time chosen. The estimated glycemic index (eGI) was calculated using the following equation (Goñi et al., 1997):

$$eGI = 39.21 + 0.803HI_{90} \quad \text{Eq. 3}$$

Where HI_{90} was the percentage of starch hydrolyzed at 90 min.

2.9. *In vitro* protein digestibility (IVPD)

In vitro protein digestibility in pastes was determined according to the method described by Espinosa-Ramírez, Garzon, Serna-Saldivar, and Rosell (2018). The percentage of protein digestibility was quantified by using the equation:

$$IVPD (\%) = 210.464 - 18.1x \quad \text{Eq. 4}$$

where x is the change in pH after 10 min (Hsu, Vavak, Satterlee, & Miller, 1977).

2.10. *Statistical analysis*

All experiments were performed at least in triplicate and values were expressed as a mean ± standard deviation. All statistical analyses were conducted using an analysis of variance

(ANOVA) to separate the responses of different flours. Fisher's test was used for the assessment of significant differences among experimental mean values with 95% confidence. Data were computed with Statgraphics Centurion XV software (2020 Statgraphics Technologies, Inc., The Plains, Virginia, US).

3. Results and discussion

3.1. Chemical composition of cocoyam flours

Flours from *Xanthosoma* spp. and *Colocasia* spp. cormels were characterized regarding the chemical composition and functional properties. Moisture content of the flours was 6.78% and 6.56% for *Xanthosoma* spp. and *Colocasia* spp., respectively. There were significant differences in the proximate composition of both flours, specifically *Colocasia* spp. flour had a higher content of proteins and ash (Table 1). This was contrary to the findings of Ndabikunze, et al. (2011), but in line with observations made by Falade and Okafor (2015). Fiber content varied from 3.29 to 4.38%, being higher in *Colocasia* spp. flour. Fiber values were higher than those reported by Markusse et al. (2018). Divergences in composition results might be attributed to variety, growing conditions, maturity at harvest, post-harvest management, and storage (Temesgen & Retta, 2015). As it was expected for a root crop, carbohydrates were the main constituent (Simsek & El, 2015; Temesgen & Retta, 2015). Both flours contained oxalates, with greater content in *Colocasia* spp. flour. This content is of great relevance since its high intake induces adverse health effects (Temesgen & Retta, 2015), and consequently has been considered a limiting factor to use cocoyam flours. However, oxalate is only harmful when raw or unprocessed foods are consumed (Iwuoha & Kalu, 1995).

3.2. Particle size distribution and morphology

The particle size distribution of the cocoyam flours revealed three main peaks corresponding to particles smaller than 70 μm , between 70–630 μm , and higher than 630 μm . The mean particle

diameter ($D [4,3]$) of *Colocasia* spp. flour was larger than that of *Xanthosoma* spp., although no significant differences were detected. However, *Colocasia* spp. flour showed a higher volume of smaller particles ($d (0.9)$). Furthermore, the polydispersity index (PDI), indicative of the particle size dispersion, was significantly lower for *Colocasia* spp. flour, describing a more homogeneous flour. Low PDI is recommended for bulk flowing limiting the surface contact and cohesion between flour particles (Bian, Sittipod, Garg, & Ambrose, 2015). Markusse et al. (2018) described a bimodal granulometric distribution of flours from cooked cocoyam tubers used to prepared paste foods. The authors reported peak sizes between 150–250 μm and 450–550 μm , showing *Xanthosoma* spp. larger particle sizes than *Colocasia* spp., which agrees with the polydispersity found in the present study. The most suitable particle size for traditional paste foods made from reconstituted flours has been reported with a median between 122-143 μm (Njintang et al., 2006). Cocoyam flours in the present study were larger than that value, but considering that *Colocasia* spp. flour has more uniform particle size distribution and lower $d (0.9)$, it might be expected better pasting performance.

Representative SEM micrographs of *Xanthosoma* spp. and *Colocasia* spp. flours are shown in Fig. 1A and B, respectively. Both flours exhibited a very fragmented structure, where starch granules were covered or embedded in a protein-fiber matrix, although *Xanthosoma* spp. flours showed more loose starch granules, likely indicating their fragile attachment to the protein-fiber fragments. For *Xanthosoma* spp. cormels, as it has been reported, two different starch granule populations were observed (Calle, Benavent-Gil, Garzón, & Rosell, 2019). The large granules tend to have truncated shapes and several grooves on the surface, whereas the small granules adopted polygonal shapes (Fig. 1C, E). The average size calculated was 19.5 μm , which agrees with the 20.7 μm reported by Srichuwong, Sunarti, Mishima, Isono, and Hisamatsu (2005). The starch granules in *Colocasia* spp. cormels had polygonal shapes and small size (average size 2.7

μm) (Fig. 1D, F), which was lower than the 5.3 μm reported by Srichuwong, Sunarti, Mishima, Isono, and Hisamatsu (2005), but within the range of reviewed *Colocasia* spp. starches (0.3-10.0 μm) (Moorthy, 2002).

3.3 Hydration properties of cocoyam flours

Hydration properties, including water binding capacity and water holding capacity, were determined for *Xanthosoma* spp. and *Colocasia* spp. flours, to assess the water strongly retained into the flour and water molecules more loosely absorbed by the flour constituents, respectively. The WBC of flours ranged from 1.04 ± 0.05 g H₂O/ g (*Xanthosoma* spp. flour) to 1.75 ± 0.15 g H₂O/ g (*Colocasia* spp. flour), suggesting that better retention of the water could be obtained with *Colocasia* gels. The WHC of flours revealed a similar trend to their corresponding WBC. *Colocasia* spp. flour had a significantly higher WHC, which might be related to the smaller starch granules and in consequence to its larger surface area. In fact, according to de la Hera, Gomez, and Rosell (2013), as particle size becomes smaller, the surface area in contact with water molecules increases, which in turn, increases water intake. Similarly, Markusse et al. (2018) reported higher water absorption capacity for *Colocasia* spp. flour than that for *Xanthosoma* spp., and Perez, Gutierrez, De Delahaye, Tovar, and Lares (2007) reported also a higher water absorption index for *Colocasia* spp. flour than for *Xanthosoma* spp. Therefore, different water hydration properties of both cormels' flours could be directly associated with their dissimilar starch granules size.

3.4. Viscosity force of the cocoyam flours

The Amylab in their testogram mode was applied to both flours to assess the apparent viscosity (Fig. 2). No change was noticeable in the initial part (first 45 s), because starch swelling during gelatinization was not enough to affect the gel strength. *Xanthosoma* spp. flour showed an early

increase in the gel strength and reached a higher gel force compared to *Colocasia* spp. flour. Indeed, parameters recorded from the plots (Table 1), indicated significant differences in the force onset (Onset₉₀) and maximum force (A1₉₀). Therefore, this device allowed discriminating cocoyam flours in a very rapid test. The gel performance of both flours might be related to their composition, since positive correlations were observed among Onset₉₀ and protein ($r = 0.99$, $P < 0.01$), ash ($r = 0.96$, $P < 0.05$) and oxalate ($r = 0.96$, $P < 0.05$) contents, and negative correlations between A1₉₀ with protein ($r = -0.99$, $P < 0.01$), ash ($r = -0.97$, $P < 0.05$) and oxalate ($r = -0.97$, $P < 0.05$) contents. Presumably, the content of protein, minerals, and oxalate delayed the starch gelatinization, likely they could shield the starch granules impeding its swelling and limiting the maximum gel force (A1₉₀).

3.5. Thermal properties

Differential scanning calorimetry was conducted to assess the thermal parameters of the flours (Table 1). Flours exhibited similar melting enthalpy (ΔH) (~16.5 J/g), which agrees with previous reports (Mweta, Labuschagne, Bonnet, Swarts, & Saka, 2010). There was no significant difference in the gelatinization peak temperature (Tp) between both flours, and values were within the range of boiling point previously described for different cocoyam starches by Falade and Okafor (2013). Those high gelatinization temperatures have been related to the resistance of cocoyam starches to swell (Mepba, Eboh, Eko, & Ukpabi, 2009). Flour from *Xanthosoma* spp. cormels had significantly lower transition temperature (T_o) than that from *Colocasia* spp. cormels, and the contrary was observed for the conclusion temperature (T_c). The opposite trend was reported by Perez, Gutierrez, De Delahaye, Tovar, and Lares (2007) when evaluating *Xanthosoma* spp. and *Colocasia* spp. flours. Discrepancies could be ascribed to the use of different tuber part, since authors did not describe if flours were obtained from corms or cormels. Falade and Okafor (2013) described a lower gelling point for *Xanthosoma* spp. starches than that for *Colocasia* spp. starches, which agrees with present DSC results. Likewise, a correlation was

found between T_0 and WBC ($r = 0.98$, $P < 0.05$), WHC ($r = 0.99$, $P < 0.01$), protein ($r = 0.99$, $P < 0.05$) and ash content ($r = 0.98$, $P < 0.05$). Again, correlations between chemical composition and onset temperature of gelatinization agree with the previously mentioned role of protein and minerals shielding the starch granules surface, and impeding water absorption and swelling, which resulted in delayed gelatinization. Meanwhile, a strong negative correlation was found between T_c and WBC ($r = -0.99$, $P < 0.05$), WHC ($r = -0.99$, $P < 0.05$), and protein ($r = -0.99$, $P < 0.05$). Therefore, non-starch constituents of the flour played a marked role in the starch gelatinization, where apart from the protecting effect on the surface of the granules, some water competition could also contribute to retard starch gelatinization.

3.6. Pasting behavior of cocoyam pastes

Pastes were prepared with *Xanthosoma* spp. and *Colocasia* spp. flours using the RVA for recording their apparent viscosity (Table 2), and also some characteristics of the pastes were determined. During heating and cooling, it was readily evident the higher viscosity obtained with *Xanthosoma* spp. vs *Colocasia* spp. Contrary findings were reported by Perez, Gutierrez, De Delahaye, Tovar, and Lares (2007) for pastes made from *Colocasia* spp. and *Xanthosoma* spp. flours. Possibly differences with the present study could be related to the part of the tuber used for preparing those flours because authors did not give details about the use of corms or cormels. In line with the present results, Mepba, Eboh, Eko, and Ukpabi (2009) reported that the same pattern was observed for cocoyam starches isolated from cormels of *Xanthosoma* spp. and *Colocasia* spp. The onset temperature indicated an earlier pasting formation in the case of *Xanthosoma* spp. compared with *Colocasia* spp., which agrees with Amylab and DSC parameters. The onset values obtained were lower than the ones reported for starches (Falade & Okafor, 2013) or flours (Falade & Okafor, 2015) from cocoyam corms, which might be attributed to either the influence of the rest of the constituents in the flour or the intrinsic

differences between corms and cormels (Calle, Benavent-Gil, Garzón, & Rosell, 2019). Although previous studies have used the blue index value to assess starch gelatinization (Aboubakar, Njintang, Scher, & Mbofung, 2009; Amon, Soro, Assemand, Due, & Kouame, 2014), in the present research RVA was employed and gelatinization of the starch was completed within the assay time. The different pasting behavior observed between tested flours can be associated with diverse starch gelatinization of *Xanthosoma* spp. and *Colocasia* spp., since their corresponding starches had exhibited similar divergences (Falade & Okafor, 2013). Nevertheless, the rest of the constituents might also affect the pasting performance because, protein content was negatively correlated with peak and final viscosity ($r = -0.98$, $P < 0.05$ and $r = -0.98$, $P < 0.05$, respectively), in agreement with results obtained in the Amylab. Similar correlations were found with ash and oxalate content. Interestingly, both samples showed similar breakdown values, but *Colocasia* spp. exhibited significantly lower setback, suggesting its lower tendency to retrograde.

3. 7. Physical properties of cocoyam pastes

SEM images, indeed, showed differences between paste structures (Fig. 1G and H). Both gels micrographs showed an aligned structure that could be induced by the mucilage, since hydrocolloids tend to lead that ordered structure (data often observed by authors). The structure of pastes containing *Xanthosoma* spp. flour consisted of big holes with homogeneous distribution and with weak needle-like walls. Conversely, a more compact structure with smaller cavities and dense walls was noticed for pastes containing *Colocasia* spp. flour.

The pH of the resulting pastes did not show significant differences between samples. It was lower than the pH reported for corms flours (Falade & Okafor, 2015), but similar to that reported by Perez, Gutierrez, De Delahaye, Tovar, and Lares (2007). In contrast, the total titratable acidity (TTA) values were lower for pastes containing *Xanthosoma* spp. flour than that found for pastes

containing *Colocasia* spp. flour. Furthermore, significant differences were observed on the pastes color (Table 2). Pastes containing *Colocasia* spp. flour showed significantly higher L^* , a^* and b^* parameters, which might result from its colored pigments that vary within cultivars, affecting also the chemical composition (Aboubakar, Njintang, Scher, & Mbofung, 2008). In fact, in the current study, correlations between L^* values and protein ($r = 0.99$, $P < 0.05$), ash ($r = 0.98$, $P < 0.05$) and oxalate ($r = 0.96$, $P < 0.05$) contents were identified. On the other hand, a^* values were positively correlated with ash ($r = 0.99$, $P < 0.01$) and fat ($r = 0.98$, $P < 0.05$) contents. Correlations that confirmed the impact of the chemical composition on the paste color parameters.

When syneresis of the pastes was evaluated during storage (Fig. 3), no changes were observed in *Colocasia* spp. but a progressive increase in the syneresis was observed in *Xanthosoma* spp. after 48 h storage. Therefore, the lower viscosity of the paste related to the greater protein content led to more compact gels with lower retrogradation and better ability to retain water within its structure. In addition, the very tight microstructure of the *Colocasia* spp. paste might have a significant contribution in retaining the water molecules during the storage.

3.8 *In vitro* digestion of pastes containing cocoyam flours

In vitro protein (Fig. 4A) and starch digestions (Fig. 4B) of formulas containing flours from *Xanthosoma* spp. and *Colocasia* spp. cormels were evaluated. Despite the relatively low protein content of these flours, *in vitro* protein digestibility was determined, since the above results revealed its important role in the techno-functional properties of the pastes. Protein digestibility test showed a faster pH drop in *Xanthosoma* spp. gels leading to higher IVPD ($70.91\% \pm 0.49$) than that obtained for *Colocasia* spp. gels ($67.56\% \pm 1.17$). Considering the pastes microstructure (Fig. 1G), the higher IVPD of *Xanthosoma* spp. could be associated with the more open gel microstructure that could favor the accessibility of proteases to the protein hydrolysis.

To further investigate the starch enzymatic susceptibility, pastes were subjected to *in vitro* digestion and the glycemic index estimated (Fig. 4B). The extent of starch digestion (C_{∞}) was significantly ($P < 0.05$) higher for pastes containing *Xanthosoma* spp. flour ($91.89\% \pm 4.99$) than that found for pastes containing *Colocasia* spp. flour ($38.42\% \pm 0.65$). In contrast to this, the fitting of hydrolysis kinetics showed that the starch digestion rate (k) of *Xanthosoma* spp. pastes was significantly ($P < 0.05$) lower than that for *Colocasia* spp. pastes. Finally, *Xanthosoma* spp. pastes led to the highest *eGI* that went from 65.84 ± 0.30 in pastes containing *Xanthosoma* spp. flour down to 61.29 ± 0.07 in the pastes containing *Colocasia* spp. flour. Simsek and El (2015) reported an estimated glycemic index for boiled *Colocasia* spp. corm, by *in vitro* method, of 90.2 ± 3.6 and 63.1 ± 2.5 using white bread and glucose as references, respectively. Likewise, despite differences in the experimental procedure, Perez, Gutierrez, De Delahaye, Tovar, and Lares (2007) also reported a lower hydrolysis index for *Colocasia* spp. (37.34%) than for *Xanthosoma* spp. (52.99%) after 60 min of *in vitro* amylolysis of the boiled flours, relating the different starch digestibility to their structural characteristics besides possible interactions with other components of the flours. Therefore, regardless of the significant differences found between *Xanthosoma* spp. and *Colocasia* spp. hydrolysis patterns, *eGI* suggested that both pastes would be classified as medium glycemic index ($56 < GI < 69$), foods (Kaye Foster-Powell, 2002).

4. Conclusions

Despite the significant differences in the physico-chemical properties of cocoyam flours from cormels of *Xanthosoma* spp. and *Colocasia* spp., both of them could be used to make paste foods. Particularly, *Xanthosoma* spp. flour had lower protein, ash, and oxalate content. Paste formation from *Xanthosoma* spp. flours occurred at lower temperatures and showed higher viscosity during heating and cooling than pastes from *Colocasia* spp. which was related to the starch granules sizes. Nevertheless, pastes from *Colocasia* spp. showed better stability, as

indicated by the lower syneresis during storage, which was associated with its very tight and closed microstructure. Protein and starch digestibility of the pastes confirmed the suitability of both cormel's flours to produce paste foods with a medium glycemic index. In this sense, the extent of protein and starch digestions (C_{∞}) was significantly higher in pastes containing *Xanthosoma* spp. flour.

Declarations

Funding Authors acknowledge the financial support of the Spanish Ministry of Science, Innovation and Universities (RTI2018-095919-B-C21), and the European Regional Development Fund and Generalitat Valenciana (Project Prometeo 2017/189).

Conflict of Interest The authors declare that they have no conflict of interest.

Availability of data and material Not applicable

Code availability Not applicable

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534

Figure captions

Fig. 1: Scanning electron micrographs of *Xanthosoma* spp. (A, C and E) and *Colocasia* spp. (B, D and F) flours at magnification of x500 (A, B), x1500 (C, D), x3000 (E, F), respectively and gels at magnification of x300 (G and H). Arrows indicated starch granules (A, B, C, D, E, F), weak needle-like walls (G) and dense walls (H).

Fig. 2: Rapid heating-stirring curves of *Xanthosoma* spp. (black solid line) and *Colocasia* spp. (grey solid line) flours using Chopin Amylab.

Fig. 3: Syneresis (%) of the starch gels obtained from *Xanthosoma* spp. (black solid line) and *Colocasia* spp. (grey solid line) flours during 90 hours storage at 4 °C.

Fig. 4: *In vitro* protein (A) and starch (B) digestibility of the *Xanthosoma* spp. (black symbols or line) and *Colocasia* spp. (grey symbols or line) gels.

547 **Table 1:** Proximate composition (g/100 g dry matter bases) and functional properties of
548 *Xanthosoma* spp. and *Colocasia* spp. flours.

Flour properties	<i>Xanthosoma</i> spp.	<i>Colocasia</i> spp.	<i>P</i> -value
<i>Chemical composition</i>			
Starch (%)	51.31 ± 1.56	53.07 ± 2.41	0.5000
Protein (%)	9.65 ± 0.12 b	10.32 ± 0.06 a	0.0194
Ash (%)	5.05 ± 0.07 b	5.65 ± 0.13 a	0.0092
Fat (%)	0.88 ± 0.06	1.03 ± 0.03	0.0815
Crude fiber (%)	3.29 ± 0.01b	4.38 ± 0.23a	0.0004
Oxalate (%)	0.22 ± 0.00 b	0.32 ± 0.03 a	0.0298
<i>Particle size distribution (µm)</i>			
d (0.1)	4.91±0.03	4.86±0.50	0.8711
d (0.5)	30.53±1.41b	117.24±8.62a	0.0001
d (0.9)	439.52±30.53a	359.47±30.69b	0.0328
D [4,3]	147.16±22.90	191.03±33.22	0.1328
PDI	14.23±0.34a	2.90±0.21b	0.0000
<i>Hydration properties</i>			
WBC (g/g)	1.04 ± 0.05b	1.75 ± 0.15a	0.0001
WHC (g/g)	2.16 ± 0.03b	3.43 ± 0.09a	0.0000
<i>Amylab parameters</i>			
Onset ₉₀ (s)	46 ± 1 b	56 ± 0 a	0.0099
A1 ₉₀ (g)	1040 ± 14 a	773 ± 11 b	0.0022
<i>Thermal properties (DSC)</i>			
T _o (°C)	77.46 ± 0.21 b	80.93 ± 0.04 a	0.0019
T _p (°C)	84.78 ± 0.12	85.53 ± 0.24	0.5610
T _c (°C)	93.99 ± 0.30 a	91.02 ± 0.68 b	0.0293
Enthalpy (J/g)	16.54 ± 0.68	16.54 ± 1.01	0.9959

549 Means in the same raw with different letters are significantly different ($P < 0.05$).

550

Table 2: Physical, pasting and nutritional characteristics of pastes obtained from flours of *Xanthosoma* spp. or *Colocasia* spp. cormels.

Paste properties	<i>Xanthosoma</i> spp.	<i>Colocasia</i> spp.	<i>P</i> -value
pH	6.29 ± 0.02	6.31 ± 0.01	0.3333
TTA (ml NaOH/ 10 g gel)	2.00 ± 0.00 a	1.51 ± 0.01 b	0.0001
Color			
<i>L</i> *	49.05 ± 0.28 a	52.30 ± 0.09 b	0.0000
<i>a</i> *	1.87 ± 0.03 a	1.98 ± 0.03 b	0.0005
<i>b</i> *	7.91 ± 0.14 a	11.16 ± 0.07 b	0.0000
Pasting properties (RVA)			
Onset temperature (°C)	79.85 ± 0.00 a	82.35 ± 0.00 b	0.0000
Peak viscosity (cP)	1763 ± 10 b	1161 ± 12 a	0.0003
Trough (cP)	1691 ± 13 b	1084 ± 11 a	0.0004
Breakdown (cP)	73 ± 4	93 ± 12	0.1526
Final viscosity (cP)	2701 ± 19 b	1628 ± 1 a	0.0002
Setback (cP)	1010 ± 6 b	560 ± 1 a	0.0001
Protein and starch digestibility			
IVPD (%)	70.91±0.49b	67.56±1.17a	0.0102
<i>k</i>	0.0050±0.0003a	0.0140±0.0006b	0.0024
<i>C</i> _∞ (%)	91.89 ± 4.99a	38.42±0.65b	0.0033
<i>eGI</i>	65.84±0.30b	61.29±0.07a	0.0000

Each row represents the analyzed parameters and the column represents the samples. Different letters within the same row indicate significant differences ($P < 0.05$).

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A.

B.