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Effect of Physicochemical Non-thermal Acidic and Alkaline Modifications on the Structural, Vibrational, Pasting, Rheological, and Functional Properties of Achira (*Canna indica* L.) Isolated Starch

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Abstract

This study investigates the effects of non-thermal acidic (CH_3COOH) and alkaline ($Ca(OH)_2$) modifications on the structural, vibrational, pasting, rheological, and functional properties of isolated achira (*Canna indica* L.) starch. Treatments were conducted at different concentrations (5%, 10%, 20% for acid; 0.15%, 0.20%, 0.30% for alkali) and analyzed by SEM, XRD, DSC, FTIR, and rheological measurements. The results showed that the alkali treatment significantly increased the amylose content (20.20%) due to amylopectin hydrolysis, while the acidic treatment had minimal effects (5.68%). SEM images showed surface damage at high acid concentrations but no visible changes with alkali treatment. XRD confirmed the preservation of nanocrystals with a hexagonal (B-type) structure in all samples. DSC thermograms showed gelatinization temperatures around 72.51°C, with enthalpy changes suggesting structural alterations. Alkali-treated starches showed improved water absorption (WAI) and swelling power (SP), while acidic-treated samples showed higher solubility (WSI). Pasting profiles showed lower viscosity in alkali-treated starches and hydrogel-like behavior in acid-treated samples. These results highlight the potential of non-thermal modifications to tailor the properties of achira starch for food and industrial applications and offer energy-efficient alternatives to conventional methods.

Keywords

Achira; Acidic treatment; Alkaline treatment; Nonthermal process; Nanocrystals

1. Introduction

Pre-gelatinization techniques are the most commonly used approach to obtain modified starches, regardless of their source. Physical starch modification by novel non-thermal methods is an innovative technique that enables the production of environmentally friendly starch, often referred to as green technology. Chemical modification below the gelatinization temperature (non-thermal methods) can offer advantages such as lower energy consumption. Such non-thermal modifications prevent complete gelatinization, preserving the crystalline structure and granular integrity. This allows the retention of functional properties such as swelling capacity and controlled solubility, which are beneficial for applications where a partially intact starch structure is advantageous, such as encapsulation [1]. In this direction, Alonso-Gómez et al. [2] analyzed the effects of non-thermal acid and alkali modification on the physicochemical properties of isolated cassava starch. This work has shown that non-thermal chemical treatments lead to acetylation in the case of acid treatment, and to cross-linking in the case of alkali treatment, at a certain Ca^{2+} concentration without altering the surface of the starch granules.

Achira is widely known under two scientific names. Linneo classified it in 1753 as *Canna indica* L., and Ker Gawler in 1824 as its synonym *Canna edulis* Ker Gawl [3]. Achira has historically had a large number of synonyms, namely 165 names, so its historical succession can be confusing [4]. In English it is known as Queensland, in Portuguese as Biri, and in French as Balisier.

Achira is a perennial plant that originated in the Andes and is traditionally cultivated in South America. Its cultivation has spread to Asia, particularly to China, Vietnam, Taiwan, and Thailand. The plant belongs to the botanical family Cannaceae and the genus *Canna*. Achira is sometimes confused with sagú, but the real sagú bread comes from *Maranta arundinacea* and *Maranta ruiziana* [4].

The yield of the achira plant varies between 15 and 40 tons of raw material with a starch content of 10 to 17% [5], which makes it an attractive raw material for baked goods and for thick noodles, sauces, condiments, and soups. Achira has industrial application potential; its rhizomes are an interesting raw material for starch production. Starch consists mainly of two macromolecules: amylose and amylopectin. Recently, the granules have been referred to as microparticles, which, in addition to these two macromolecules, also contain Ca, K, and P, among others [6]. All these ions interact under heating conditions and lead to interesting changes in the viscoelastic forces of the gels formed. In addition, the technical and functional properties of the starch products depend on the amylose-amylopectin ratio [7] and the intrinsic mineral content inside the granules [8].

Industrial use requires technical properties that differ from the natural properties of starch. These changes can be achieved by the addition of chemicals [9] because the mechanical properties of hydrogels produced from starch are determined by van der Waals interactions. These modifications also result in a higher alkali number and increased susceptibility to enzymes such as amylase [10]. According to the literature, the native starch of some rhizomes and tubers has a high content of minerals such as K, Ca, Na, and P, which influence their physicochemical properties. For example, it was found that the addition of Ca2+ ions to jicama starch increased the gelatinization and pasting temperature to higher values and led to a decrease in the peak and final viscosity of the samples, which behaved like hydrogels [8]. According to Kainuma et al. [11], starch can be categorized into three different types depending on its amylose content: starch (18-30% amylose), waxy starch (about 1%), and high amylose starch (about 70%).

Other studies have used acetic acid to modify cassava starch. This type of modification is referred to as acetylation. Thus, acid treatment resulted in a loss of pasting, a decrease in swelling power, an increase in solubility, an increase in $\triangle H$ value, an increase in gelatinization temperature, and a decrease in the tendency to retrograde [2]. Khurshida et al. [12] confirm that swelling decreases with acetylated starches, while solubility increases, and that the viscosity of the paste is significantly lower compared to native cassava starch. In a study on cassava starch films containing acetic acid, the analysis shows that the crystalline index of the films is reduced by the acid treatment [13]. This study contradicts the study by Beninca et al. [14], which states that acid treatments (HCl or acetic acid) at low concentrations can change the polymorphism of the starch from C- to A-type and increase the crystallinity fraction.

The most studied starches used in industry today are cereal starches [15]. Therefore, unconventional starch sources and their properties need to be studied in order to achieve concrete profitability on an industrial scale [16].

According to the results of Fonseca-Florido et al. [17], Achira starch contains about 31% amylose, its granules have a spherical, oval, or elliptical shape and a size of 26 to 67 μm, which is related to their swelling capacity and the amount of water they can absorb [18].

Yaruro-Cáceres et al. [19] evaluated the physicochemical, thermal, and microstructural properties of the starch of four Colombian ecotypes of achira (*Canna edulis* sp.). For achira starch, an oval morphology with a smooth surface was observed. The swelling capacity of achira starch increased from 70 °C, reaching a swelling capacity of 39.75% at 90 °C, as well as the reported gelatinization temperature of 70.95 °C. Recently, achira starch has been modified with octenyl succinic anhydride (OSA) to produce thermoplastic thin films [20]. These authors also

classified the X-ray structure of this starch as B-type. However, they did not index the crystal structure and did not investigate the mineral content.

Regarding the granule size of native starch from achira, a particle size distribution of 24.40 to 102.53 μm was reported [21], showing the large difference between starch types depending on the source, variety, and ecotype of the raw materials from which the starch is extracted. The reported particle size values are 38.6 μm (average diameter) for commercial Colombian achira starch and 47.2 μm (average diameter) for isolated Brazilian starches from rhizomes grown in Brazil. The Colombian and Brazilian starches were classified as crystalline B-type structure [22].

From a crystallographic point of view, the B-type is a classification for starches containing nanocrystals with a hexagonal crystal structure [23]. Therefore, the detailed crystal structure remains unindexed, and further investigation of the mineral content and physicochemical properties is necessary to open up new application possibilities.

Recently, a new approach to the modification of starch has been investigated. Much of the research deals with heat treatments near or above the gelatinization temperature, but Alonso-Gómez et al. [2] proposed reducing energy costs by modifications at low temperatures. Based on this research, it can be hypothesized that achira starch can be modified by the addition of calcium ions from $Ca(OH)_2$ and CH_3COOH

Therefore, the aim of this work was to investigate the chemical and physical properties of isolated achira starch and the effects of the addition of calcium ions from Ca $(OH)_2$ and the addition of CH_3COOH on the starch at low temperatures through a complete investigation of the changes in its rheological, thermal, structural, and mechanical properties.

The results of this study will allow food manufacturers to change the properties of achira starch through physical and/or chemical modifications. These changes in physico-chemical properties will therefore make it possible to add value to the starch and expand its competitive opportunities in the food and non-food markets.

2. Materials and Methods

The whole achira plant, its flower, and rhizomes of *Canna indica* L. are shown in Figure 1a, b, and c, respectively. The achira rhizomes were kindly donated by a "rallandería" in Granada, Meta, Colombia. The achira was harvested in April 2022 and processed immediately.

2.1 Achira starch isolation

Achira starch was isolated using a wet milling method proposed by Alonso-Gomez et al. [24]. As shown in Figure 1d, the achira rhizomes were peeled, washed, crushed, and mixed with cold distilled water. The slurry was drained through a 20-mesh sieve, and the resulting suspension was refrigerated at 4°C for 24 hours until the starch had precipitated. This process was repeated 5 times. The supernatant was then decanted, and the precipitate was washed thoroughly with distilled water to remove the soluble fibers and other unwanted compounds. The isolated starch was then dried for 8 hours at 40 ± 5°C in an oven (MMM, ecocell 222, H202080, Planegg, Munich, Germany). Finally, the dried starch was ground using a knife mill (Gyratory mill SR200 Gusseisen, Redsch GmbH, Germany) and sieved through a USA standard mesh size of 100 (147 μm).

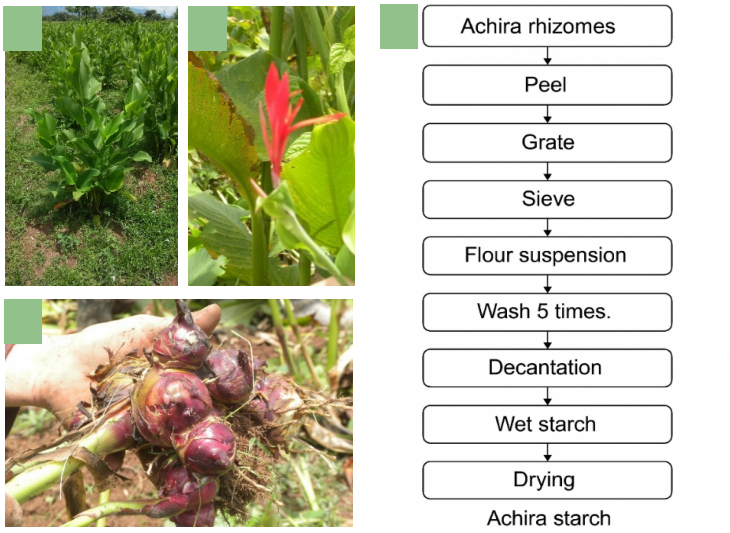


Figure 1. The whole achira plant (a), flower (b), rhizomes (c) of *Canna indica* L., and the block diagram of the process used to obtain achira starch (d).

2.2 Addition of CH3COOH and Ca (OH)2

The isolated achira starch was modified according to the method proposed by Contreras-Jiménez et al. [8] and Alonso-Gomez et al. [2]. A sample of 20 g of dry-based achira starch was added to 100 mL of a solution containing 5, 10, and 20% v/v (CH_3COOH) (0.87, 1.73, and 3.46 N, respectively). Solutions containing 0.15, 0.20, and 0.30% w/w Ca $(OH)_2$ (0.04, 0.05, and 0.08 N, respectively) were added in the same way. These treatments were applied to evaluate the effects on the physicochemical, pasting, rheological, and functional properties of achira starch. The samples were shaken every 1 hour for 24 hours, and the temperature was maintained at 4 °C to prevent microorganisms from affecting the experimental conditions. After the 24-hour modification of the starch, the samples were dried at 40 °C in forced air to constant weight.

2.3 Starch characterization

2.3.1 Morphological analysis by scanning electron microscopy (SEM)

Samples of isolated achira starch and modified achira starch obtained by acidic and basic treatments at different concentrations were analyzed using a high vacuum scanning electron microscope (JEOL, JSM-6060LV, Tokyo, Japan) with a resolution between 1000× and 5000× in HV mode and under measurement conditions operating at an electron accelerating voltage of 20 kV and a high vacuum (HV) mode with a pressure of 12-20 Pa. The samples were mounted on a bronze holder using carbon tape.

2.3.2 Water absorption index (WAI), Swelling power (SP), and water solubility index (WSI)

The water absorption index (WAI), swelling power (SP), and water solubility index (WSI) of the isolated achira starch and the modified acidic and alkali starches were determined according to the method described by Khurshida et al. [12] with a slight modification. A 0.4 g starch sample was mixed with 20 mL of distilled water. The sample mixture was kept in a hot water bath at a temperature of 90 °C for 30 minutes. Then, the samples were cooled to room temperature and centrifuged at 1500×g for 15 minutes. The supernatant was collected, and the swollen starch sediment was weighed to determine the indices according to the following equations (4), (5), and (6):

$$WAI = \frac{(\text{sediment weight})}{(\text{dry starch weigth})} \tag{4}$$

$$SP\ \left(\frac{g}{g}\right) = \frac{(\text{sediment weight})}{(\text{dry starch weight} - \text{dry supernatant weight})} \tag{5}$$

$$WSI\ (\%) = \frac{(\text{dried supernatant weight})}{(\text{dry starch weight})} \times 100 \tag{6}$$

2.3.3 Thermal properties of starch

Samples of isolated achira starch and modified achira starches were analyzed by differential scanning calorimetry (DSC) by treating them with acidic (5, 10, and 20% v/v) and basic (0.15, 0.20, and 0.30% v/v) solutions; these analyses were measured with a calorimeter (model DSC 1-Star System weighing, Mettler Toledo, Greifensee, Switzerland). A 10 mg sample was weighed and mixed with distilled water (1:6). The dish with the sample was heated from 30 to 100 °C at a heating rate of 5 °C/min.

2.3.4 Crystal identification by X-ray diffraction

The crystal structure of the isolated achira starch and acidic and alkali-modified starches was analyzed using a Rigaku-Ultima IV diffractometer (Rigaku, Tokyo, Japan) at 35 kV, 15 mA, and a CuK_α radiation wavelength of λ = 0.1540 nm. High-resolution measurements were performed from 5 to 35° on the 2θ scale with a step size of 0.01°. The X-ray patterns were indexed according to the methodology proposed by Rodriguez-Garcia et al. [25].

2.3.5 Vibrational analysis

The main functional groups of isolated achira starch and modified achira starches were analyzed by Fourier transform infrared (FTIR) spectroscopy in the wavenumber range from 600 to 4000 cm-1. Carbohydrate absorption spectra can be characterized by analyzing the bonds of D-glucose monomers and their linkages in amylose (α-1,4) and amylopectin (α-1,6) [26]. An IR spectrophotometer (Model Spectrum Two, Perkin Elmer, Waltham, MA, USA) was used for these measurements.

2.3.6 Pasting profiles

Isolated achira starch as well as acidic and alkali-modified starches were analyzed with an MCR-102 rheometer (Anton Paar, Graz, Austria) to determine the pasting profiles. The samples were prepared according to the methodology proposed by Rincón-Londoño et al. [7]. First, for each sample, the temperature of the system was set to 50 °C for 1 minute and then heated from 50 to 90 °C for 5.3 minutes. The sample was then cooled to 50 °C for 5.3 minutes, and finally, this temperature was maintained for 1 minute.

2.4 Statistical analysis

The tests were performed in triplicate, and data are presented as mean ± standard deviation. An analysis of variance (ANOVA) was performed, with a *p*-value of less than 0.05. The mean values were compared using Fisher's test. The ANOVA and the Fisher test were performed with the statistical program Minitab 18 Statistical software (Minitab Inc., State College, PA, USA).

3. Results and Discussion

3.1 Amylose content

Figure 2a shows the amylose content of isolated achira starch (IAS) compared to the acidic treatments IAS-A5, IAS-A10, and IAS-A20 and the alkali treatments IAS-B0.15, IAS-B0.20, and IAS-B0.30. The acidic treatment showed no significant changes ($p > 0.05$), whereas the alkaline treatment resulted in a significant increase ($p < 0.05$). The acidic treatment resulted in an increase of only 5.68%, while the alkali treatment showed an increase of 20.20%. This change can be attributed to a possible hydrolysis, in which the amylopectin chain is broken down into the amylose chain.

Wang and Copeland [27] studied pea starch treated with Na $(OH)_2$ for 15 and 30 days and found that the amylose content decreased by 20-25%. These authors suggest that this is due to the amylose leaching from the granules, but the surface of the pea granules shows no evidence of damage.

Figures 2b, c, and d show the changes in WAI, WSI, and SP for IAS with acidic and alkali treatment. The untreated IAS had a WAI of 1.99%, indicating a moderate water absorption capacity. With acidic treatment, the WAI increased slightly at lower acid concentrations (2.01% for IAS-A5 and 2.04% for IAS-A10), indicating minor structural changes that improve water retention. However, at higher acid concentrations (IAS-A20), WAI decreased to 1.9%, probably due to excessive degradation of starch granules, which impairs their ability to absorb water. In contrast, the alkali treatment had a more pronounced effect. WAI gradually increased, reaching a maximum value of 2.29% at IAS-B0.20, indicating that a moderate alkali concentration significantly improved water absorption, possibly by loosening the structure of the starch granules. Higher alkali concentrations (IAS-B0.30) slightly decreased WAI (2.14%), indicating an optimum treatment level for maximum absorption.

The untreated IAS had a low WSI (0.74%), typical of native starch with limited solubility. Acidic treatment significantly increased solubility, especially for IAS-A5 (2.19%), which may be attributed to hydrolysis of starch polymers into smaller, more soluble fragments. However, at higher acid concentrations (IAS-A10 and IAS-A20), the WSI fluctuated (1.26% and 1.89%, respectively), indicating different degradation effects. Alkali treatment also increased solubility, but to a lesser extent, with WSI ranging from 1.09% (IAS-B0.15) to 1.83% (IAS-B0.30). The highest value in this group (1.76% for IAS-B0.20) indicates that alkali modifies starch solubility without causing the extreme breakdown seen in acidic-treated starches.

The IAS sample had an SP of 2.09%, indicating moderate swelling of the starch granules. Acidic-treated starches showed a slight increase (2.11-2.13%) at lower concentrations, probably due to a slight structural weakening that facilitates water absorption. However, at higher acid concentrations (IAS-A20), the SP dropped to 2.02%, indicating excessive degradation. Alkali treatment consistently increased SP, with the most significant increase observed at IAS-B0.20 (2.44%), consistent with the high WAI. suggests that alkali treatment effectively disrupts starch granules and improves their swelling capacity. Even at higher alkali concentrations (IAS-B0.30), SP remained elevated (2.24%), emphasizing the effectiveness of alkali in improving swelling properties. The alkali treatment, especially at a concentration of 0.20%, is optimal for improving water absorption and swelling, while the acidic treatment is more effective for improving solubility.

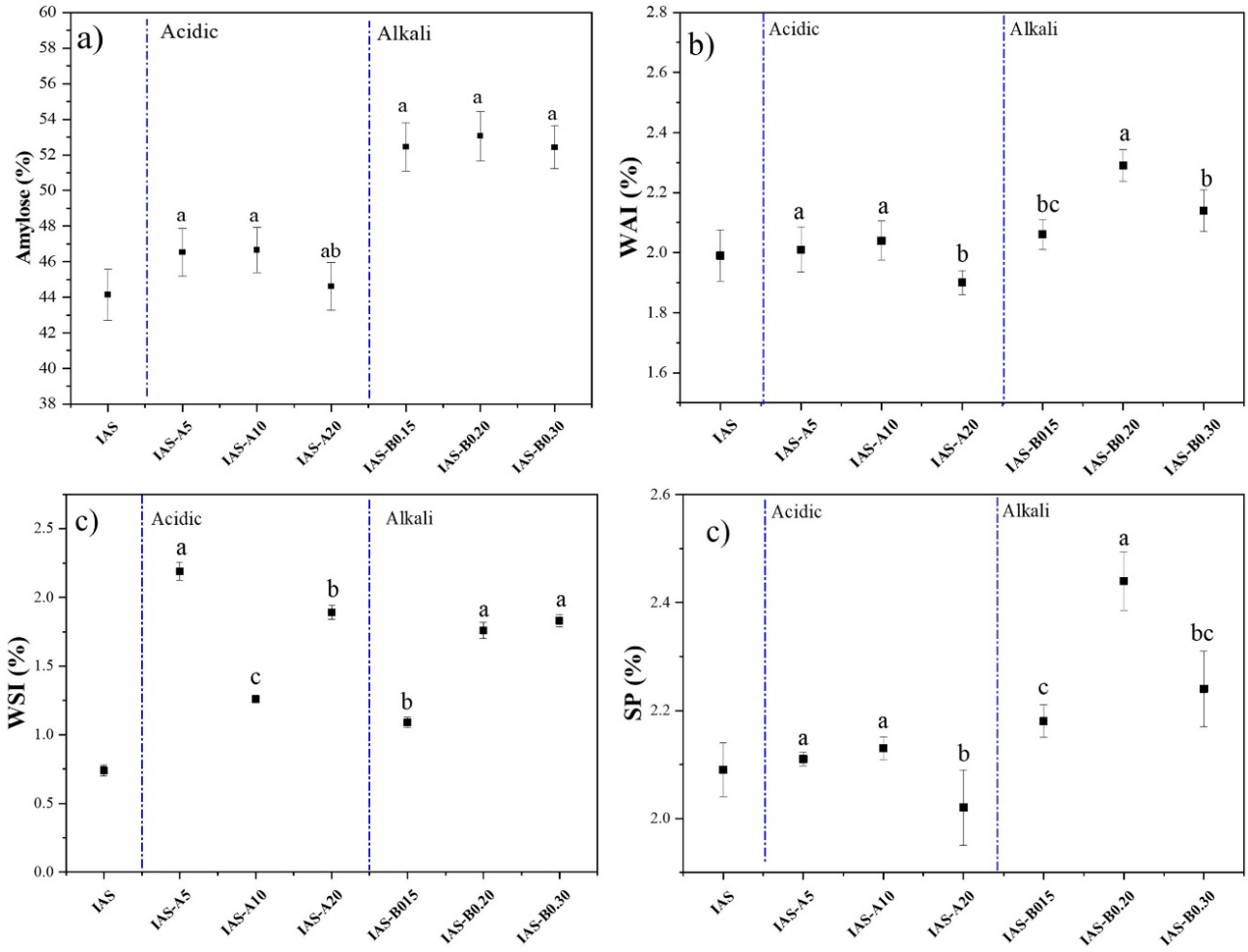


Figure 2. Amylose content (a) and functional properties of achira starch and acidic and alkali-modified achira starch. (b) Water absorption index (WAI), (c) water solubility index (WSI), and (d) swelling power (SP) of isolated achira starch (IAS). Acidic treatment IAS-A5, IAS-A10, and IAS-A20 and alkali treatment IAS-B0.15, IAS-B0.20, and IAS-B0.30.

3.2 Morphological analysis

3.2.1 Alkali treatment

Figure 3a and b show the SEM images of the isolated achira starch, taken at 700× and 2000×. Semispherical, ellipsoidal, and irregular granules were identified. The average length of the granules is 54.34 ± 17.28 µm, and the width is 34.93 ± 11.04 µm. The average granule size reported by Castillo-Paz et al. [21] for achira was 45.4 µm, with oval to elliptical morphology and a smooth surface. Figure 3c and d show (0.10%) the SEM images of achira starch treated with alkali (0.10, 0.15, and 0.30%).

Figure 3e and f show the SEM images of IAS-B0.20, and Figure 2g and h show the SEM images of IAS-B0.30. As you can see, the alkali treatment at this concentration and stepping time (24 hours) does not lead to any change in the starch surface. However, this does not necessarily indicate that Ca^{2+} ions do not induce internal changes in starch components and thus no changes in the other physicochemical properties. Alonso-Gómez et al. [2] found the same results for non-thermal alkali treatment of isolated cassava starch. This means that it is necessary to investigate the changes in the starch components: Amylose, amylopectin, proteins, fat, and nanocrystals with a hexagonal crystal structure, which can be studied by IR spectroscopy. The alkali treatment could influence the hydrolysis of amylose and amylopectin.

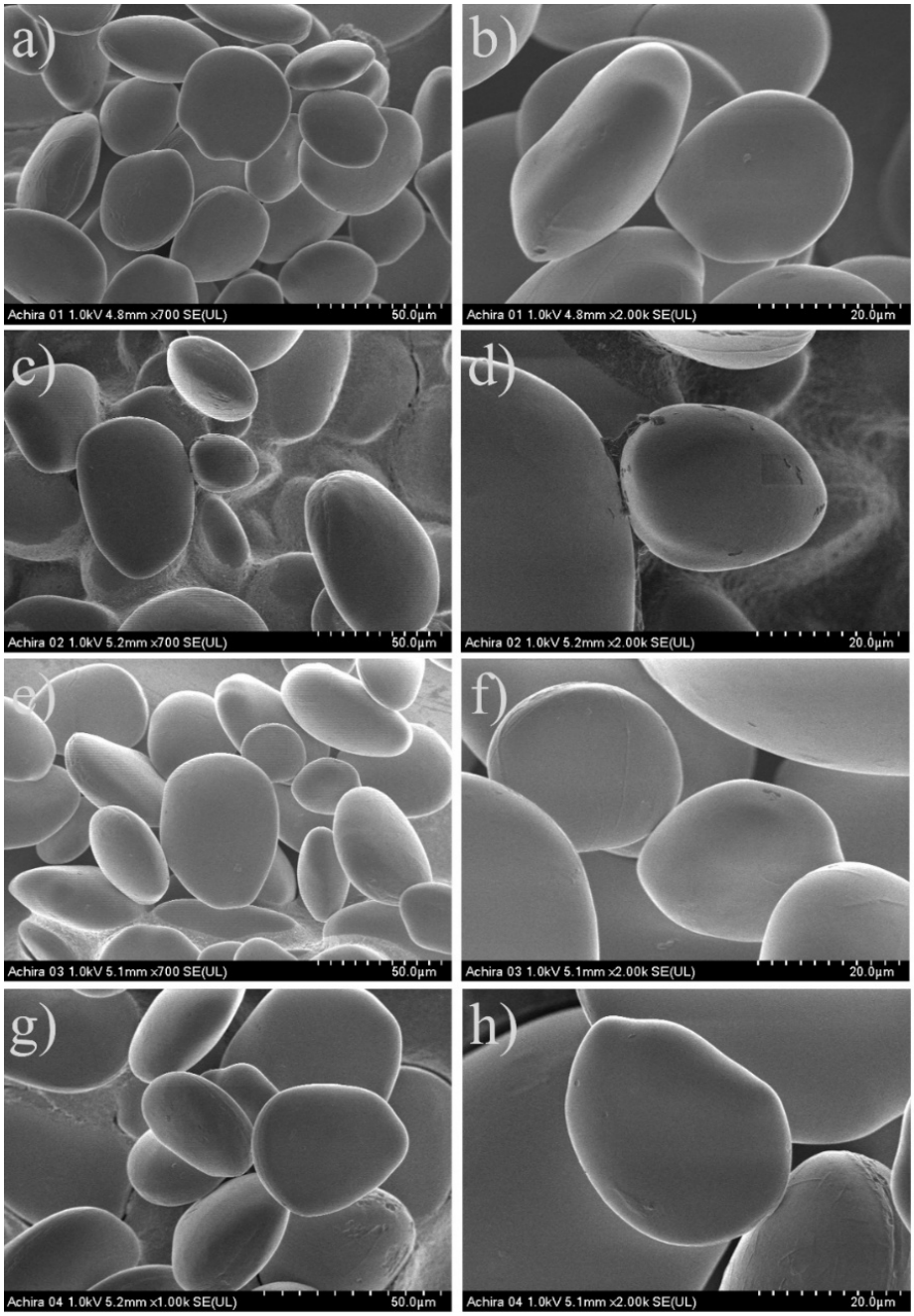


Figure 3. SEM images of isolated achira starch and alkali-treated achira starch (a to h).

3.2.2 Acid treatment

Figure 4a and b show the SEM images of isolated achira starch (IAS) with acidic treatment (IAS-A5), taken at 1000× and 2000×. Semispherical, ellipsoidal, and irregular granules were identified. This treatment has no effect on the surface of achira granules. However, the acidic treatment leads to the formation of micrometric particles, which could be protein accumulation.

Figure 4c and d show the SEM images of isolated achira starch (IAS-A10) with acidic treatment. The surface was not damaged, but some uncharacterized particles were observed. Figure 4e and f show the SEM images of isolated achira starch (IAS-A20) with acidic treatment. At this acid concentration, the surface damage of some starch granules is obvious, which may have been caused by the hydrolysis of proteins and fats. The origin of these particles remains unclear and requires detailed EDS analysis.

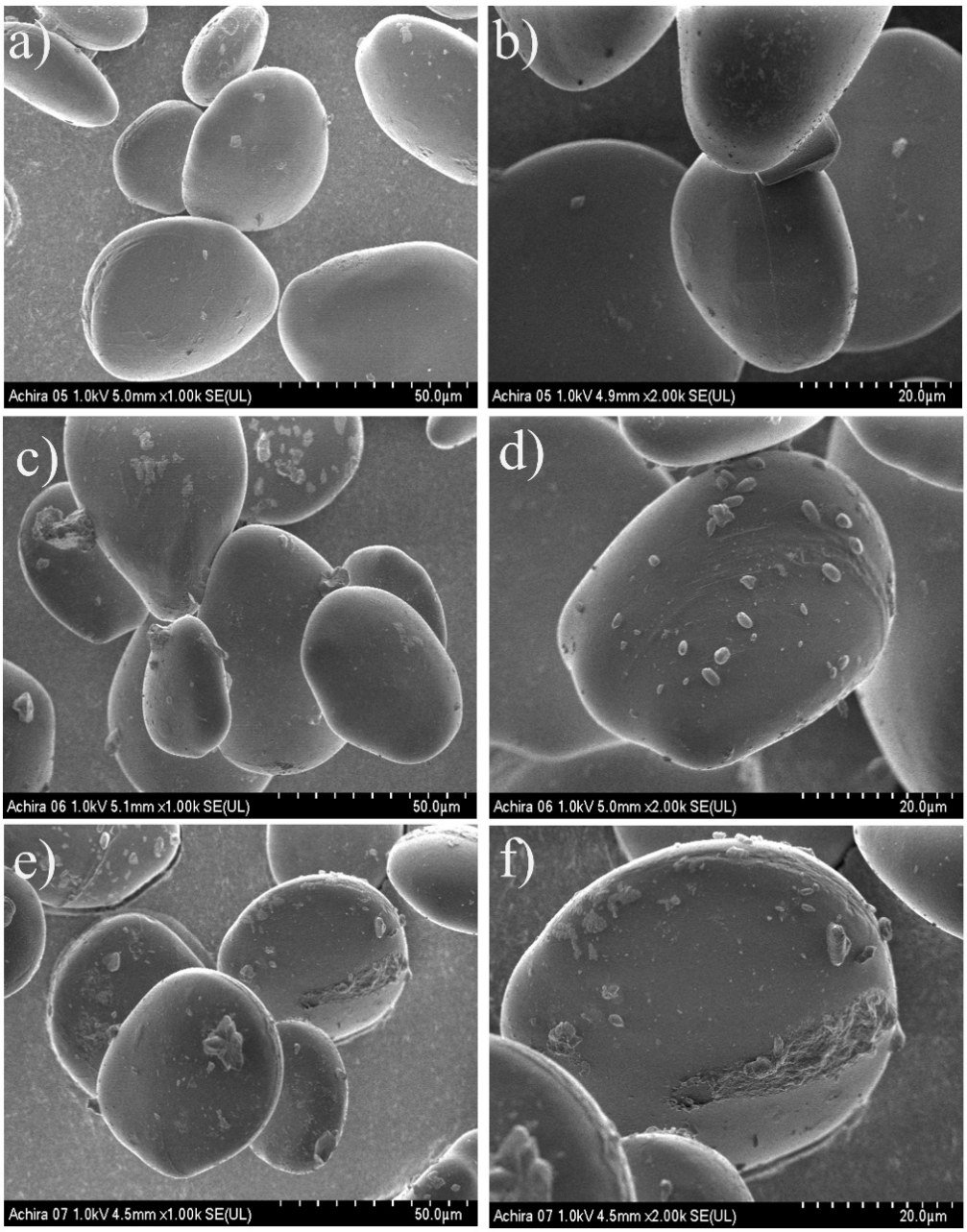


Figure 4. SEM images of isolated achira starch and acidic-treated achira starch (a to f).

3.2.3 Structural properties

Figure 5a shows the X-ray diffraction patterns of isolated starch that has undergone alkaline treatment. These patterns are characterized by the presence of broad diffraction peaks, which are usually attributed to the presence of semi-crystalline structures in the starch. However, this broadening has been attributed to the presence of nanocrystals with a hexagonal crystal structure, resulting from elastic and inelastic X-ray scattering [6]. Nanocrystals of achira were isolated from starch granules by acid hydrolysis to remove the polymer chains, confirming the above statement [21]. The TEM analysis reported by them clearly shows that the nanocrystals isolated from achira starch have a hexagonal crystal structure. The dashed line in Figure 5a shows the identification of nanocrystals with a hexagonal crystal structure, so the achira starch can be classified as B-Type. The X-ray patterns show changes as a function of acid concentration for the IAS-B0.30 sample. Figure 5b shows the X-ray patterns of isolated starch that has undergone acid treatment. The patterns are broad, as in the alkaline treatment, which is due to the presence of

nanocrystals. The acid treatment does not lead to a change in the crystal structure, and the X-ray diffraction patterns show the presence of nanocrystals with a hexagonal crystal structure.

Figure 5c shows the changes in the quality of crystallinity, crystallinity index, determined by the ratio of two diffraction peaks, in this case, $I_{(131)}/I_{(121)}$ [23]. The reason for using this method is that X-ray patterns are usually obtained using the X-ray powder technique, which assumes that the powder is isotropic and has no internal structure. However, starches are known to have an internal structure consisting of nanometric rings containing nanocrystals with a hexagonal and/or orthorhombic crystal structure. This fact indicates destructive interferences, so the X-ray pattern of whole grains is not the best technique to determine the crystalline quality of starches. Non-thermal alkaline and acidic treatments do not lead to a change in the crystal structure of the nanocrystals with a hexagonal crystal structure. This result is interesting because, according to Rojas-Molina et al. [23], resistant starch type 2 (RS_2) is formed in this case by the nanocrystals with a hexagonal crystal structure. The determination of their concentration is still an open problem due to the standardization of the technique.

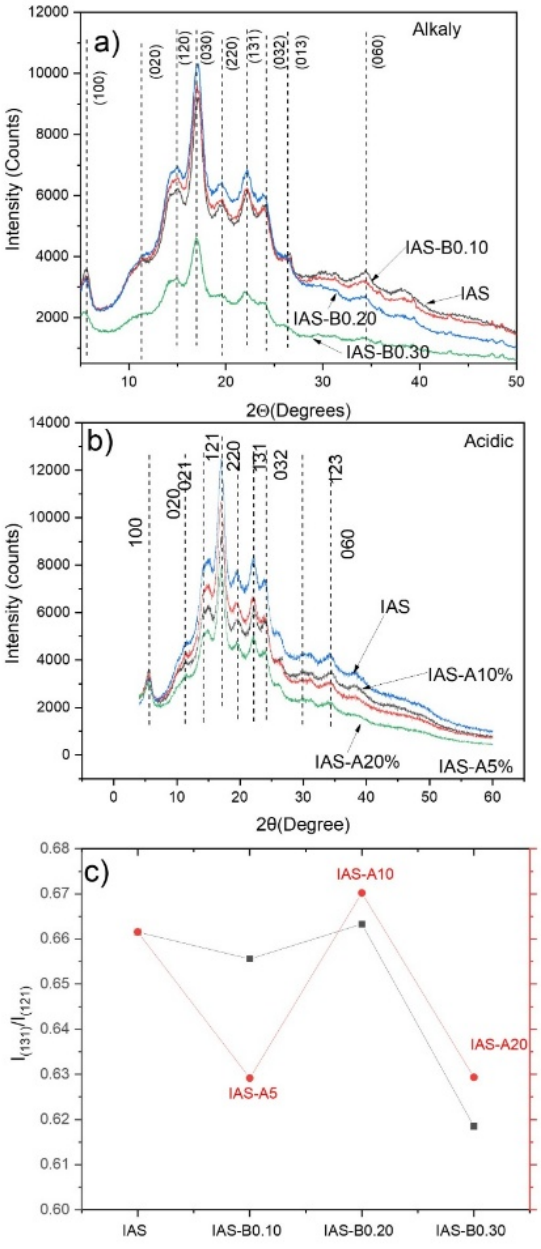


Figure 5. (a) X-ray diffraction patterns of IAS, IAS-B0.15, IAS-B0.20, and IAS-B0.30, (b) IAS-A5, IAS-A10, and IAS-A30, and (c) the changes in relative crystallinity.

3.2.4 Thermal properties

Figure 6a shows the DSC thermogram of the starch/water suspension for the isolated achira starch and the isolated achira starch with alkaline treatment. The isolated starch shows an endothermic event at 72.51°C. When the non-thermal alkaline process is performed, this endothermic peak shifts slightly to the right. Since these starches were isolated, no additional thermal transitions were observed. As mentioned above, starch is composed of amylose, amylopectin, fat, proteins, water, ions, etc., and in the case of achira starch, also nanocrystals with a hexagonal crystal structure [26], and all components play an important role in gelatinization. In this case, the explanation for the first endothermic peak is that the nanocrystals may undergo structural disruption in excess water upon heating. This endothermic transition thus corresponds to gelatinization, which is partly associated with the solvation of the nanocrystals with a hexagonal crystal structure. This means that the samples contain nanocrystals with a hexagonal crystal structure (ordered) before T_p and become largely amorphous (disordered) after T_p due to the solvation of these nanocrystals. As you can see in Figures 5a and b, these nanocrystals have a hexagonal crystal structure. Figure 6c shows the changes in enthalpy as a function of treatment. The enthalpy of the acid-treated samples shows a decrease in this parameter, indicating that the sample suffers structural damage (decrease in relative crystallinity). In contrast, the enthalpy value in alkali treatment depends on the Ca^{2+} ion concentration.

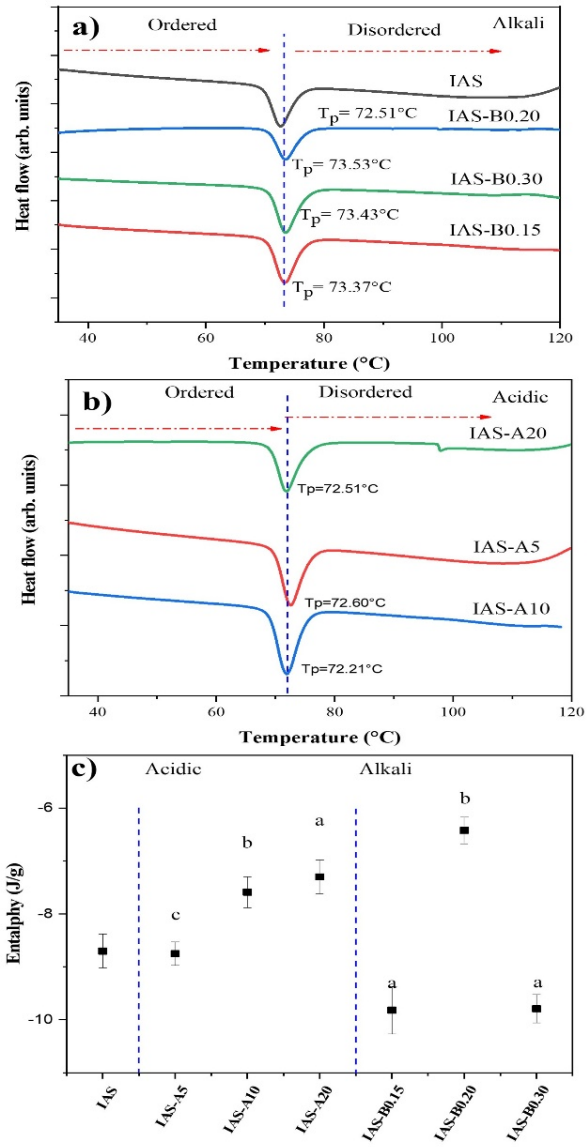


Figure 6. DSC thermograms of (a) IAS-B0.15, IAS-B0.20, and IAS-B0.30, (b) IAS-A5, IAS-A10, and IAS-A30, and (c) the changes in enthalpy as a function of treatment.

Cabrera Canales et al. [28] reported a gelatinization temperature of 63 °C for Colombian achira. However, they did not explain the origin of this thermal event, nor did they give any indication of the crystal structure present in the achira starch. And more importantly, there was no correlation between the structural and thermal properties.

3.2.5 Pasting profiles

The pasting profiles of isolated and modified starches depend on intrinsic and extrinsic parameters. Intrinsic parameters such as chemical composition, grain size distribution, grain surface condition, and others, and extrinsic parameters such as grain size, starch modifications, natural (germination), physical, chemical, and combined changes in grain morphology and chemical composition, and others,

Figure 7a shows the changes in the pasting profile for IAS with alkali treatment. This non-thermal change affects the peak and final viscosity (see Figure 7b). This indicates that this process can be used for the development of food products where it is important to reduce the peak viscosity. The final viscosity behaves like a custard [29], i.e., the sample exhibits gel-like behavior with no measurable flow, and the inclusion of Ca^{2+} ions reduces the end viscosity [29]. Figure 7b shows the pasting profiles for samples treated with acid. In this case, peak and final viscosity are drastically affected (see Figure 7d), but the end viscosity now behaves like a hydrogel with kinematic viscosity.

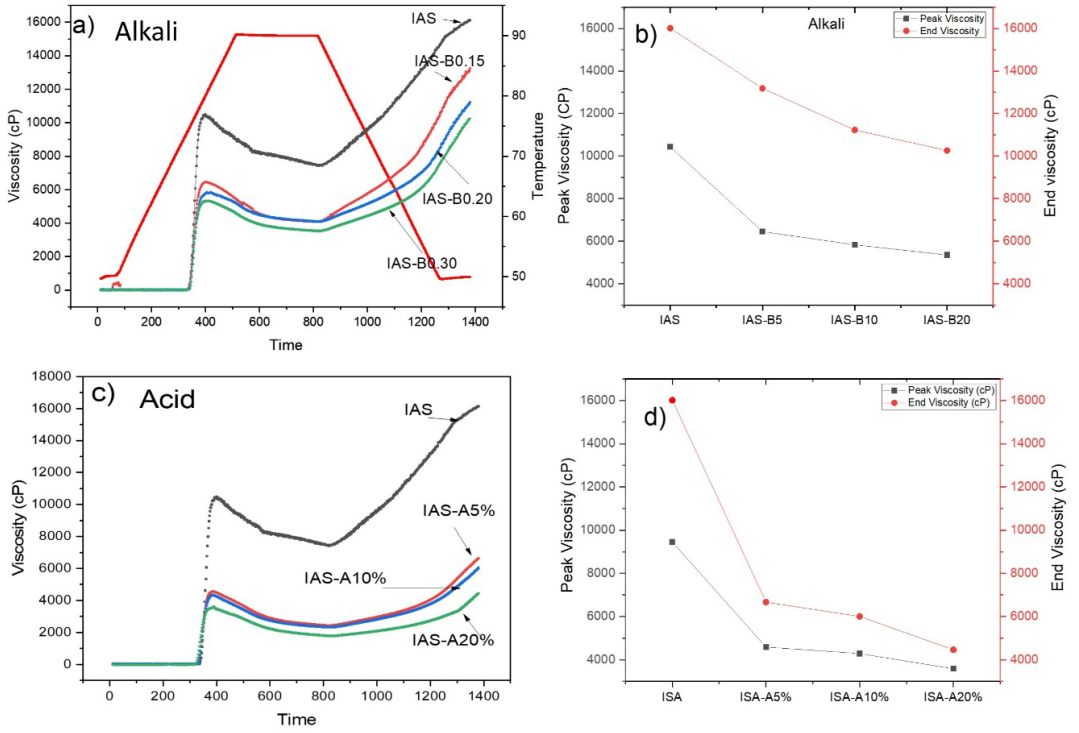


Figure 7. (a) Pasting profile of the alkali-treated IAS and IAS samples IAS-B0.15, IAS-B0.20, and IAS-B0.30, (b) changes in peak and end viscosity as a function of alkali concentration, (c) pasting profiles of the acidic-treated IAS and IAS samples IAS-A5, IAS-A10, and IAS-A20, and (d) changes in peak and end viscosity as a function of acid concentration.

3.2.6 Vibrational analysis by IR

Before you analyze the IR spectrum of the individual samples, you must bear in mind that the IR spectrum of the starch is a superposition of the individual spectra of the individual components. This means that the IR spectrum of starch is the superposition of the IR spectra of amylose, the IR spectrum of amylopectin, the IR spectrum of fat, the IR spectrum of proteins, the IR spectrum of water, etc., and the IR spectrum of nanocrystals with a hexagonal crystal structure. For the IR analysis of starch, the IR spectrum of nanocrystals has not been reported, and only a few cases have been published for fatty acids. This is an indication that IR analysis of starches remains not fully established. Fig. 8a and b show the IR spectrum of IAS after acid and alkali treatment. In this case, we only show a spectral window from 600 to 1800 cm-1, but the same analysis is also possible for the complementary region. As you can see, no new IR bands appear because of the treatment. The changes in intensity can be linked to Van de Wall interactions that change the chemical environment and lead to changes in the IR absorption coefficient (β_λ).

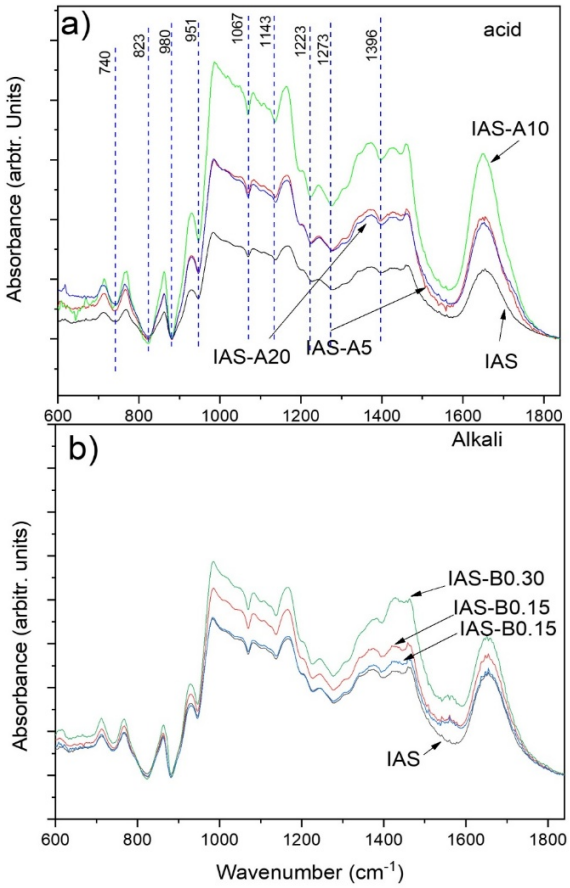


Figure 8. Spectral window of the IR spectra for IAS for acidic (a) and alkali (b) treatments.

4. Conclusions

The study shows that non-thermal acidic and alkali treatments effectively alter the properties of achira starch without affecting its granular integrity. Alkali treatment improved the amylose content and functional properties such as water absorption and swelling, making it suitable for applications requiring improved texture and stability. Acidic treatment increased solubility and pasting behavior, suggesting potential use in encapsulation or hydrogel formulations. Structural analysis confirmed the preservation of nanocrystals with a hexagonal (B-type) structure in all samples, while thermal and rheological data provided insights into their behavior under processing conditions. These modifications offer a sustainable, energy-saving approach to adapting starch to various industrial requirements. Future research could investigate the scalability of these methods and their applicability to other starch sources. Overall, this work expands the potential of achira starch as a versatile, environmentally friendly material in the food and non-food industries.

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Data Availability

Data will be made available on request.

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