*Journal homepage: www.fia.usv.ro/fiajournal*
*Journal of Faculty of Food Engineering,*
*Ştefan cel Mare University of Suceava, Romania*
*Volume XXIII, Issue 3- 2024,* pag. 171-185

# FUNCTIONAL AND PASTING PROPERTIES OF SUCCINYLATED COCOYAM (*Xanthosoma sagittifolium*) STARCH: AN INSIGHT INTO ITS POTENTIAL INDUSTRIAL APPLICATIONS

***Wasiu AWOYALE[1], Adeniyi A. OYEBANJI[1] and Emmanuel A. IRONDI[2]**
[1]*Faculty of Agriculture. Kwara State University, Malete, Nigeria,*
[2]*Faculty of Pure & Applied, Kwara State University, Malete, Nigeria*
*Corresponding author: wasiu.awoyale@kwasu.edu.ng,
Received 5th Marth 2024, accepted 5th September 2024

**Abstract:** *The recent increase in starch utilization for food and other applications demands research into other potential sources of starch. Hence, starch isolated from cocoyam corm, was succinylated and the functional and pasting properties were determined, to provide an insight into its potential applications. The succinylation was done by blending the cocoyam starch (CS) with succinic anhydride (SA), using the central composite rotatable design of the Design Expert software. The succinylated and native cocoyam starches were evaluated for their functional and pasting properties using standard methods. The 39.64 g CS: 7.50 M SA succinylated starch differed significantly from the native cocoyam starch in all the functional properties except swelling power. However, a succinylated starch of comparable functional and pasting properties to that of the native cocoyam starch was produced from the blends of 100.00 g CS and 3.00 M SA. Additionally, succinylation had a significant effect on all the pasting properties of the starch samples. The pasting properties of 50.00 g CS: 3.00 M SA (except breakdown viscosity), 39.64 g CS: 7.50 M SA (except pasting temperature), 110.36 g CS: 7.50 M SA (except peak viscosity), and 50.00 g CS: 12.00 M SA (except peak viscosity) succinylated starches were significantly different from the native cocoyam starch. Therefore, the succinylated cocoyam starch could find applications as a binder, thickener, stabilizer, and emulsifier in the food industries, depending on the level of succinylation.*

**Keywords**: *Xanthosoma sagittifolium starch, succinylated starch, functional properties, pasting properties, industrial uses*

## 1. Introduction

A staple food for subsistence, cocoyam (*Xanthosoma sagittifolium*) is utilised throughout most of the tropics and sub-tropics, particularly in Nigeria. The edible starch found in its corms is the main reason it is farmed [1]. Along with its amylose and amylopectin contents, which varied from 23.05 to 81.07% and 18.93 to 76.95%, respectively, depending on the varieties, cocoyams are a very good source of starch for domestic and industrial applications due to their high carbohydrate content (34.60%) and widespread availability in tropical countries [2], [3]. In terms of industrial uses, cocoyam is a much-underutilised corm compared to cassava and potato. Although cocoyam starch output is quite high, supply has not kept up with demand. Therefore, it is essential to increase the production and modification of cocoyam starch, particularly in nations where native starch supplies are supplemented by imports. The physiochemical and functional qualities of starch and its derivatives play a major role in the many uses of these materials in the industry. A lack of knowledge about the qualities of cocoyam starch for industrial and culinary uses is the reason for its underutilization in a variety of forms [4]. Native starches, like cocoyam starch, have several drawbacks, such as

***DOI: https://doi.org/10.4316/fens.2024.014***

limited stability under shear stress and at high temperatures, thermal degradation, and a strong propensity for retrogradation [5], [6]. Usually, these difficulties can be solved by modification techniques like succinylation. Succinylation is a method that chemically modifies starch. It is an esterification reaction of a hydroxyl group in the starch molecule with succinic anhydride [7]. It results in higher viscosity, greater thickening power, and a lower retrogradation rate of starch [8].

Previous studies on modification by succinylation were conducted on yam starch [7], sorghum starch [8], corn starch [9], rice starch [10], and corn and amaranth starch [11]. The succinylation process confers many advantages, such as high solubility in cold water, high viscosity, better thickening power, increased paste clarity, retarded retrogradation, and freeze-thaw stability [10]. Also, the succinylation of starch modifies the physicochemical properties of the starch, thereby widening its range of applications in the food and non-food industries such as pharmaceuticals, paper, and textile industries.

Given the reported advantages of succinylation of native starches, this study aimed to evaluate the functional and pasting properties of succinylated cocoyam starch and to provide insight into its potential industrial application.

## 2. Materials and methods

### 2.2 Sample Preparation

#### 2.2.1 Isolation and purification of cocoyam starch

After making certain modifications, the cocoyam starch was isolated and purified using the method outlined by Emeje et al. [12]. Peeling, cleaning, and chopping the cocoyam corms into smaller pieces (1 cm thick) were done. After that, the cocoyam slices were submerged for five minutes in a 0.2% (w/v) sodium metabisulphite solution to stop enzymatic browning. A conventional blender was used to mix the slices that had been treated. After sifting the resulting slurry through muslin cloth, it was let to soak for one hour in 1.5 L of 0.03 M NaOH solution. After the supernatant was poured off, the residue was brought to pH 6.0 by neutralising it with a 0.5 M HCl solution. After three distilled water washes, the neutralised residue was centrifuged for five minutes at 1500 rpm. Following a 12-hour drying period at 50 ℃ in a draft air Fisher Scientific IsotempR Oven model 655F, Waltham, Massachusetts, United States, the resulting wet starch was spread out on a stainless-steel tray, cooled, and then sealed in zip-lock bags for additional processing.

#### 2.2.2 Succinylation of cocoyam starch

The pure cocoyam starch was succinylated at room temperature (30 °C) using the Awokoya et al. [13] method. Using a 0.03 M NaOH solution, the various amounts of cocoyam starch (Table 1) were mixed with 300 mL of distilled water and magnetically agitated for one hour before being brought to a pH of 11. The samples were then succinylated using the cocoyam starch and succinic anhydride blend ratios that were optimised using the Design Expert software shown in Table 1. The mixture was then gently swirled for two hours using a magnetic stirrer. Each slurry was pH-adjusted to 6.0 at the end of the reaction using a 0.03M NaOH solution, filtered, and then dried in a hot air oven (draft air Fisher Scientific IsotempR Oven model 655F, Waltham, Massachusetts, United States) at 50 °C for 12 hours. The slurred materials were then packed in zip-lock bags and stored in a desiccator to prevent moisture from reabsorbing before additional analyses.

**Table 1.**

**Optimized blend ratios of cocoyam starch and succinic anhydride for succinylated cocoyam starch production obtained from Design Expert software**

| Runs | Cocoyam starch (g) | Succinic anhydride solution (M) |
|---|---|---|
| 1 | 75.00 | 1.14 |
| 2 | 50.00 | 3.00 |
| 3 | 75.00 | 13.86 |
| 4 | 100.00 | 12.00 |
| 5 | 75.00 | 7.50 |
| 6 | 75.00 | 7.50 |
| 7 | 39.64 | 7.50 |
| 8 | 75.00 | 7.50 |
| 9 | 75.00 | 7.50 |
| 10 | 75.00 | 7.50 |
| 11 | 110.36 | 7.50 |
| 12 | 100.00 | 3.00 |
| 13 | 50.00 | 12.00 |

## 2.3 Functional properties of succinylated cocoyam starch

### 2.3.1. Water and Oil Absorption Capacities

Using Beuchat's method [14], the water (WAC) and oil (OAC) absorption capacities of the samples were determined. About 10 mL of distilled water and oil were combined with 1 g of starch sample for the WAC and OAC, respectively, and the mixture was blended for 30 seconds.

After letting the suspension rest for half an hour, it was centrifuged for half an hour at 3500 rpm at room temperature (30±2 °C).

The WAC/OAC was determined by subtracting the volume of the supernatant from the original amount of water or oil added to the sample after the supernatant was decanted.

### 2.3.2 Swelling power

This was determined using the Leach et al. [15] method but with a little modification to the mass of the sample. A pre-weighed test tube holding 10 mL of distilled water was filled with a 0.1 g sample, which was then heated in a water bath for 30 minutes at 60 °C. This was shaken constantly as it heated up. Ultimately, the test tube was centrifuged for 15 minutes at 2200 rpm to remove the supernatant. The starch paste was then carefully decanted, and its weight was recorded.

Equation 1 was then used to calculate the swelling power (SWP).

$$\text{SWP} = \frac{\text{Weight of starch paste}}{\text{Weight of dry starch sample}} \quad (1)$$

SWP - swelling power

***DOI: https://doi.org/10.4316/fens.2024.014***

### 2.3.3 Bulk Density

This was determined by the use of the AOAC method [16]. An accurately weighed 50 mL graduated measuring container held the 7 g starch sample. After lightly tapping the cylinder on the palm to achieve a constant volume, the bulk density (BD) was calculated using Equation 2.

$$\text{BD} = \frac{\text{Weight of sample}}{\text{Volume of sample after tapping}} \quad (2)$$

BD - bulk density

### 2.3.4 Dispersibility

The Kulkarni et al. [17] method was used to determine the starch samples' dispersibility. After weighing the samples (10 g each) into a measuring cylinder with a capacity of 100 mL, distilled water was added. After giving the setup a good shake, it was left to settle for three hours. After being measured and deducted from 100, the volume of settling particles was determined. The difference was then expressed as the percentage dispersibility.

### 2.3.5 Pasting properties

Pasting parameters (peak viscosity, trough, breakdown viscosity, final viscosity, set back viscosity, peak time, and pasting temperature) were determined using the IITA [18] method. A Rapid Visco Analyzer (Model RVA-4C, Newport Scientific, Warriewood, Australia) with a link to a personal computer running the thermocline software from the same manufacturer was used to test the pasting properties of the samples.

### 2.4 Statistical Analysis

The Statistical Package for Social Sciences (SPSS) software version 21 was used to determine mean values, standard deviations, and significant differences between test samples at a 95% confidence level. Each evaluation was carried out three times.

## 3. Results and discussion

### 3.1 Functional properties of starch samples

Table 2 shows the functional properties of native cocoyam starch (control) and succinylated cocoyam starch derived from blends of cocoyam starch (CS) and succinic anhydride (SA). The fundamental characteristics of food that represent the intricate relationships between the chemical conformation, compositions, and physical and structural characteristics of food components and the environment and circumstances in which these are measured and related are known as functional properties [19].

The functional properties of starches have mean values of 83.74% for oil absorption capacity (OAC), 72.93% for water absorption capacity (WAC), 8.87% for swelling power, 83.19% for bulk density, and 16.75% for dispersibility (Table 2). All of the cocoyam starch's functional characteristics were greatly impacted by

the succinylation process, except the swelling power, which was not.

Additionally, all the functional characteristics of the 39.64 g CS: 7.50 M SA succinylated starch were considerably ($p$<0.05) different from those of the native cocoyam starch, except swelling power, which did not change significantly ($p$>0.05).

**Table 2.**

**Functional properties of succinylated and native cocoyam starches**

| Samples | Oil absorption capacity (%) | Water absorption capacity (%) | Swelling power (%) | Bulk Density (g/ml) | Dispersibility (%) |
|---|---|---|---|---|---|
| 75.00 g CS: 1.14 M SA | 82.00±1.00$^{b}$ | 62.33±3.51$^{c}$ | 8.72±0.23$^{a}$ | 92.35±2.50$^{ab}$ | 16.40±0.20$^{b}$ |
| 50.00 g CS: 3.00 M SA | 81.67±11.68$^{b}$ | 72.67±0.58$^{b}$ | 8.80±0.08$^{a}$ | 93.80±2.50$^{a}$ | 16.33±2.34$^{b}$ |
| 75.00 g CS: 13.86 M SA | 86.33±6.43$^{b}$ | 74.00±1.00$^{b}$ | 9.14±0.11$^{a}$ | 85.86±4.37$^{a-d}$ | 17.27±1,29$^{b}$ |
| 100.00 g CS:12.00 M SA | 89.00±7.00$^{b}$ | 75.67±0.58$^{b}$ | 9.76±0.17$^{a}$ | 87.07±3.79$^{a-d}$ | 17.80±1.40$^{b}$ |
| 39.64 g CS: 7.50 M SA | 109.00±2.65$^{a}$ | 75.00±1.00$^{b}$ | 8.61±0.33$^{a}$ | 92.35±2.50$^{ab}$ | 21.80±0.53$^{a}$ |
| 75.00 g CS: 7.50 M SA | 76.07±15.48$^{b}$ | 73.40±8.18$^{b}$ | 8.34±1.87$^{a}$ | 79.74±8.21$^{cd}$ | 15.21±3.10$^{b}$ |
| 110.36 g CS: 7.50 M SA | 88.33±1.53$^{b}$ | 56.00±1.00$^{d}$ | 10.17±1.44$^{a}$ | 66.87±4.47$^{e}$ | 17.67±0.31$^{b}$ |
| 100.00 g CS: 3.00 M SA | 86.33±3.51$^{b}$ | 85.00±1.00$^{a}$ | 9.83±0.21$^{a}$ | 82.22±1.92$^{b-d}$ | 17.27±0.70$^{b}$ |
| 50.00 g CS: 12.00 M SA | 88.67±4.04$^{b}$ | 66.67±3.06$^{c}$ | 8.13±0.18$^{a}$ | 88.51±6.10a-c | 17.73±0.81$^{b}$ |
| 100 g CS | 80.67±11.02$^{b}$ | 86.67±2.52$^{a}$ | 9.40±0.45$^{a}$ | 76.92±0.00d | 16.13±2.20$^{b}$ |
| Mean | 83.74 | 72.93 | 8.87 | 83.19 | 16.75 |
| $p$ level | * | *** | NS | *** | * |

Means with different letters within the same column differ significantly (p<0.05).
CS=Cocoyam starch, SA=Succinic anhydride; *p<0.05, ***p<0.001, NS-Not significant

However, blends of 100.00 g CS and 3.00 M SA yielded a succinylated starch with functional characteristics similar to native cocoyam starch (Table 2). Because oil enhances flavour and imparts a smooth texture to food, OAC is a crucial component in food composition [20, 21]. The starch samples' OAC varied from 76.07 to 109.00%; the lowest was found in the 75.00 g CS: 7.50 M SA starch, while the highest was found in the 39.64 g CS: 7.50 M SA starch (Table 2). High OAC values are characteristic of food components that hold taste even after cooking into a paste, according to Awoyale et al. [22].

This suggests that because of its high OAC, using 39.64 g CS: 7.50 M SA starch as a thickening in food items may help preserve flavour when it is cooked into a

paste. Due to its low OAC, this could not apply to the 75.00 g CS: 7.50 M SA. This supports the findings of Olu-Owolabi et al. [23], who found that starch modification increases OAC because it gives starch molecules functional groups, which increases their binding ability compared to native starch. This investigation found that an increase in succinylation did not result in a commensurate increase in the OAC of the starch samples, despite findings by Arueya and Oyewale [24] suggesting that a rise in succinylation can raise the OAC of starch. The OAC values of cocoyam starch revealed in this study are lower than the values (214–282%) reported for succinylated acha starch by Arueya and Oyewale [24], but they agree with the findings (78.00–107.33%) of Raji et al. [25] for wild yam starch. It is noteworthy to mention, nonetheless, that the OAC of all the succinylated starches was not statistically different from the native starch ($p$>0.05), except 39.64 g CS: 7.50 M SA starch, which showed a significant difference ($p$<0.05). The low proportion of cocoyam starch in the blend ratio might be the cause of this.

The ability of a sample to absorb water is known as its water absorption capacity (WAC), and it is a crucial characteristic when the sample is reconstituted in hot water to produce a cooked paste. It results from greater solubility due to reduced granule sizes [26]. Lower WAC values show the compactness of the starch molecular structures, whilst higher WAC values reflect the better capacity of the starch to retain water mixed with the loose structure of the starch polymers [22].

The native starch has a higher WAC (86.67%) than the 110.36 g CS: 7.50 M SA starch (56.00%). Nevertheless, there was not a significant difference ($p$>0.05) between the native starch and the 100.00 g CS: 3.00 M SA starch's WAC. Because of their high WAC, this indicates that the native and 100.00 g CS: 3.00 M SA starches can be utilised as stabilisers in baked and frozen foods like ice cream [27]. It's possible that a boost in starch crystallinity prevented water from entering the succinylated cocoyam starch granules, which is why the WAC of the starches decreased. This is contrary to the results of Arueya and Oyewale's study [24], which showed a modest expansion of the acha starch's amorphous area and a rise in WAC of both native and succinylated acha starches due to an improved hydrophilic inclination.

The swelling power, which is a measurement of hydration capacity, indicates the extent to which the interior structure of starch granules is exposed to the action of water [28]. Table 2 shows that the maximum swelling power was recorded by the 110.36 g CS: 7.50 M SA starch (10.17%), while the lowest was recorded by the 50.00 g CS: 12.00 M SA (8.13%). All of the succinylated starches and native starch had the same swelling power; there was no statistically

significant difference ($p$>0.05). Because bulk density affects package design and material selection, it is a metric that may be used to determine the porosity of food products [29]. According to Ikujenlola [30], selecting the appropriate packing material requires an understanding of the bulk density of each given product.

The starches' bulk densities varied from 66.87 to 93.80%, with the maximum bulk density being 50.00 g CS: 3.00 M SA starch and the lowest being 110.36 g CS: 7.50 M SA starch (Table 2).

The bulk density of native cocoyam starch in this study is higher than the bulk density of native acha starch (56%) reported by Emeje et al. [12], but it is in line with the studies of Oladebeye et al. [2] for sweet potato starch (76%). According to Raji et al. [25], there is a correlation between an increase in succinylation level and an increase in bulk densities (71–82%) of wild yam starch. These values are within the stated range for succinylated cocoyam starches. Because of its low bulk density, the study's findings suggest that a greater quantity of 110.36 g CS: 7.50 M SA starches may be packaged in each container capacity, minimising the amount of space required and associated packing and transportation expenses [31]. The better the flour reconstitutes in water, the greater its dispersibility, which is a measure of how well flour reconstitutes in water [3]. Dispersibility ranged from 15.21% for the 75.00 g CS: 7.50 M SA starch to 21.80% for the 39.64 g CS: 7.50 M SA starch. The 39.64 g CS: 7.50 M SA starch's high dispersibility suggests that it can reconstitute more readily than the other starches, including the native starch. All of the succinylated cocoyam starches, except the 39.64 g CS: 7.50 M SA starch, did not significantly vary from the native starch ($p$>0.05).

The dispersibility of the starches in this investigation differs from native tropical breadfruit starch (Akanbi et al., [32] at 40.67% and native cocoyam starch (86.50%) reported by Arawande and Ashogbon [3]. This might be explained by different types of starch and processing methods.

**2. Pasting properties of starch samples**

Understanding pasting qualities is crucial for predicting how food items and raw materials based on starch will behave both before and after cooking [33]. The pasting characteristics of native and succinylated cocoyam starch samples are shown in Table 3. The peak, 367.81; trough, 288.67; breakdown, 79.14; final, 457.54; and setback, 168.87 RVU viscosities; peak time, 5.08 min; and pasting temperature, 83.77 °C are the average values of the starches' pasting characteristics. All of the starch samples' pasting characteristics were significantly ($p$<0.05) influenced by the succinylation process. Furthermore, in terms of their pasting properties, the succinylated starches 50.00 g CS: 3.00 M SA (except

breakdown viscosity), 39.64 g CS: 7.50 M SA (except pasting temperature), 110.36 g CS: 7.50 M SA (except peak viscosity), and 50.00 g CS: 12.00 M SA (except peak viscosity) differed significantly ($p$<0.05) from the native cocoyam starch. Nevertheless, blends of 100.00 g CS and 3.00 M SA succinylated starch yielded a starch with pasting qualities comparable to those of native cocoyam starch (Table 3). The starch samples' peak viscosities varied from 334.75 to 402.88 RVU. Peak viscosity was highest for the 75.00 g CS: 1.14 M SA starch and lowest for the 50.00 g CS: 3.00 M SA starch. Peak viscosity is the highest viscosity that forms during or shortly after the heating phase and helps give starchy paste its desirable texture [27]. Higher peak viscosity starch can therefore be effectively utilised as a binder or stabiliser. This suggests that due to its high peak viscosity, the 75.00 g CS: 1.14 M SA starch may be appropriate for use as a binder or stabiliser in the food industry. In comparison to native cocoyam starch, the 75.00 g CS: 1.14 M SA starch had a greater peak viscosity, which might indicate that the succinylated granules become less dissolving and tougher over time [25]. Additionally, this study's peak viscosity (94.36–274.69 RVU) was higher than that of Raji et al.'s [25] research on succinylated wild yam starch. This might be explained by variations in the basic materials utilised. The starch's resistance to breaking down when cooled is known as its trough viscosity [34]. The trough viscosity of the 75.00 g CS: 7.50 M SA starch was the greatest at 324.63 RVU, while the 50.00 g CS: 12.00 M SA starch was the lowest at 265.59 RVU. Arueya and Oyewale [24] observed a reduced range of trough viscosity values (133.45-206.60 RVU) for acha starch succinates. This study's 75.00 g CS: 7.50 M SA starch's high trough viscosity suggests that the paste may have a significant resistance to breaking down when cooled [25]. Remarkably, this starch's increased trough viscosity suggests that it could be useful in food systems that need high paste stability during cooling [35].

A food sample's resistance to heat and shear stress during cooking decreases with increasing breakdown viscosity [31]. The starch samples' breakdown viscosities varied from 56.21 to 119.67 RVU. The breakdown viscosity of the 50.00 g CS: 3.00 M SA starch was the lowest, while the 110.36 g CS: 7.50 M SA starch was the highest. The high breakdown viscosity of the 110.36 g CS: 7.50 M SA starch might be attributed to its low WAC. This is because Table 4 shows a negative and significant correlation ($p$<0.01, r=-0.81) between the WAC and the starch's breakdown viscosity. As a result, it may be better to use the 50.00 g CS: 3.00 M SA starch with the lowest breakdown viscosity as a stabiliser as it can tolerate heat and shear stress while being cooked into a paste. The results obtained for succinylated

starch samples in this investigation are higher than the breakdown viscosities of native wild yam starch and succinylated starch (7.94–81.28 RVU) reported by Raji et al. [25]. The capacity of food materials to produce a viscous paste is indicated by its final viscosity [36]. The capacity of the starch-based substance to form a viscous paste or gel after cooking and cooling, as well as the paste's resistance to shear force during stirring, are both most commonly determined by its final viscosity [37]. In the 100.00 g CS: 3.00 M SA starch, the final viscosity was greater at 559.30 RVU, whereas in the 110.36 g CS: 7.50 M SA starch, it was lower at 411.42 RVU. The 100.00 g CS: 3.00 M SA starch's high final viscosity indicated that, in comparison to the other starches, it will gel more quickly after being cooked into a paste. Additionally, Table 4 shows a significant and positive correlation ($p$<0.05, r=0.71) between the WAC and the starch's final viscosity. In comparison to the results of the current investigation, the final viscosities of succinylated and native acha starch (167.14–324.62 RVU) [24] and wild yam starch (113.69–367.36 RVU) [25] were lower. Differences in the raw materials and the method of succinylation utilised may be the cause of the variances in the final viscosities of the starches. While a low setback value during the cooling of paste made from starch or starch-based food suggests increased resistance to retrogradation, a high setback value during the freeze-thaw cycles of starchy products is linked to syneresis or weeping [36]. This suggested that because of its significant retrogradation, the low setback viscosity of the 110.36 g CS: 7.50 M SA starch (137.75 RVU) indicates that the starch succinates may find usage in food preparation, where staling, rapid sol precipitation, and viscosity decrease are necessary [38]. Because of its high setback viscosity, the 100.00 g CS: 3.00 M SA starch (240.88 RVU) could not be an example of this. The high starch WAC may be related to the high setback viscosity of the 100.00 g CS: 3.00 M SA starch. The reason for this is that Table 4 shows a strong and positive correlation ($p$<0.05, r=0.77) between the setback viscosity and the starch's WAC.Additionally, the native cocoyam starch's setback viscosity was decreased by the succinylation process (apart from 100.00 g CS: 3.00 M SA starch). This finding supports the findings of Arueya and Oyewale [24], whose investigation revealed a drop in the setback values of succinylated starch from acha (33.7 – 147.70 RVU). The peak time indicates how easy cooking is; so, the easier cooking is, the shorter the peak time [35]. While all the starch samples may create a cooked paste in less than 5.5 minutes, the peak times varied from 4.79 minutes for the 110.36 g CS: 7.50 M SA starch to 5.27 minutes for the 50.00 g CS: 3.00 M SA starch. The starch samples' low peak times suggested that they may be used to

**Table 3.**

**Pasting properties of succinylated and native cocoyam starches**

| Samples | Peak viscosity (RVU) | Trough viscosity (RVU) | Breakdown viscosity (RVU) | Final viscosity (RVU) | Setback viscosity (RVU) | Peak time (min) | Pasting temperature (°C) |
|---|---|---|---|---|---|---|---|
| 75.00 g CS: 1.14 M SA | 402.88±0.29$^{a}$ | 294.34±0.12$^{a-c}$ | 108.55±0.18$^{a}$ | 452.75±0.35$^{cd}$ | 158.42±0.23$^{cd}$ | 5.05±0.07$^{cd}$ | 83.15±0.07$^{a-c}$ |
| 50.00 g CS: 3.00 M SA | 334.75±2.83$^{e}$ | 278.54±1.71$^{bc}$ | 56.21±4.54$^{d}$ | 433.34±2.00$^{cd}$ | 154.79±0.30$^{cd}$ | 5.27±0.00$^{a}$ | 82.78±0.60$^{c}$ |
| 75.00 g CS: 13.86 M SA | 366.58±1.41$^{b-d}$ | 301.50±0.24$^{ab}$ | 65.09±1.65$^{cd}$ | 471.79±1.36$^{bc}$ | 170.30±1.59$^{c}$ | 5.24±0.05$^{a}$ | 83.93±1.10$^{a-c}$ |
| 100.00 g CS:12.00 M SA | 359.88±1.00$^{c-e}$ | 275.55±3.71$^{bc}$ | 84.34±2.71$^{b}$ | 424.88±0.64$^{cd}$ | 149.34±3.06$^{cd}$ | 4.97±0.06$^{de}$ | 82.83±0.53$^{bc}$ |
| 39.64 g CS: 7.50 M SA | 353.56±19.83$^{de}$ | 273.83±22.74$^{bc}$ | 79.72±10.95$^{bc}$ | 421.04±37.49$^{cd}$ | 147.21±16.25$^{d}$ | 5.13±0.06$^{bc}$ | 84.47±1.01$^{ab}$ |
| 75.00 g CS: 7.50 M SA | 394.17±5.42$^{ab}$ | 324.63±3.01$^{a}$ | 69.54±2.42$^{b-d}$ | 517.88±0.77$^{ab}$ | 193.25±2.23$^{b}$ | 5.20±0.00$^{ab}$ | 84.73±0.04$^{a}$ |
| 110.36 g CS: 7.50 M SA | 393.33±0.00$^{ab}$ | 273.67±0.006$^{c}$ | 119.67±0.00$^{a}$ | 411.42±0.23$^{d}$ | 137.75±0.24$^{d}$ | 4.79±0.01$^{f}$ | 82.30±0.28$^{c}$ |
| 100.00 g CS: 3.00 M SA | 383.79±0.30$^{a-c}$ | 318.42±0.12$^{a}$ | 65.38±0.18$^{cd}$ | 559.30±0.18$^{a}$ | 240.88±0.06$^{a}$ | 5.05±0.02$^{cd}$ | 84.65±0.07$^{a}$ |
| 50.00 g CS: 12.00 M SA | 346.84±11.08$^{de}$ | 265.59±6.24$^{c}$ | 81.25±4.84$^{b}$ | 413.05±5.13$^{d}$ | 147.46±1.12$^{d}$ | 5.07±0.00$^{e}$ | 82.83±0.60$^{bc}$ |
| 100 g CS | 370.88±5.01$^{b-d}$ | 310.34±5.55$^{a}$ | 60.55±0.53$^{d}$ | 543.00±11.43$^{a}$ | 232.67±5.89$^{a}$ | 4.93±0.00$^{e}$ | 84.63±0.11$^{a}$ |
| Mean | 367.81 | 288.67 | 79.14 | 457.54 | 168.87 | 5.08 | 83.77 |
| *p* level | ** | ** | *** | *** | *** | *** | * |

Values with different letters within the same column differ significantly ($p<0.05$)

**Table 4.**
**Pearson correlation of the functional and pasting properties of succinylated and native cocoyam starches**

| Attributes | OAC | WAC | SWP | BD | Disp. | Peak | Trough | Breakdown | Final | Setback | Peak time | Pasting temp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OAC | 1.00 | | | | | | | | | | | |
| WAC | -0.12 | 1.00 | | | | | | | | | | |
| SWP | -0.27 | 0.22 | 1.00 | | | | | | | | | |
| BD | 0.34 | 0.12 | -0.47 | 1.00 | | | | | | | | |
| Disp. | 1.00** | -0.12 | -0.27 | 0.34 | 1.00 | | | | | | | |
| Peak | 0.18 | -0.24 | 0.22 | -0.19 | 0.18 | 1.00 | | | | | | |
| Trough | 0.26 | 0.54 | 0.09 | 0.13 | 0.26 | 0.55 | 1.00 | | | | | |
| Breakdown | -0.07 | -0.81** | 0.15 | -0.33 | -0.07 | 0.53 | -0.42 | 1.00 | | | | |
| Final | 0.05 | 0.71* | 0.16 | -0.01 | 0.05 | 0.39 | 0.94** | -0.53 | 1.00 | | | |
| Setback | -0.07 | 0.77** | 0.19 | -0.09 | -0.07 | 0.28 | 0.84** | -0.56 | 0.98** | 1.00 | | |
| Peak time | 0.35 | 0.25 | -0.44 | 0.72* | 0.35 | -0.40 | 0.21 | -0.64* | 0.08 | 0.00 | 1.00 | |
| Pasting temp. | 0.17 | 0.80** | 0.12 | 0.09 | 0.17 | 0.19 | 0.77** | -0.57 | 0.79** | 0.76* | 0.31 | 1.00 |

to make meals that require less processing time [25]. The low bulk density ($p$<0.05, r=0.72) of the 110.36 g CS: 7.50 M SA starch may be the cause of its low peak time (Table 4). In contrast to this investigation, the range of peak time values (5.30–6.93 min) observed for succinylated and native wild yam starch was greater [25]. The pasting temperature, which represents the swelling of the starch paste and is influenced by the starch concentration level, is the temperature at which the first measurable viscosity is detected in an amylogram [39]. Because of the high cost of energy, greater pasting temperature starch might not be advised for certain products [40]. This indicates that because of its low pasting temperature, the 110.36 g CS: 7.50 M SA starch (82.30 °C) may lower the cost of energy when employed in food compositions. Due to its high pasting temperature, the 75.00 g CS: 7.50 M SA starch (84.73 °C) might not fit this description. A positive and significant correlation ($p$<0.05, r=0.80) was found between the pasting temperature and the starch's WAC, suggesting that the high WAC of the 75.00 g CS: 7.50 M SA starch might be the cause of its high pasting temperature (Table 4). All of the starches had pasting temperatures that suggest they could all combine to make a paste below the boiling point of water, which would save energy. The pasting temperatures of succinylated and native wild yam starch were reported to range from 94.36 to 94.70 °C, which is higher than the values found in this work [25]. On the other hand, the starch samples used in this investigation had a pasting temperature that is within the recorded range of values (76.7–89.63 °C) for succinylated acha starches [24].

## 4. Conclusion

The increasing rise in the use of starch in food and other uses necessitates the succinylation of prospective starch sources like cocoyam starch. All of the functional and pasting characteristics of the cocoyam starch, except swelling power, were greatly impacted by the succinylation procedure. The final viscosity and pasting temperature were significantly correlated with the starch's water absorption capacity, however, the breakdown viscosity of the starch was negatively correlated. Additionally, there is a strong positive correlation between the starch's peak time and bulk density. Thus, depending on the degree of succinylation, the cocoyam starch that has been succinylated may find use in the food industry as a binder, thickening, stabiliser, and emulsifier.

## 5. Acknowledgments

The authors would like to acknowledge the contribution of Mrs. Kudirat Ajao of the Food Processing Laboratory, Kwara State University Malete, Kwara State.

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