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Research Article

Physicochemical and Nutritional Characterization of Starch Isolated from *Colocasia antiquorum* Cultivated in Oaxaca, Mexico

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The physicochemical and nutritional characteristics of *Colocasia antiquorum* (taro coconut or Chinese taro) starch cultivated in Oaxaca, Mexico, were determined. The granules of *Colocasia antiquorum* presented a truncated ellipsoidal shape. The chemical composition analysis showed levels of moisture, ash, protein, fat, fiber, and NFE in a dry base of 10.29, 0.18, 2.0, 0.05, 0.01, and 97.76, respectively, as well as amylose and amylopectin contents of 13.05 and 86.95%, respectively. Gelatinization temperatures, onset (T_o), peak (T_p), and final (T_f), were 72.86, 82.91, and 93.05°C, respectively. Solubility, swelling power (SP), and water absorption capacity (WAC) correlate directly with increments in temperature. Transmittance value (% T) for taro coconut was 0.3% and its apparent viscosity ranged from 100 to 150 cp. The nutritional characterization of *Colocasia antiquorum*'s starch amounted to 97.88% of total starch (TS), while available (AS) and resistant starch (RS) were 93.47 and 3.70%, respectively. *Colocasia antiquorum*, grown in Oaxaca, Mexico, is an unconventional source of starch with added value due to its potential use as an ingredient in the development of new products or as a substitute for conventional starch sources in industrial processes.

1. Introduction

Starch is currently used as a human food and as an ingredient in the food industry, in animal feed systems, and in industrial applications. Contained in myriad foods in the human diet, starch is converted into maltose by amylase activity in the human gastrointestinal tract. Maltose is a disaccharide composed of two glucose molecules that provide 4 cal g^{-1} and represents 80% of the world's dietary energy intake [1]. In the food industry, starch is used as an additive in food systems to take advantage of its numerous properties, such as thickener, emulsifier, binder, stabilizer, and sweetener. When used in animal feed systems, starch has been reported to be an adequate alternative for increasing nonstructural carbohydrate and energy levels. Almost 80% of the starch used in industrial applications is used as an adhesive in paper and paperboard manufacturing. It is also used in the textile industry to increase fabric brightness and weight and to improve print texture and quality. Superficial application of starch improves clothing appearance and fit. In the pharmaceutical industry,

starch is used in tablets as a vehicle to bind active ingredients [2]. The cosmetics industry uses it in the manufacture of make-up powders and as a viscosity improver and vehicle for semiliquid materials such as cold creams [1].

On-going research into alternative starch sources responds to three main motivations. First, more starch is always needed to meet market demand. Second, new starches with different or better functional properties than conventional starch sources are needed to meet industry demands [3]. And, third, new starch sources can help begin resolving challenges in worldwide food production such as the scarcity of arable land, unproductive land, land degradation, and irrigation problems.

The principal conventional sources for extraction of this polysaccharide are cereal grains such as corn, wheat, rice, and sorghum; tubers such as potatoes, cassava, sweet potato, and sago; and leaves, seeds, and fruits of some plants. However, increasing emphasis is being placed on the search for unconventional starch sources with different physicochemical, structural, and functional features. These new starches can expand the possible range of starch uses in industry. Tubers are becoming a significant source of starch. They already play a significant role in the global food system and contribute to the energy requirements of millions of people in developing countries. The most important worldwide root and tuber crops are cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), potato (*Solanum tuberosum*), yam (*Dioscorea* spp.), malanga (*Colocasia esculenta*), and tannia (*Xanthosoma* spp.). In conjunction, these six crops occupy about 50 million hectares worldwide [4].

Starch from tubers is the current international market leader among starch sources. In a report on the starch market in 2012, the International Starch Institute stated that cassava starch was the most widely available on the market, followed by sago starch, and potato starch was found to have the best balance between supply and demand. Known by several common names, including taro coconut or Chinese taro, *Colocasia antiquorum* can grow to 2.5 m in height and has elongated ovoid stems called corms that store starch. The plant crown is linked to the stems or petioles, while the base of the corm, at the bottom of the plant, is attached to the root. The corm cuticle or shell is brown with rings marking layers formed during its biological cycle. Pulp color can be white-veined lilac to violet [5, 6]. A dietary ingredient in many parts of the world, it is eaten cooked or fried in dishes such as soups and stews and when finely ground functions as a flour substitute. Its suitable organoleptic and nutritional characteristics make *C. antiquorum* a promising potential source of starch for use in a wide array of foods for children, adults, and the elderly (e.g., cookies, candy, baby food, hot beverages, liquor, and fried foods).

Chinese taro (*C. antiquorum*) is an important cash crop for producers in the Papaloapan region, Oaxaca, Mexico. For example, in 2011, exports to the United States generated approximately $600,000 USD for regional producers. It is mainly marketed as a fresh tuber and therefore must meet export quality guidelines. However, in an effort to open new markets for *C. antiquorum*, producers have developed taro-based products and presented them at trade shows and national events. Another potential new use is as an alternative starch source, although this will require analysis to quantify its starch's physicochemical, functional, and nutritional characteristics. No research has been done to date on *C. antiquorum* starch, making the present study the first study to characterize this starch with a view to its use in food and industrial systems. Any new data on starch from this crop will also help add value to its cultivation, benefiting producers both socially and economically.

Figure 1: *Colocasia antiquorum*: taro coconut or Chinese taro.

The objective of present study was to describe the physicochemical, functional, and nutritional characteristics of starch extracted from Chinese taro (*Colocasia antiquorum*) grown in the state of Oaxaca, Mexico.

2. Materials and Methods

2.1. Materials. *Colocasia antiquorum* (taro coconut or Chinese taro) was obtained from the September 2012 harvest in the State of Oaxaca, Mexico, from Agroempresarios del Papaloapan SPR de RL (Figure 1). *Manihot esculenta* was used as a reference from a recognized source of starch. All chemicals were reagent grade and purchased from J.T.Baker (Phillipsburg, NJ, USA) and Sigma (St. Louis, MO, USA).

2.2. Colocasia antiquorum Starch. Starch extraction was carried out according to Novelo-Cen and Betancur-Ancona [7]. In summary, *C. antiquorum* was manually peeled, cut into cubes (approx. 3 cm^3), and soaked for 30 min in a sodium bisulphite solution (concentration of 1500 ppm SO_2) at a ratio of 1 : 3 (by mass per volume). After soaking, the cubes were milled (Fatosa C-3527, Barcelona, Spain) for 2 min to reduce particle size and the resulting mass was distributed in bowls containing a sodium bisulphite solution (concentration of 1500 ppm SO_2) at a ratio of 1 : 1 (by volume). The starch was then passed through an 80-mesh plastic cloth to eliminate the fiber, and the filtrate was centrifuged at 3000 ×g for 20 min at 5°C. After the liquid was removed, the sediment (starch) was washed three times with water and centrifuged for 12 min at 1317 ×g. The product was dried at 50°C for 24 h in an air convection laboratory oven (Imperial V, Labline, Maharashtra, India), weighed, and then milled in a Foss Cyclotec mill (Tecator, Hoganas, Sweden) and W.S. Tyler Ro-Tap RX-29-E until it passed through a 100-mesh screen.

2.3. Physicochemical Characterization

2.3.1. Shape and Size of Granules. The shape of *Colocasia antiquorum* starch was determined using Scanning Electron Microscopy. Samples of starch grains were mounted on a plate and covered with a thin coal film for 20 sec by means of coal deposit by evaporation in a JOEL Coal Evaporator Model JEE4X. The samples were analyzed on a ZEISS Scanning Electron Microscope Model DSM-950 (HV = 15 KV with SE, WD = 10 mm).

2.3.2. Chemical Composition. Nitrogen, fat, ash, fiber, and moisture content were determined according to AOAC procedures (methods 954.01, 920.39, 923.03, 962.09, and 925.09, resp.) [8]. Nitrogen content (N_2) was determined with a Kjeltec Digestion System (Tecator, Sweden), using cupric sulphate and potassium sulphate as catalysts. Protein content was calculated as nitrogen × 6.25. Fat content was obtained from a 1 h hexane extraction. Ash content was calculated from sample weight after burning at 550°C for 4 h. Crude fiber content was calculated after acid and alkaline digestion with a Fibertec system (Tecator, Sweden). Moisture content was measured based on sample weight-loss after oven-drying at 110°C for 2 h. Carbohydrate content was determined as nitrogen-free extract (NFE). Apparent amylose content was calculated after iodine complexation using the Morrison and Laignelet method [9]. Amylopectin content was calculated by the difference of total starch minus amylose contents.

2.4. Functional Characterization

2.4.1. Differential Scanning Calorimetry (DSC). Starch gelatinization was determined with a DSC-7 (Perkin-Elmer Corp., Norwalk, CT, USA) using the technique described by Ruales and Nair [10]. The DSC was calibrated with indium and the data analyzed using the Pyris software program. Two milligrams (d.b.) of starch was placed in an aluminium pan and the moisture level adjusted to 70% by adding deionized water. The pan was then hermetically sealed and left to equilibrate for 1 h at room temperature. It was then placed in the calorimeter and heated from 30 to 120°C at a rate of 10°C min^{-1}, using an empty container as reference. The gelatinization temperature was determined by automatically computing onset temperature (T_o), peak temperature (T_p), final temperature (T_f), and gelatinization enthalpy (ΔH) from the resulting thermogram.

2.4.2. Solubility, Swelling Power (SP), and Water Absorption Capacity (WAC). Solubility, water absorption, and swelling power patterns at 60, 70, 80, and 90°C were determined using a modified version of the Sathe et al. [11] method. Summing up, 40 mL of a 1% starch suspension (w/v) was prepared in a previously tared, 50 mL centrifuge tube. A magnetic stir bar was placed in the tube and kept at a constant temperature (60, 70, 80, or 90°C) in a water bath for 30 min. The suspension was then centrifuged at 2120 ×g for 15 min; the supernatant was decanted and the swollen granules were weighed. 10 mL of the supernatant was dried in an air convection oven (Imperial V) at 120°C for 4 h in a crucible to constant weight. Percentage solubility and swelling power were calculated using the following equations:

$$\%\ \text{Solubility} = \frac{(\text{dry weight at } 120^\circ\text{C})\,(400)}{\text{sample weight}},$$

$$\text{Swelling Power} = \frac{(\text{weight of swollen granules})\,(100)}{(\text{sample weight})\,(100 - \%\ \text{solubility})}. \quad (1)$$

Water absorption capacity was measured using the conditions mentioned above, and it was expressed as weight of the gel formed per sample, divided by weight of the sample.

2.4.3. Starch Clarity. Starch clarity was determined according to the Bello-Pérez et al. method [12]; transmittance of a 1% starch paste was measured at 650 nm on a Beckman DU-650 spectrophotometer. Starch suspensions (1%) in tubes with threaded caps were placed in a water bath at 100°C for 30 min with vortex stirring every 5 min and left to cool at room temperature.

2.4.4. Viscosity. Apparent viscosity was measured by the Ruales and Nair [10] method. Pastes were prepared in a Brabender viscoamylograph. To summarize, 400 mL of a 2.5% (d.b.) starch suspension was heated to 95°C at a rate of 1.5°C min^{-1}, held at this temperature for 15 min, then cooled to 50°C at the same rate, and held at this temperature for another 15 min. The apparent viscosity of the gelatinized suspension was determined on a Brookfield HADV-II+ PRO viscometer with a number 2 *spindle* and a cutting speed of 200 rpm.

2.5. Nutritional Characterization

2.5.1. Total Starch (TS). Total starch content was quantified by adapting the Tovar et al. methodology [13] using KOH 4 M to guarantee starch solubilization. Hydrolysis was achieved using thermostable α-amylase (Sigma TO-3306) and *Aspergillus niger* amyloglucosidase (BioChemika 10115, 70 solid units mg^{-1}). Reactivated glucose oxidase/peroxidase (GOD-PAP) (DiaSys, reagent 10250021) was used for the colorimetric determination of glucose, and the concentration was determined at 540 nm using a spectrophotometer (Thermospectronic Genesis 10UV, Madison, WI, USA). Calculation of sample glucose concentration was carried out according to the following equations:

$$\text{Glucose}\left(\text{mg dL}^{-1}\right) = \left(\frac{\text{ST}_A - B_A}{S_A - B_A}\right)(\text{SC})$$

$$\%\ \text{Starch} = \left(\frac{\text{mg}_{\text{glucose}} \times 200 \times 0.90}{\text{sample weight}}\right)(100), \quad (2)$$

where ST_A is starch sample absorbance, B_A is blank absorbance, S_A is standard absorbance, SC is standard concentration (100 mg dL^{-1}), 200 is dilution factor, and 0.90 is glucose transformation factor.

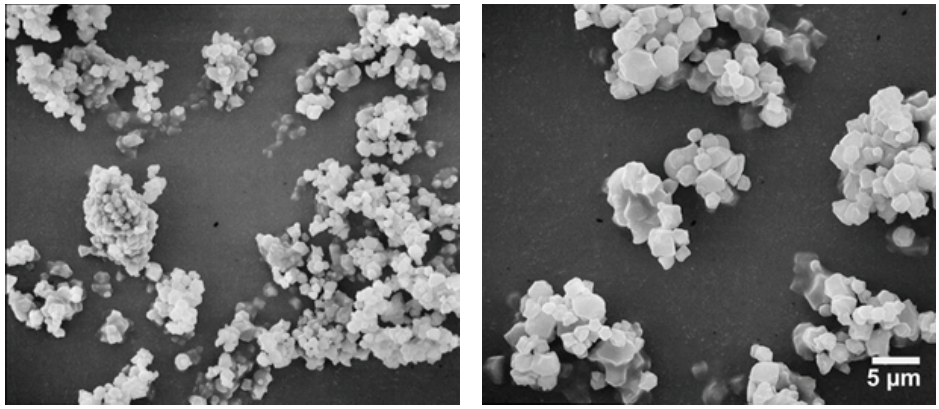

Figure 2: Micrography of *Colocasia antiquorum* starch (1000 and 2000x).

Table 1: Gelatinization parameters of *Colocasia antiquorum* and *Manihot esculenta* starch.

Starch	T_o (°C)	T_p (°C)	T_f (°C)	ΔH (J g^{-1})
Colocasia antiquorum	72.86 ± 3.41[a]	82.91 ± 0.05[a]	93.05 ± 1.85[a]	20.48 ± 0.57[a]
Manihot esculenta	63.44 ± 0.26[b]	70.30 ± 0.00[b]	81.39 ± 0.17[b]	22.14 ± 0.38[b]

[a-b]Different superscript letters in the same column indicate statistical difference ($P < 0.05$).

2.5.2. Available Starch (AS). AS was quantified as TS, adapting the methodology of Holm et al. [14], without KOH 4 M treatment.

2.5.3. Resistant Starch (RS). RS was obtained by the difference of TS minus AS according to Tovar et al. [15].

2.6. Statistical Analysis. All physicochemical and nutritional determinations were carried out in triplicate. Statistical analyses were done to determine the data's central tendency and deviations. An analysis of variance (ANOVA) was applied to calculate means (5% significance level) and Duncan's test was used to determine sample differences between means. All analyses were conducted according to Montgomery [16] and processed using the Statgraphics Plus version 5.1 software.

3. Results and Discussion

3.1. Physicochemical Characterization. The granules of *Colocasia antiquorum* presented a truncated ellipsoidal shape (Figure 2) similar to that reported in [2, 17] for *Colocasia esculenta* starch. *Manihot esculenta* starch was used as a reference and presented a spherical-truncated shape. The chemical composition of *Colocasia antiquorum* revealed values of moisture 10.29 ± 0.06, ash 0.18 ± 0.02, protein 2.0 ± 0.10, fat 0.05 ± 0.01, fiber 0.01 ± 0.00, and NFE 97.76 ± 0.06% in dry base compared to *Manihot esculenta*, moisture 6.40 ± 0.11, ash 0.03 ± 0.01, protein 0.05 ± 0.01, fat 0.07 ± 0.01, fiber 0.02 ± 0.00, and NFE 99.82 ± 0.27%. In *Colocasia antiquorum* starch, the amylose content was 13.05 ± 0.10% and amylopectin content was 86.95 ± 0.10%, in respect to *Manihot esculenta* starch with 23.88 ± 0.88% of amylose and 76.12 ± 0.88 of amylopectin. The amylose content found in taro starch determined in this work was lower than that reported by Jane et al. [18] in five varieties of taro flours, Bun-long (22.1 ± 0.1%), Dasheen (22.2 ± 0.3%), Hawaii Red (Lehua) (18.1±0.1%), Hawaii White (18.5±0.2%), and Niu'e (19.6 ± 0.2%). Starches with high amylose content present good mechanical properties; they are less soluble, and their high adhesion strength makes them suitable for the paper industry.

3.2. Functional Characterization. Gelatinization onset (T_o) 72.86°C, peak (T_p) 82.91°C, and final (T_f) 93.05°C temperatures were determined for *Colocasia antiquorum* starch granules (Table 1). Similar values of T_p (81.3–83.5°C) were reported for *Colocasia esculenta* (L.) Schott starch [18, 19]. These values were higher than those reported for *Manihot esculenta* starch (63.44, 70.30, and 81.39°C). Gel enthalpy ΔH (Jg^{-1}) for the *Colocasia antiquorum* starch was 20.48 Jg^{-1}, whereas it was 22.14 Jg^{-1} for the *Manihot esculenta*; that is, the former requires less energy to gelatinize. This is not consistent with the results reported by Czuchajowska et al. [20], who stated that lower gelatinization enthalpy values are linked to higher amylose levels. In our hands, the *Manihot esculenta* starch showed that the amylose proportion was higher (23.88%) than that of the *Colocasia antiquorum* starch (13.05%). The reference starch (*Manihot esculenta*) enthalpy value was higher than that of the taro starch suggesting that gelatinization may be governed more by the crystal structure than by amylose content. Differences in enthalpy values between the *C. antiquorum* and *M. esculenta* and starches may also be because they have different crystalline structures.

X-ray diffraction (XRD) patterns for taro starch are reported to be A-type [18], while those of *M. esculenta* starch are C-type [3]. Starch XRD patterns characterize crystal packing in native starch granules. Based on these patterns and their characteristics, starches exhibiting a semicrystalline structure have different polymorphic forms that are classified

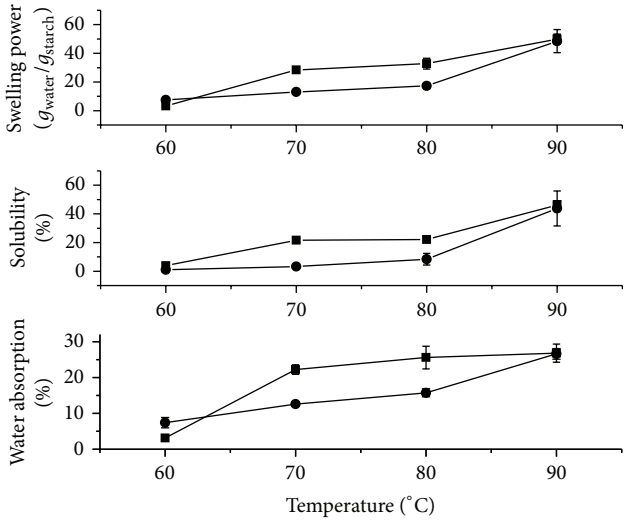

Figure 3: Water absorption, solubility, and swelling power capacity of *Colocasia antiquorum* (■) and *Manihot esculenta* (●) starch.

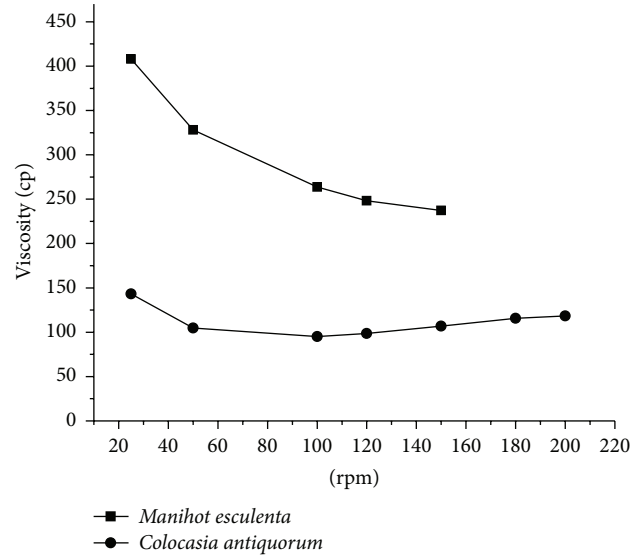

Figure 4: Apparent viscosity of *Colocasia antiquorum* and *Manihot esculenta* starch.

into three types: A (rhomboid crystal); B (hexagonal crystal); and C (both rhomboid and hexagonal crystals). Hexagonal crystals have more compact structures, which require more energy to melt because their glycosidic bonds are less exposed than in rhomboidal crystals. Hexagonal crystals are also very stable and have a fusion temperature of approximately 150°C [21].

There was a direct correlation between solubility, SP, and WAC with increments in temperature (Figure 3). *Colocasia antiquorum* starch solubility tests showed that, in the 60 to 90°C range, polysaccharide chains (mainly linear and short chains) contents on the granules presented higher solubility than those of *Manihot esculenta*. At 60°C, *Colocasia antiquorum* showed a lower SP and WAC than *Manihot esculenta*; however, in the 70 to 90°C range, both SP and WAC values were higher than those of cassava starch. The results suggest that, in the 70–90°C temperature range, the granules gradually swelled as the temperature increased due to breakage of the intermolecular hydrogen bonding in the amorphous areas, which allowed for successive water absorption.

The transmittance value of *Colocasia antiquorum* starch was 0.3%, whereas for *Manihot esculenta* starch it was 10.2%. According to Novelo-Cen and Betancur-Ancona [7], the starches with higher SP and lower amylose content are easily dispersed and show higher transmittance values. Such behaviour was not observed in our studies: *Colocasia antiquorum* presented the highest SP values and the lowest amylose content in the temperature range of 70–90°C. Craig et al. [22] established that starch clarity is a result of high reflection, since the characteristic arrangement of gel molecular chains reduces the intensity of the light transmitted. Clarity is a key parameter in starch paste quality because it provides shine and opacity to the product color [23]. The results suggest that *Colocasia antiquorum* starch is suitable for salad dressings, meat, and baking, while *Manihot esculenta* starch is suitable for marmalades as well as jellies.

The apparent viscosity of *Colocasia antiquorum* starch was in a range of 100 to 150 cp (Figure 4). The viscosity values of taro starch did not change with the increment of the strain rate. On the other hand, the apparent viscosity of *Manihot esculenta* starch decreased from 410 cp to 250 cp when the viscometer velocity was increased from 20 to 150 rpm (Figure 4). However, the higher viscosity of cassava starch suggests that it can be used as a thickener in fruit syrups and baby foods.

3.3. Nutritional Characterization. *Colocasia antiquorum* presented a high TS value (97.88%) which is in line with what Lara and Ruales [24] recorded for chickpea starch (97.5%) but higher than that of lentils (91.3%) as reported by Tovar et al. [15] and Chinese taro (80.1%) and yam (76.1%) as reported by Aprianita et al. [25]. The results point to a high purity of the starch being analyzed, and this level of purity is similar to that of commercial starches.

The enzymatically available starch content of *Colocasia antiquorum* was 93.47%. This value was similar to those for lentils (91.3%) [26], wheat (92.25%), cassava (93.9%), canna (91.3%) [27], and amaranth (94.4%) [24].

The resistant starch (RS) content was 3.70% in *Colocasia antiquorum* starch. This ability to resist enzymatic hydrolysis gives the property to behave as dietary fiber. The value was higher 2.5 times than that reported for *C. esculenta* var. *antiquorum* [18]. Compared to other sources of RS, as green banana starch (40.9%), the RS level in *C. antiquorum* starch is low. The hydrolysis resistance is due to the crystalline arrangement of molecules of amylose and amylopectin within the granule [28].

Colocasia antiquorum starch, therefore, is a natural source of dietary fiber that could be advantageous to foods due to its

functional properties. In addition, starch possesses the physiological advantages of consuming RS since it behaves like dietary fiber which can be fermented by intestinal microflora, resulting in short chain fatty acids (mainly acetic, propionic, and butyric acids). Short chain fatty acids, in turn, can have certain health benefits. Butyric acid produced by intestinal fermentation, for instance, inhibits cancer formation in epithelial cells. The addition of RS in food reduces caloric content, and some food processing systems, to which taro starch could be added, would further increase RS content.

4. Conclusion

Colocasia antiquorum starch was extracted and physicochemical and nutritional properties were evaluated. The results indicate that taro coconut or Chinese Taro could be a suitable ingredient for the development of new products and as a natural source of dietary fiber which could prove advantageous for human nutrition due to its functional properties.

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

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