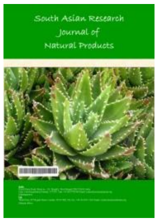

South Asian Research Journal of Natural Products

3(4): 18-30, 2020; Article no.SARJNP.62414

Granule Morphology and Physicochemical Properties of Flours of Three Yams Species: *Colocasia esculenta*, *Xanthosoma sagittifolium* and *Plectranthus rotundifolius*

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Authors' contributions

This work was carried out in collaboration among all authors. Authors HACOH and VPNP designed the study and performed the statistical analysis. Authors HACOH and VPNP wrote the first draft of the manuscript and managed the analyses of the study. Authors HACOH, VPNP, KDPPG and AMMUA managed the literature searches and wrote the protocol. All authors read and approved the final manuscript.

Article Information

Editor(s):
(1) Dr. Nargis Jamila, Shaheed Benazir Bhutto Women University, Pakistan.
Reviewers:
(1) I. Iwanegbe, Auchi Polytechnic, Nigeria.
(2) T. Krishnakumar, ICAR-Central Tuber Crops Research Institute, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/62414

Original Research Article

Received 28 August 2020
Accepted 03 November 2020
Published 26 November 2020

ABSTRACT

Aims: *Colocasia esculenta* (Gahala), *Xanthosoma sagittifolium* (Kiriala) and *Plectranthus rotundifolius* (Innala) are three underutilized yam varieties in Sri Lanka, which have not been exploited sufficiently for various aspects in the food industry. Therefore, the research was conducted to evaluate the granule morphology, physicochemical and functional properties of flours obtained from three yams.
Study Design: Complete Randomized Design.
Place and Duration of Study: Department of Food Science and Technology, Faculty of Livestock, Fisheries and Nutrition, Wayamba University of Sri Lanka, Makandura, Gonawila, (NWP), Sri Lanka between April 2016 and August 2016.
Methodology: Granule morphology, proximate composition, swelling power (SP), solubility index (SI), least gelation concentration (LGC), water holding capacity (WHC) and oil holding capacities

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(OHC), viscosity, emulsifying capacity and emulsion stability, foaming capacity and foam stability (FS) of flour samples (≤0.250 mm) were determined. Gelatinization characteristics were evaluated using Brabender viscoamylograph.

Results: At 80°C, higher SI were observed compared with other temperatures used and were within the range of 16.85-22.21%. LGC of all flours were within the range of 5-7% (w/v) indicating that they can be utilized as gel-forming material in food products. Gelatinization temperatures (GT) for *Colocasia esculenta, Xanthosoma sagittifolium*, and *Plectranthus rotundifolius* flour the ranged between 65-84°C, 75-94.5°C, 72-86.25°C respectively. *Colocasia esculenta* flour showed the lowest GT (65-84°C) and which is more preferable over other flour types.

Conclusion: Hence it is perceptible that flours obtained from above yam species can be utilized in the food industry.

Keywords: Yams; flour; functional; gelatinization; proximate; viscosity.

1. INTRODUCTION

The plants that produce stems, corms, rhizomes, tubers, and starchy roots are categorized as roots and tubers, which are mostly grown in tropical and sub-tropical regions and some species in a temperate climate. Due to high moisture content (70-80%) they are having a short storage life under ambient conditions [1]. They contain 16-24% starch and trace quantities of proteins and lipids and also contains varying amount of fiber, minerals, and vitamins [2]. *Colocasia esculenta* (Fig. 1A) is an aroid belonging to the family Araceae. It is an herbaceous perennial plant and edible roots are harvested at the end of the season. *C. esculenta* is considered as a staple diet in most African countries, which is grown by small scale farmers as a subsistent crop. Sri Lanka is having three popular cocoyam varieties under *C. esculenta* knowingly 'Dehi ala', 'Weli ala' and 'Sewel ala'. Several studies have shown that *C. esculenta* contains digestible starch, protein of good quality, vitamin C, thiamin, riboflavin, niacin, and high amount of amino acids [3]. *C. esculenta* can be processed in many ways; boiling, roasting, frying, milling, conversion to soup thickeners, flour for baking, chips, beverage powder, porridge, specialty food for gastro-intestinal disorders [3]. The presence of oxalates, which impart acrid taste or cause irritation when foods are prepared, is a major limiting factor in the utilization of *C. esculenta* [3]. The flour prepared from *C. esculenta* has good potential to be used as a food binding agent due to its high water and oil absorption capacities [4]. Cocoyam has been found to have more crude protein than other root and tubers and its starch is highly digestible [5]. *Xanthosoma sagittifolium* (kiri ala) (Fig. 1B) is an herbaceous perennial plant having a corm or main underground stem in the form of a rhizome. There are few varieties of kiriala such as "Ada dam kiriala, Kalu kiriala and Rathu iri Kiriala" found in Sri Lanka. Rathu iri kiriala is the major variety cultivated and commonly known as "Isuru", which can be grown throughout the year with sufficient water supply and consumed in households as food by boiling and preparing curries. *Plectranthus rotundifolius* (Fig. 1C), known as Innala in Sri Lanka and country potato or Hausa potato in other countries, is an annual tuber crop [6]. The two varieties, 'Bola innala' and 'Dik innala' [2] are commonly called "Binari" and consumed domestically by preparing curries. They can also be eaten boiled, roasted, baked or fried. Innala is a rich source of iron than other tuber crops, according to Premathilake [6].

Many studies on physicochemical and functional properties of flour obtained from these yams have evidentially proved the potential of these flours to be used in the food industry under various aspects. In Sri Lanka, the deficit of such research evidence has made them concealed from exploitation. These yams can be utilized as soup thickeners, flour for baking, chips, beverage powder, porridge and specialty food for gastro-intestinal disorders [4]. There have been several reports on the granule morphology of *C. esculenta* and *P. rotundifolius* starch [7,2] which reveals that starch granule morphologies can be used for characterization and identification of flour type. It is controversial as Nikuni [8] reported that it can be difficult to identify and characterize flour type using starch granule morphology as it is largely dependent on the genetic composition of the plant and even the size and shape can be modified by both the internal and external environment of the plant. Hence the research study was conducted to find the granule morphology, chemical composition (proximate composition), physical properties

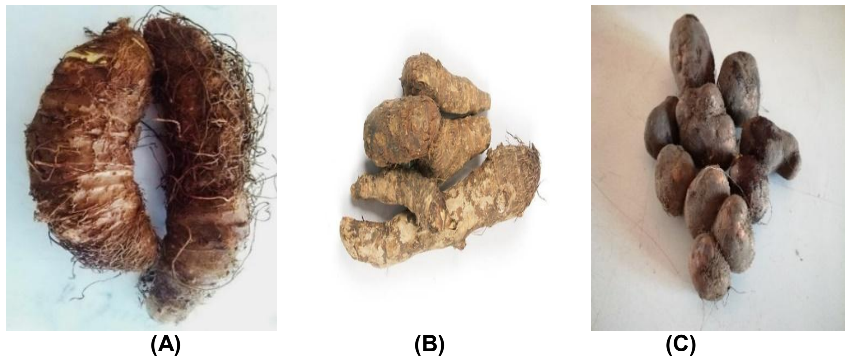


Fig. 1. A) *Colocasia esculenta* (Cocoyam roots) (B) *Xanthosoma sagittifolium* (Kiriala tubers) (C) *Plectranthus rotundifolius* (Innala tubers)

(swelling power and solubility patterns), functional properties (water and oil absorption capacity, gelatinization characteristics, emulsion activity and stability, foaming capacity and foaming stability, least gelation capacity) of flour obtained from three varieties of yams- *Colocasia sculenta*, *Xanthosoma sagittifolium* and *Plectranthus rotundifolius* grown in Sri Lanka. It is expected that this study would pave way for the successful exploitation of these underutilized yams in the food industry. The results may be beneficial not only to food processors but also to other researchers in the nutraceutical industry.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Gahala

'Dehi ala variety' (*Colocasia esculenta*) was obtained from the local market in Meegahakiwula area in Badulla district, Sri Lanka.

2.1.2 Kiriala

Isuru variety (*Xanthosoma sagittifolium*) was obtained from the local market in Veyangoda, Gampaha district, Sri Lanka.

2.1.3 Innala

Binari variety (*Plectranthus rotundifolius*) was obtained from the local market in Makandura area in Kurunegala district, Sri Lanka. Standard mineral solutions (Ca, Fe, Zn, Mg, Mn, Cd, Ni, Pb) and other chemicals of analytical grade .used in this study for analysis were purchased from SIGMA-ALDRICH Co., 3050 Spruce Street, St. Louis, MO 63103 USA through Analytical Instruments (pvt) Ltd, Sri Lanka. All the experiments were conducted at the Department of Food Science and Technology, Faculty of Livestock, Fisheries and Nutrition, Wayamba University of Sri Lanka, Makandura, Gonawila, (NWP), Sri Lanka between April 2016 and August 2016.

2.2 Methods

2.2.1 Flour preparation

This was done according to a modified method of Senanayake et al. [9]. 5 kg of the tubers were washed, hand peeled and trimmed to remove defective parts. Then the tubers were sliced into thin chips (~5mm) and immediately soaked in 0.25% citric acid for 5 min and were dried in a drier (Model:32706 TSM products, Buffalo, New York, USA) at 50˚C for 24h to 14% moisture. The dried chips were powdered using a laboratory-scale grinder (Jaipan Grinder model IS:4250, India) and sifted through 250 µm sieve. The flour samples were packed and sealed into airtight polyethylene (LDPE) containers and stored at -18°C for further analysis. The yield of flour was determined as the percentage of the initial tuber weight.

2.2.2 Starch extraction

The extraction of starch was done with slight modifications of the method described by Jayakody et al. [2]. The tubers were washed; peeled and fibrous roots were removed, before slicing them into 2-3cm cubes. They were soaked in Potassium metabisulfite (50mg/L) for 1h and then shredded in a Waring blender (Model no; HGB150, USA) for 10s at high speed for 15s. The starch in the slurry was separated from the cell debris by vacuum filtration through a muslin cloth. The filtrate containing the starch was allowed to stand [2-12 hrs] at room temperature until a dense firm starch layer was obtained. The supernatant was siphoned and discarded and the precipitate was suspended in excess 0.02% sodium hydroxide. After standing [4 h] the supernatant was removed. The washing-sedimentation process with alkali was repeated until the supernatant layer was almost free of color and suspended haze. The final sediment was suspended in deionized water, filtered through a Buchner funnel and thoroughly washed on the filter (Whatman no. 02, diameter: 110 mm) with deionized water. The starch was air-dried at room temperature and then passed through a 250 µm test sieve to obtain a free-flowing powder. Then starch was packed into airtight polythene bags and stored in the laboratory freezer at -18°C.

2.2.3 Microscopic Characteristics of flour

2.2.3.1 Granular shape of flour

The granular shape of flour was examined according to the method described by Snyder [10] and Wijesinghe and Gunathilake [11]. A small drop of water was placed on one side of a standard microscope slide. About 5 mg of flour sample was transferred on to the water using a dissecting needle. The flour was mixed thoroughly to disperse flour. A cover slip was placed over the suspension taking care to avoid entrapment of air bubbles. Excess water was wicked off with a small piece of tissue paper held at the edge of the cover slip to obtain a thin film. The granular shape was examined under a polarized light microscope at 40 x magnification.

2.2.4 Chemical analysis of flour samples

2.2.4.1 Proximate composition

All three flour samples were tested for moisture, ash, crude protein, crude fat using standard AOAC methods [12] and crude fibre and mineral (Ca, Mg, Fe, Cu, Zn, Al, Mn, Co) contents. Crude fiber contents were determined by Weendy method using Fibertec^{TM} M6 fiber analysis system (Model: Fibertec^{TM} M6, Denmark). About one gram of dried flour was accurately weighed into the crucible. The crucibles were placed in a fiber analyzer and 100 ml of 1.25% H_2SO_4 was added followed by the addition of 1 ml Octanol. The residue was washed with acetone and dried at 105°C to a constant weight and content in the crucible was incinerated 550°C for three hours. The final weight of the crucible was measured to calculate the crude fiber content of the flour.

2.2.4.2 Determination of mineral contents (Ca, Mg, Mn, Zn, Fe, Ni, Cd, Pb)

The first 0.5 g of each flour sample was accurately weighed into the digestion tubes followed by the addition of 6 mL of Conc. HNO_3. The samples were digested using the MARS 6-Microwave digestion unit (Model-MARS 6 240/50, USA) in One Touch Method for one hour. Digested samples were filtered through filter papers (Whatman 1-pore size: 11µm) into 50 mL volumetric flasks and filled up to mark with deionized water. All the samples were transferred into 50 mL falcon tubes, properly sealed with lids and stored in the refrigerator at 5°C. Standard solutions of 1 ppm, 2 ppm and 3 ppm were prepared from Calcium, Magnesium, Zinc, Manganese, Nickle, Iron, Cadmium and Lead standard stock solutions (1000 mg/L). Calcium, Magnesium, Zinc, Manganese, Nickle, Iron, Cadmium and Lead concentrations in each digested flour sample were analyzed using Thermo Scientific Atomic Absorption Spectrophotometer (Model: iCE 3000 series, USA). The spectrophotometer was calibrated with prepared standard solutions corresponding to each element just before the analysis.

2.2.5 Functional Properties of flour

2.2.5.1 Swelling power and solubility index

Swelling power and solubility were determined according to the method described in Mweta and collegues [7] by dispersing 0.5g of starch samples in 20mL of distilled water in pre-weighed centrifuge tubes. The slurries were heated in a thermostatically controlled water bath at 60, 70, 80 and 90°C for 30min with shaking every 5 min to keep the starch granules suspended. The heated slurries were then cooled to room temperature and centrifuged at 12,100 rpm for 10 min to separate gel and supernatant. The supernatant was decanted carefully and poured into the dish for subsequent analysis of the solubility pattern. Weight of swollen starch was determined and swelling power was determined as the ratio of the weight of the swollen starch to the weight of the starch sample and expressed as a percentage.

2.2.5.2 Water and oil absorption capacity

Water and Oil absorption capacities of the flour samples were determined according to the method described by Beuchat [13] methods. One gram of the flour was mixed with 10 mL of water or oil in a centrifuge tube and allowed to stand at room temperature (30±2°C) for 1h. It was then centrifuged at 4500 rpm for 30 min. The volume of water or oil on the sediment-water was measured. Water and oil absorption capacities were calculated as ml of water or oil absorbed per gram of flour.

2.2.5.3 Gelatinization characteristics

Gelatinization characteristics were determined using Brabender Visco-amylograph (Model: 8001, Duisburg, Germany). Sixty grams of sieved flour were weighed and mixed firmly in a beaker with 350 mL water to smooth slurry without lumps. This slurry was poured into the central bowl. The probe was placed carefully in the center of the bowl. The instrument was allowed to continue working until the temperature reaches 95°C. When a temperature of 95°C was reached the slurry was held at 95°C for 30 min followed by cooling from 95°C to 50°C. It was again held for 30 min at 50°C before ending the process.

2.2.5.4 Viscosity

The viscosity of flour samples was measured using the method described by Reddy and Bhotmange [14] with some slight modifications. A Rotational Viscometer (Fungilab Rotational Viscometer Model: VISCO ELITE-R, Barcelona, Spain) was used to determine the viscosity. The flour solution (3% w/v) was prepared by mixing three different tuber flour varieties with distilled water. The flour solutions were boiled for 10 minutes and then cooled to room temperature (30°C). The reading of time was noted at 100 rpm, the reading of viscosity in Centipoise. During heating and cooling, gruels were stirred intermittently.

2.2.5.5 Emulsion activity and stability

Emulsifying properties were determined according to the method given by Naczk et al. [15] with slight modifications. Flour sample (3.5 g) was homogenized for 30s in 50 mL water in a homogenizer at high speed and 25 mL of mustard oil was added before homogenizing the mixture again for 90s. The emulsion was divided evenly into two 50 mL centrifuge tubes and centrifuged at 1100 rpm for 5 min. Emulsifying Activity (EA) was calculated. The emulsion stability (ES) was determined using the samples prepared for the measurement of EA. They were heated for 15 min at 85°C, cooled and centrifuged again 1100 rpm for 5 min. The ES was expressed as the % of EA remaining after heating.

2.2.5.6 Foaming capacity and foam stability

The method used to determine foam capacity and foam stability was described by Narayana and Narasinga [16]. Two grams of flour sample was added to 50 mL distilled water at 30±2 ˚C in a 100 mL measuring cylinder. The suspension was mixed and properly shaken to foam and the volume of the foam after 30s was recorded. The foam capacity was expressed as a percentage increase in volume. The foam volume was recorded 1h after whipping to determine the Foam Stability as a percentage of the initial foam volume.

2.2.5.7 Least gelation concentration (LGC)

LGC was determined by Sathe et al. [17]. Test tubes containing suspensions of 2,4,6,8,10, 12,14,16,18 and 20% (w/v) of material in 5 mL distilled water were heated for 1 hour in boiling water bath followed by rapid cooling under running tap water. The tubes were further cooled under running tap water. The tubes were further cooled at 4°C for 2h in a thermostat-controlled cooling device. LGC is the concentration above which the sample did not fall or slip when the test tube inverted.

2.3 Statistical Analysis

Significant differences between the results were calculated using ANOVA (General linear model and Tukey test) with the help of Minitab 18. Differences at $P < 0.05$ were considered to be significant. Complete Randomized Design (CRD) was used for the study. Results were expressed as mean ± Standard deviations. Values were the average of triplicate experiments.

3. RESULTS AND DISCUSSION

Microscopic techniques are widely used to characterize the size and shape of starch granules. *C. esculenta* flour is having polygonal-shaped starch granules (Fig. 2A). *X. sagittifolium* flour is having round-shaped and hemispherical shaped starch granules (Fig. 2B). Whereas, *P. rotundifolius* flour has dome-shaped, spherical and hemispherical starch granules with 4-5 facets (Fig. 2C). The smallest granule size is observed in *C. esculenta* flour when compared with *X. sagittifolium* and *P. rotundifolius* flour which are having more or less similar granule sizes. As indicated by Mweta et al. [7] *C.*

esculenta (Cocoyam) is having polygonal (polyhedral) and truncated shape small starch granules. According to Moorthy [18], *X. sagittifolium* starch granules are mostly rounding. The granule shape of *P. rotundifolius* starch observed in this study is following the Jayakody et al. [2]. As stated in Sefa-Dedeh and Sackey [19], the deference in starch granule shapes have also been known to be greatly influenced by the environment of growth. Senanayake et al. [9] reveal that the digestibility of starch with smaller granule sizes is fairly high when compared to larger size granules. Starch granule size and shape is vital as properties of starch depend on them. Microscopic views of the flours obtained from three yams are shown in Fig. 2.

3.1 Proximate Composition and Mineral Content

X. sagittifolium had the best flour yield (20.7 %) and *P. rotundifolius* gave the lowest flour yield 11.39%. Flour yield of *C. esculenta* was 14.5 %. As recorded in Table 1, The highest moisture content (80.46%) was recorded for *C. esculenta* when compared with *X. sagittifolium* (69.77%) and *P. rotundifolius* (77.91%). The presence of components like lipids, protein, carbohydrates, fibres, moisture, ash affects physicochemical properties and they are interconnected with functional properties as well. There was a significant difference among the moisture contents of raw tubers of *C. esculenta*, *X. sagittifolium* and *P. rotundifolius* ($p<0.05$). The ash content is an estimation of the total mineral content of the flour. There was a significant difference ($p<0.05$) in the ash content of *X. sagittifolium* and *P. rotundifolius* flours when compared with *C. esculenta*. Ash contents of three flours ranged from 2.08 to 3.67% (Table 1). It has been suggested that higher ash contents of starch are a result of the presence of material commonly referred to as “fine fibre” [20]. Nevertheless, the higher ash content has indicated the lower yield of flour due to higher fine fibre content. The protein content of the flour is a significant chemical attribute since most of the functional properties like Water Holding Capacity, Oil Holding Capacity, Emulsifying Activity, and Emulsion Stability, Foaming Capacity and Foam Stability and Least Gelation Concentration depend on the protein available in the flour. The amount of crude protein present in three flour types ranged from 3.52% to 9.63% (Table 1). *P. rotundifolius* flour (9.63%) exhibited the highest protein content and *C. esculenta* flour (3.52%) was having the lowest protein content according to the study. The study reveals that *C. esculenta*, *X. sagittifolium*, and *P. rotundifolius* flour have protein contents nearly similar to wheat flour, having 10% protein content and corn flour having 6.9% protein content. There were very less amount of crude fat present in C. esculenta and *P. rotundifolius* flours, whereas *X. sagittifolium* flour (0.570%) had a considerable amount of crude fat (Table 1). Therefore, unlike wheat flour which is having 1% of fat and corn flour which is having 0.1% of fat, *P. rotundifolius* and *C. esculenta* flour can be much healthier in terms of reducing fat consumption as substitutes to corn and wheat. According to Eddy et al. [1], Since high fat intake and obesity appear to relate to the incidence of cancer of the breast, colon, and ovary, increasing disease risk by influencing turn over behavior than actually being causative, *C. esculenta* with its relatively low-fat content (0.01) recommendable for obese patients. According to Premathilake [6], *P. rotundifolius* raw tubers are said to have 0.1-0.2 g of fat per 100g of raw tubers. As per this study, when *P. rotundifolius* is processed into flour considerable reduction in fat can be observed. As reported by Senanayake et al. [9], *X. sagittifolium* flour is said to have 2.3% of crude fat content which is much higher than the results obtained for *X. sagittifolium* flour (0.57%) this study. The crude fibre content of *C. esculenta*, *X. sagittifolium*, and *P. rotundifolius* flour was considerably high ranging from11.25% to 13.75% (Table 1). There was no significant difference among the crude fibre contents of all three flour types ($p>0.05$).

According to Table 2, only Cadmium and Lead were not detected which depicts that these three tuber flours do not contain any trace amount of heavy metals like Cd and Pb. The highest Calcium content was recorded for *C. esculenta* flour (0.23%) and the lowest Calcium content was recorded for *X. sagittifolium* flour (0.16%). As reported by Premathilake [6], *P. rotundifolius* had 0.006 % of Iron in this study; the content of Iron was recorded as 0.007% which is acceptable. A high content of Calcium in *C. esculenta* may lead to irritation due to Calcium oxalate crystals as Oxalate is present in high amounts in *C. esculenta*. Hence, it can affect the palatability of *C. esculenta*. According to Iwuoha and Kalu, [4], Oxalate content can be reduced by boiling *C. esculenta* to increase palatability.

3.2 Swelling Power

The swelling power of starch granules is critical to be known in the food process industry for noodle production. Characteristic swelling quality of dried instant/noodle products during boiling can be elucidated by the swelling power of starch granules. The highest swelling powers for yam flours were observed at 80°C and 90°C. Swelling powers of three flours were significantly different ($p<0.05$) at four different temperatures (60°C, 70°C, 80°C, 90°C) but there was no any significant difference ($p>0.05$) among swelling powers of three flour types at each measured temperature (Fig. 3). The highest swelling power lied within the gelatinization temperature range of each flour type. The highest swelling power (13.174%) at 80°C was observed for *C. esculenta* flour and swelling power had reduced with the increment of temperature to 90°C. It is due to *C. esculenta* flour, having a low gelatinization temperature range where it completes the gelatinization of all starch granules before 90°C. *X. sagittifolium* and *P. rotundifolius* flours showed increments in swelling power with the increasing temperature up to 90°C and at 90°C *X. sagittifolium* flour showed the highest swelling power. This was because *X. sagittifolium* and *P. rotundifolius* flour may be having a high gelatinization temperature range compared to *C. esculenta* flour. According to Adeleke and Odedeji [21], the Swelling powers of wheat flour, Rice flour and Potato flour are 17.6%, 15.2%, and 42.9% respectively.

3.3 Solubility Index

The Solubility indices of starch are attributable to how well the starches can be extruded in the development of extruded products. The best solubility indices for *C. esculenta*, *X. sagittifolium*, and *P. rotundifolius* flour were seen at 80°C as indicated in Fig. 4. The solubility indices of three flours at four different temperatures (60°C, 70°C, 80°C, 90°C) were significantly different ($p<0.05$). There was no significant difference ($p>0.05$) among solubility indices of three flour types at each measured temperature. With the maximization of the gelatinization process, the starch granules swell and burst to leach out starch into the solution.

3.4 Water Holding Capacity and Oil Holding Capacity (WHC & OHC)

The highest WHC (1.789 mL/g) was recorded for *P. rotundifolius* flour and the lowest WHC (1.091 mL/g) was recorded for *X. sagittifolium* flour (Fig. 5.). However, there was no significant difference ($p>0.05$) among WHCs of three flour types and there was no significant difference ($p>0.05$) among OHCs of three flour types. High WHC of *P. rotundifolius* flour may be due to the high availability of polar amino acids like aspartic acid and glutamic acid. Low WHC in some flours may be due to less availability of polar amino acids. WHC of flours suggests that the flours can be used in the formulation of some foods such as sausage, dough, processed cheese, and bakery products. The increase in the WHC has always been associated with an increase in the amylose leaching and solubility and loss of starch crystalline structure. According to Butt and Batool [22], the flour with high water absorption may have more hydrophilic constituents such as polysaccharides.

The same pattern as in WHC could be observed in OHC as the highest OHC (0.991 mL/g) was recorded for *P. rotundifolius* flour and lowest OHC (0.498 mL/g) was recorded for *X. sagittifolium* flour. The presence of high-fat content in flour might have affected adversely the OHC of the *X. sagittifolium* flour (Fig. 5). However, the flours in the present study are potentially useful in structural interaction in food especially in flavor retention, improvement of palatability and extension of shelf life particularly in bakery or meat products where fat absorption is desired.

3.5 Gelatinization Characteristics

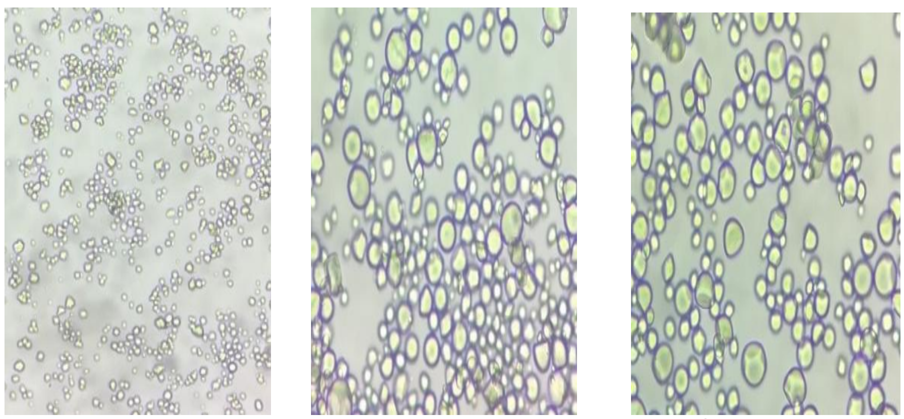
As summarized in Table 3, gelatinization characteristics can be calculated from Brabender Viscoamylographs shown in Fig. 6 (A), (B) and (C) respectively for *C. esculenta* flour, *X. sagittifolium* flour, and *P. rotundifolius* flour. Gelatinization temperatures (GT) of *C. esculenta*, *X. sagittifolium*, and *P. rotundifolius* flour ranged between 65-84°C, 75-94.5°C, 72-86.25°C respectively. *C. esculenta* flour had the lowest GT, which is more preferred as it may consume less energy for pasting. The highest peak gelatinization viscosity was recorded for *X. sagittifolium* flour (2510 BU). From the three flour types, *C. esculenta* exhibited the least time (36 min.) to reach peak viscosity. When compared with Wheat and Corn flours these tuber flours exhibit high gelatinization viscosity values. The gelatinization temperature ranges are similar to that of wwheat, Corn and Rice flour. According to Ubwa et al. [23], gelatinization temperature ranges of wheat, corn, and rice are 52-66°C, 66.2-77°C, 66-82°C respectively. Hence with high viscosities within appropriate gelatinization temperature ranges of *C. esculenta*, *X. sagittifolium*, and *P. rotundifolius* flour, they can be utilized in many aspects of the food industry.

3.6 Viscosity

Viscosity is a significant rheological property that indicates the behavior of slurry with the increment of temperature and application of mechanical agitation. *P. rotundifolius* flour exhibited the highest viscosity of 280cP. The viscosities of flours followed the order; *P. rotundifolius* > *X. sagittifolium* > *C. esculenta*. *C. esculenta* flour has the lowest viscosity (50cP). It is even depicted by the results obtained for gelatinization viscosities as *C. esculenta* had the lowest viscosity ranges during gelatinization. However, this high viscous flour may be used in the food industry successfully, to develop thickeners that may be used in sauces, dressings and the like.

3.7 Emulsifying Activity and Emulsion Stability

Emulsifying activity (EA) and emulsion stability (ES) are two attributes held by the protein component of a flour type. *P. rotundifolius* flour exhibited the highest emulsion stability (112.65%) but a lower emulsifying activity. *C. esculenta* flour had both emulsifying activity (33.98%) and emulsion stability (62.71%) at a considerable level. Increasing EA, ES, and fat binding during processing are primary functional properties of the protein that can be possessed by a food ingredient for them to be used in foods such as comminuted meat products, salad dressing, frozen desserts, and mayonnaise.



(A) (B) (C)

Fig. 2. Microscopic view of starch granules of (A) *C. esculenta* flour (B) *X. sagittifolium* flour (C) *P. rotundifolius* flour at ×400 magnification as observed under Compound Light Microscope

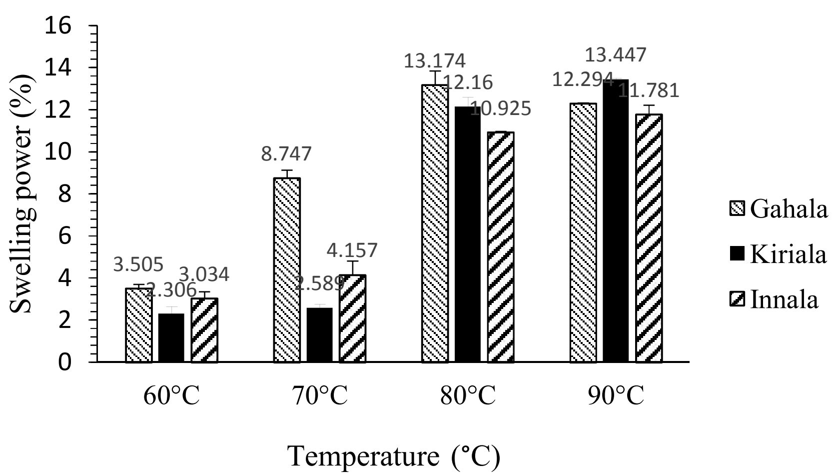


Fig. 3. Swelling powers of Gahala (*C. esculenta*), Kiriala (*X. sagittifolium*) and Innala (*P. rotundifolius*) flours at 60°C, 70°C, 80°C and 90°C

Table 1. Proximate composition of flour obtained from *C. esculenta*, *X. sagittifolium* and *P. rotundifolius*

Flour type	Moisture %	Ash %	Crude protein %	Crude fat %	Crude fibre %
C. esculenta	80.46±1.41[a]	3.67±0.01[a]	3.52±0.23[c]	0.016±0.00[b]	11.25±0.32[a]
X. sagittifolium	69.77±1.09[c]	2.47±0.09[b]	5.39±1.13[b]	0.570±0.36[a]	13.75±0.73[a]
P. rotundifolius	77.91±1.06[b]	2.08±0.57[b]	9.63±0.95[a]	0.006±0.00[c]	11.35±0.67[a]

Average values of three measurements (For n=3 ± SD), All data reported on a dry basis, Values followed by the same letter in each column are not significantly different (p>0.05) by Tukey's test

Table 2. Composition of selected minerals of flour obtained from *C. esculenta*, *X. sagittifolium* and *P. rotundifolius* (Dry weight basis)

Flour type	Mineral composition (%)							
	Ca	Mg	Zn	Fe	Mn	Ni	Cd	Pb
C. esculenta	0.23±0.01[a]	0.127±0.00[a]	0.009±0.00[a]	0.009±0.00[a]	0.001±0.00[a]	0.004±0.00[a]	ND	ND
X. sagittifolium	0.16±0.01[c]	0.071±0.00[c]	0.002±0.00[b]	0.008±0.00[a]	0.001±0.00[a]	0.003±0.00[b]	ND	ND
P. rotundifolius	0.21±0.00[b]	0.084±0.00[b]	0.003±0.00[b]	0.007±0.00[a]	0.001±0.00[a]	0.002±0.00[c]	ND	ND

Average values of three measurements (For n=3 ± SD), All data reported on a dry basis, ND means Not Detected

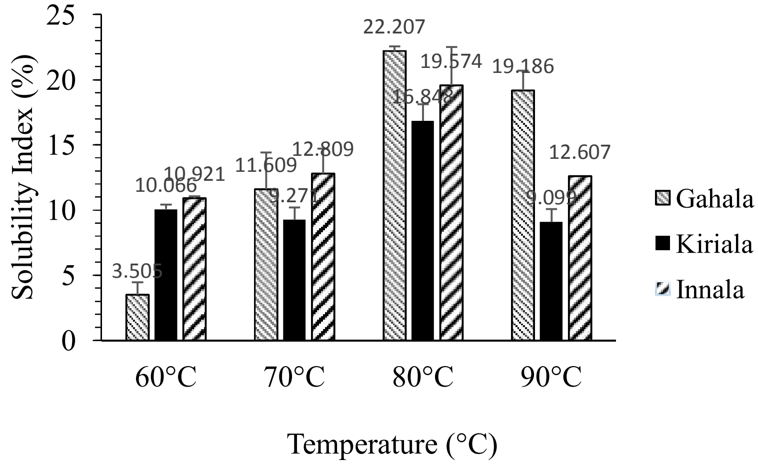


Fig. 4. Solubility indices of Gahala (*C. esculenta*), Kiriala (*X. sagittifolium*) and Innala (*P. rotundifolius*) flours at 60°C, 70°C, 80°C and 90°C

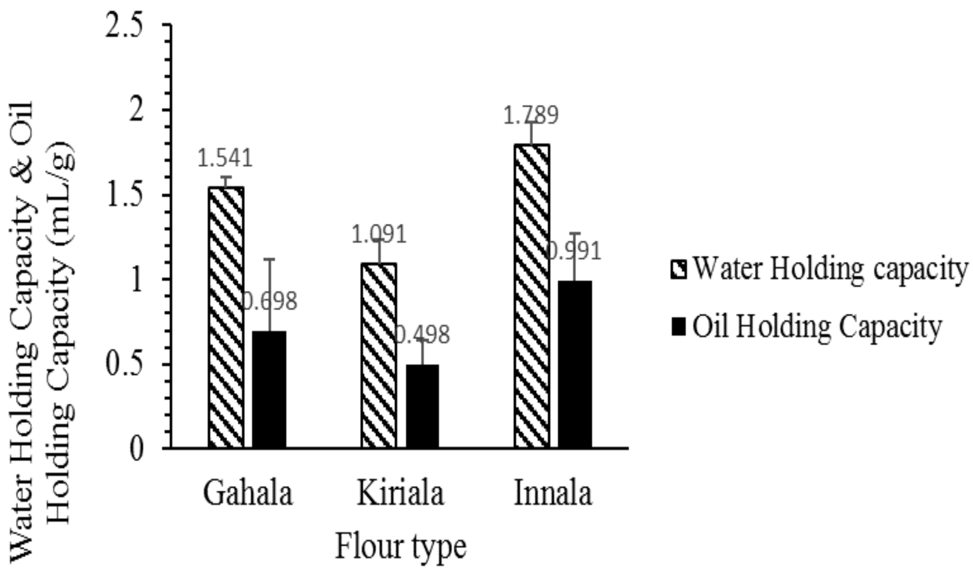


Fig. 5. Water and oil holding capacities of gahala (*C. esculenta*), kiriala (*X. sagittifolium*) and innala (*P. rotundifolius*) flours

Table 3. Gelatinization characteristics of *C. esculenta*, *X. sagittifolium* and *P. rotundifolius* flour as calculated from respective Brabender Visco-amylographs

Sample	Peak Viscosity (BU)	Viscosity at 95°C (BU)	Viscosity after holding at 95°C (BU)	Viscosity at 50°C (BU)	Viscosity after holding at 50°C (BU)	Peak time (minutes)	Gelatinization temperature range (°C)
C. esculenta	1240.0±31^{b}	1070±12^{c}	830±31^{b}	1080±61^{b}	1520±10^{b}	36.±2 min^{b}	65-84°C
X. sagittifolium	2510.0±18^{a}	2500±21^{a}	1130±23^{a}	1190±39^{a}	1820±7^{a}	43±3 min^{a}	75-94.5°C
P. rotundifolius	2490.1±20^{a}	1955±11^{b}	870±44^{b}	1055±43^{b}	1415±6^{c}	37.5.±1min^{b}	72-86.25°C

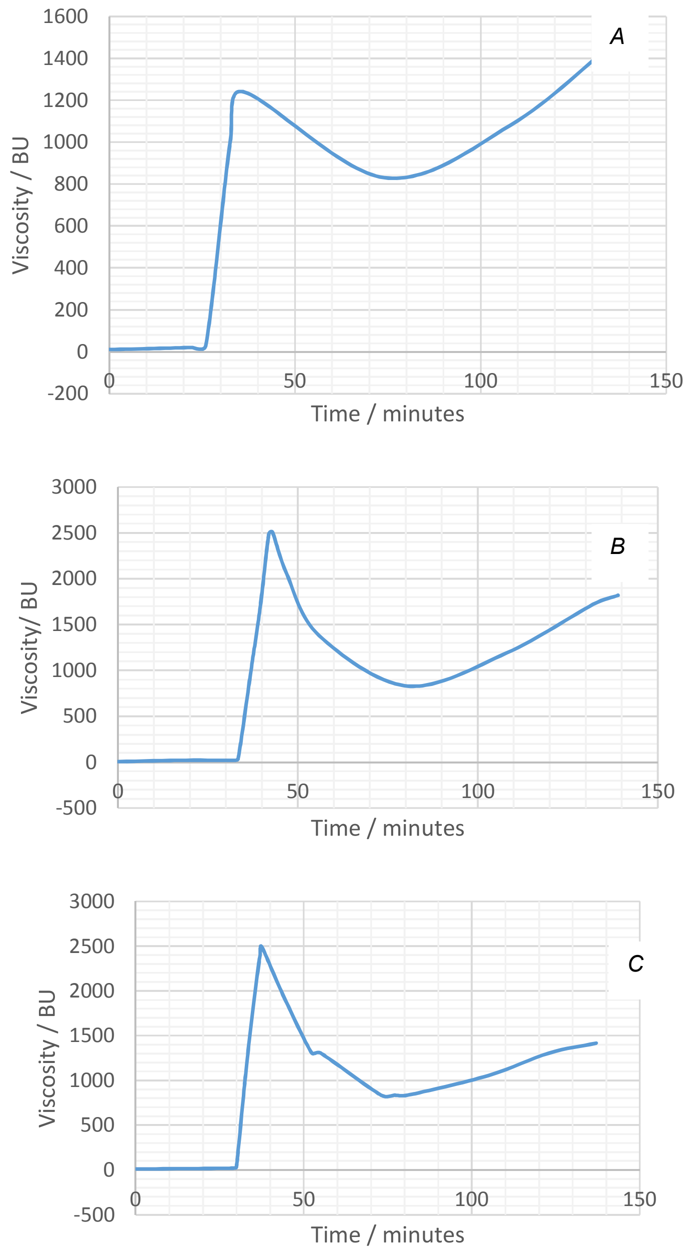


Fig. 6. Brabender visco-amylograph for (A) *C. esculenta* flour (B) *X. sagittifolium* flour (C) *P. rotundifolius* flour

3.8 Foaming Capacity and Foam Stability

For the development of bakery products, it is equally important to consider the foaming capacity and foam stability of flour. Foaming capacity ranged between 4.33 - 12.81% and foam stability ranged between 32% and 83.93% for *C. esculenta*, *X. sagittifolium*, and *P. rotundifolius* flour. All three flour types showed low foam capacity and high foam stability, which are highly desirable in the food industry. Flour with high foaming ability is known to form large air bubbles surrounded by thinner less flexible protein film. According to Jitngarmkusol et al. [24], air bubbles easily collapse and consequently lower foam stability.

3.9 The Least Gelation Concentration

LGC is indicative of the gelation ability of protein components in flour. LGC of *C. esculenta*, *X. sagittifolium*, and *P. rotundifolius* flours were 7%, 6%, and 5% respectively. *P. rotundifolius* flour had the lowest Least Gelation Concentration. The gelation capacity of flour is influenced by physical competition for water between protein gelation and starch gelatinization (Kaushal et al. [25]. The lower the LGC, the better the gelation ability of the protein ingredient. These three types of tuber flour are having similar LGC when compared with LGC of corn (6%), rice (6%) and wheat (8%) [25]. Therefore, they would be useful in food systems such as puddings, sauce and other foods that require thickening and gelling.

4. CONCLUSION

The study evaluated on the granule morphology, physicochemical and functional properties of flour obtained from Gahala (*C. esculenta*), Kiriala (*X. Sagittifolium*), and Innala (*P. rotundifolius*) grown in Sri Lanka and to manifest their potential in utilization in the food industry. The study revealed that there is a considerable amount of protein (9.63%) in *P. rotundifolius* flour by which it can be concluded that *P. rotundifolius* flour should be having good functional properties as well. It can be inferred that these flour types may be exploited in the food industry as the functional properties due to proteins (water holding capacity, oil holding capacity, foaming capacity & stability, emulsifying capacity, least gelation concentration) were showing such propensity. The high amounts of crude fiber in three types of flour indicate the importance of investigating dietary fibre available in *C. esculenta*, *X. Sagittifolium* and *P. rotundifolius*. Gelatinization characteristics revealed that *C. esculenta* flour had the lowest GT, which is more preferred as it may consume less energy for pasting. Hence it is evident that the overall study sheds some light on the fact that there is a potential for utilizing *C. esculenta*, *X. Sagittifolium* and *P. rotundifolius* flour in the food industry, as they can be successfully incorporated in food products through further research and product development.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

ACKNOWLEDGEMENTS

We greatly acknowledge the financial support provided by the Wayamba University Research Grant (SRHDC/RP/04/16-12).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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