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FULL PAPER

Sulawesi endemic tubers and perimedular flour properties an initial consideration for alternative sources for food starch ingredient

[1]Moko, E.M., [2,*]Rahardiyan, D., [1]Ngangi, J. and [1]Yalindua, A.

[1]*Biology Department, Mathematics and Natural Sciences Faculty, Manado State University, Tondano, 95619, Indonesia*
[2]*Faculty of Agriculture Universitas Katolik De La Salle Manado, Manado, 95253, Indonesia*

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Abstract

North Sulawesi is located in the North-Eastern regions of the Indonesian Archipelago. As it is with most parts of Indonesia, North Sulawesi is dependent on rice as their staple food. Not all islands within the North Sulawesi cluster of islands can grow paddy or corn for their carbohydrate needs or starch ingredients in their diet and must have them shipped from other places with the dire consequences of transportation costs. The endemic biodiversity of these islands also has many plants with the potential as an alternative food carbohydrate source. This study was to explore these endemic plants for potential food ingredients for starch replacements for rice and corn. The many diversities available for these starch ingredients amongst them are tuber sources (Taro – *Colocasia esculenta*, Dalugha – *Cyrtosperma merkusii*, Gembili – *Discorea esculenta* and Banggai – *Discorea alata*) and perimedular sources (Sago Tanah and Sago Baruk). Many studies have researched these plants individually in various originating from many other parts of the world, but not many have made a head-to-head comparison and explored the potentials of these underutilized plants as starch food ingredients. This study extracted starches of these plants in a standardized manner and compared the properties side-by-side. These plants were found to be potentially healthy alternatives to rice as functional food starch with lower digestibility which would lead to lower GI staples, especially for the livelihoods of North Sulawesi coastal dwellers.

1. Introduction

Indonesia's food security to date has been very dependent on rice as the major staple food of the people. Rice is the daily staple, while tubers and perimedular starch foods though exist amongst the staples of the people has not been the main staple food. In some corners of the archipelago, these tubers and perimedular foods are staples or used to be staples from long lost cultures of the older generations. Nowadays these foods have lost their popularity amongst the younger generations.

Roots and tuber food crops are considered an important food source in the global food supply with wide applications since the roots are good storage of food starch materials (Chandrasekara *et al*., 2016). These tubers and perimedular crops are endemic to most parts of the Indonesian archipelago but are much underutilized. Yet they are an abundant source of food starch ingredients.

North Sulawesi is one of the North-Eastern islands of the archipelago that is rich in endemic biodiversity with much potential as a source of staple carbohydrates and as functional foods. Amongst the local plants of North Sulawesi that are potential staples are the popular *Colocasia esculenta*, *Ipomoea batatas* and Sago (*Metroxylon sagu*), Sago Baruk (*Arenga microcarpha*) and Dalugha (Giant Swamp Taro/*Cyrtosperma merkusii*) and Sago Tanah (*Tacca leontopetaloides*). These plants are mainly endemic to islands surrounding North Sulawesi (Islands of Sangihe and Talaud). *Colocasia esculenta*, *Ipomeae batatas* and Dalugha (Giant Swamp Taro/*Cyrtosperma merkusii*) are tuber-based starch origin, while Sago (*Metroxylon sagu*), Sago Baruk (*Arenga microcarpha*) and Sago Tanah (*Tacca Leontopetaloides*) are starch staples that are taken from the perimedular of the plant. *Colocasia esculenta* is a very popular tuber crop in most tropical ecosystems like Indonesia, and mainly used for its corm (Alcantara *et al*., 2013). *Colocasia esculenta* is a very popular traditional food source that has been cultivated for over 10,000

*Corresponding author.
Email: *drahardiyan@unikadelasalle.ac.id*

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years in Papua New Guinea and the Solomon Islands (García-de-lomas, 2012).

Many pieces of research have been done on these plants and their starches throughout the archipelago. Only a few were done on endemic plants of North Sulawesi. *Dalugha* (Sundar, 2016), *kolerea* (Sundar, 2016; Tattiyakul *et al*., 2006), *longki* and *wongkai* (Lintang *et al*., 2017) are some of the plants that have been studied and were characterized with significant differences in amylose and amylopectin ratios in their starch (42.70-47.51%, 15-27.47%, and 16-27% respectively). All flours of these plants had different whiteness indexes, while *longki* had the highest whiteness index and the lowest brownness index. *Kolerea* in this report had the best potential for a prospect starch source food with the highest yield of 31.2% and the highest starch content of 49.51% and protein of 3.47%. Ranking second on amylose content at 25.74% (Lintang *et al*., 2017). Unfortunately, not many of these researches have reported a head-to-head comparison on the properties of these starch sources and built on the potential of utilizing these plants for the main starch ingredient in foods, especially in places where rice or corn are not available or grow. The importance of this research emphasized the potential of reviving underutilized crops of North Sulawesi as local resources that could contribute to starch food ingredients in North Sulawesi, which to a certain degree would have their contributions to the carbohydrate-based foods and further to the food security and sustainability of region.

2. Materials and methods

2.1 Materials

Samples of taro tubers (*Colocasia esculenta*), dalugha tubers (*Cyrtosperma merkusii*), banggai tubers (*Discorea alata*), gembili tubers (*Discorea esculenta*), sago tanah perimedulars (*Tacca leontopetaloides*) and sago baruk perimedulars (*Arenga microcarpa*) are all collected from the island clusters of Sangihe Regency and Talaud Regency, of the Northern islands of North Sulawesi. Except for *Colocasia esculenta*, the other tubers and perimedular food sources are underutilized. Sago (*Metroxylon sagu*) are also found within these island clusters but were not sampled since they are more commonly used even though are positioned as the main staple. Chemicals used in the analysis and tests are all analytical grades.

2.2 Starch extractions

All samples (tubers and perimedulars) were extracted for starch. All tubers were pureed, while the perimedulars were collected, and all were individually soaked in distillate water for 24hours and further filtered with a filter cloth. The supernatant was left again for another 24 hrs until more starch sediments and further separated. Collected starch was then left to dry at room temperature until the starch was completely dried.

2.3 Physico-chemical properties of starches

Characteristic testing of starches includes moisture content (gravimetry method-AOAC - Association Of Analytical Chemist, 2019), ash content (gravimetry method-AOAC, 2019), fat content (Soxhlet-AOAC, 2019), protein content (micro Kjeldahl method-AOAC, 2019), carbohydrate (difference method-AOAC, 2019), fibre (gravimetry method-AOAC, 2019), energy (AOAC, 2019), starch content (tetrimetry-AOAC, 2019), amylose content (spectrophotometry-AOAC, 2019), amylopectin (difference method-AOAC, 2019), enzymatic starch digestibility (Belitz *et al*., 2009) and resistant starch by the analytical method according to the Goñi *et al*. (1996).

The procedure for the enzymatic starch digestibility was done by a vortex of 0.25 g of flour (starch) with 25 mL of distillate water, a starch solution is then heated in a water bath up to 90°C in constant shaking, after reaching 90°C solutions is then cooled, 2 mL of the solution is then moved to reaction tubes and 3 mL of distillate water and 5 mL of phosphate buffer (pH 7) was added. Which was repeated twice, where 1 was coded as sample (A) and the other as blank (a). The blank is used as a base for initial glucose/maltose content (not post enzymatic hydrolysis). Both tubes were closed, vortexed and incubated at 37°C for 30 mins. Sample tube (A) was added 40 mg/mL α-amylase (Sigma A-3176) that was previously diluted in phosphate buffer (pH 7), while blank (a) was added 5 mL of phosphate buffer (pH 7), both vortexed and left incubating for another 30 mins. 1 mL of each A and a was pipetted and moved to reactions tubes which were previously added with 2mL DNS (3,5-Dinitrosalicylic Acid; Sigma Aldrich-128848.100 g), Mixtures were heated in boiling water for 10 mins then cooled under running water. The distillate water (10 mL) was added to mixtures and homogenized. Absorbency was measured at 520 nm. Readings are then plotted towards a standard curve. The standard curve was designed as 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 mL stock maltose (0.5mg/mL) which was standardized to 1.5 mL with distillate water and follow through with the process.

Starch digestibility was then calculated as:

$$\text{Starch Digestibility (\%)} = \frac{A - a}{B - b} \times 100\%$$

Where A = Maltose content in the sample, a = Maltose content in blanks, B = Maltose in Pure Starch, and b = Maltose in Pure Starch blanks

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3. Results and discussion

Properties of the starch flours of all the tubers and perimedulars which includes Taro, Gembili Tuber, Dalugha's from both Sangihe and Talaud, Sago Tanah and Sago Baruk, and finally the Banggai Tubers are in Table 1 and Table 2.

3.1 Moisture content

Flour of Sago baruk had the highest moisture content and Sago Tanah flour had the lowest moisture content (Table 1). The flour of Dalugha from Talaud, unlike the ones from Sangihe had higher moisture, close with the moisture contents of Taro's (*Colocasia escculenta*). Previous work (Lintang *et al*., 2017) have discovered that the moisture content of dalugha was 9.20%, while the findings of Sangihe dalugha was 20.07±0.08% and Talaud dalugha was 29.08±0.03%. Differences may have been due to the different methods of drying, temperature and initial conditions of the tubers. The important role of moisture is closely related to gelatinization and therefore works much like a plasticizer, keeping starch granules pasted together throughout heat processing (Sudha and Leevathi, 2012). Most common commercial starch products like potato starch (flour) have a moisture content of 15.98%, rice starch has a moisture content of 8.51% (Tharise *et al*., 2014). Moisture content is important regulator of rheological properties (adhesiveness, hardness and cohesiveness). These properties would impact the solidness of the mass, in which the higher the moisture content the looser and waterier the mass would be (Quintanar *et al*., 2009). Whereas lower moisture content would affect shelf life due to more stable water activity. Product quality degradation is minimum on products with low moisture content due to the restriction of the respiration process and microbial activities.

3.2 Ash content

Ash content of Sago Baruk and Sago Tanah was the lowest. Both Dalugha tubers (Sangihe and Talaud) had more ash content than other flours, with 0.60±0.05% for the Talaud Dalugha and the Sangihe Dalugha flour had the highest ash content of 1.14±0.03% (Table 1). In previous research, the ash content of dalugha was 1.55% (Lintang *et al*., 2017). In comparison to ash contents of several other flours in Indonesia such as rice flour, potato flour, soy flour and cassava flour are 0.39%, 0.16%, 4.23% and 1.06% respectively (Tharise *et al*., 2014). Mocav flour on the other hand had 0.4% ash content and wheat flour 1.3% .

3.3 Fat content

The highest fat contents were in Sago Tanah, Taro and Gembili (Table 1). The fat content of potato flour, rice flour, cassava flour and soy flour was 0.29%, 0.58%, 0.65% dan 27.15% (Tharise *et al*., 2014), mocav flour had a fat content of 0.4% and wheat flour had fat contents at about 1.5-2% (Triyono *et al*., 2019). Fat content in starches and flours can interrupt gelatinization. Fat can form complex compounds with amylose, hence slowing the release of amylose from starch granules. Fat also inhibits the water from being absorbed by amylose, which would render the granules dense and with lowering the pasting capacity of the starch, as well as other properties such as elasticity and hydrophobicity (Stasiak *et al*., 2014). The lowest fat content was apparent in the starches of the dalugha tubers, sago baruk perimedulars and the banggai tubers. Fat loss in flour processing is most likely to be the effect of the drying process (Alcantara *et al*., 2013).

Table 1. Properties of the flours of tubers and perimedulars endemic to North Sulawesi

	Taro	Gembili	Dalugha Sangihe	Dalugha Talaud	Sago Tanah	Sago Baruk	Banggai
Total Moisture (%)	30.23±0.25	21.20±0.05	20.07±0.08	29.08±0.03	14.52±0.03	39.99±0.05	16.15±0.05
Total Ash (%)	0.23±0.03	0.39±0.04	1.14±0.03	0.60±0.05	0.09±0.01	0.07±0.01	0.28±0.02
Total Fat (%)	0.97±0.02	0.98±0.01	0.27±0.02	0.42±0.03	0.87±0.02	0.22±0.02	0.38±0.02
Total Protein (%)	0.50±0.10	1.43±0.07	0.32±0.03	0.33±0.03	0.22±0.02	0.22±0.02	0.83±0.03
Total Carbohydrates (%)	68.14±0.02	76.02±0.03	78.22±0.03	69.56±0.04	84.32±0.03	59.54±0.02	82.32±0.03
Total Fiber (%)	1.37±0.03	1.62±0.02	2.77±0.15	1.73±0.15	0.76±0.01	0.63±0.02	1.43±0.02
Energy (cal/100 g)	276.67±1.53	312.33±2.52	302.00±2.65	276.67±1.53	343.33±1.53	237.67±2.52	331.33±1.53

Table 2. Starch Properties of the flours of tubers and perimedulars endemic to North Sulawesi

	Taro	Gembili	Dalugha Sangihe	Dalugha Talaud	Sago Tanah	Sago Baruk	Banggai
Amylose (%)	33.43±0.02	19.81±0.02	15.58±0.02	29.63±0.01	26.38±0.02	29.08±0.02	47.39±0.01
Amylopectin (%)	41.88±0.03	56.28±0.03	52.86±0.02	32.88±0.02	28.28±0.02	24.02±0.03	29.88±0.02
Starch Content (Total %)	75.31±0.04	76.10±0.10	68.43±0.03	65.52±0.02	54.63±0.03	53.08±0.03	77.25±0.02
Starch Digestion	38.60±0.36	51.22±0.03	44.30±0.26	28.28±0.03	35.33±0.15	40.48±0.03	34.33±0.03
Resistant Starch	7.24±0.02	9.37±0.02	11.37±0.03	8.97±0.02	14.96±0.02	10.73±0.02	10.17±0.01

3.4 Protein content

Both Sago Tanah and Sago Baruk have the lowest protein content. Following are the Dalugha of Sangihe and Talaud. Gembili had the highest protein content (Table 1). Protein contents of the flours in the findings were low compared to some other reports that had protein contents up to 6.79% in Sago Tanah (*Tacca leontopetaloides*) flour (Ogbonna *et al*., 2017), 2.3%-4.5% in Taro (Alcantara, 2013), 0.9% in Dalugha or *Cyrtosperma merkusii* (Plucknett, 1977; Ratag *et al*., 2013). Variances and differences in protein content could be caused by variances in soil fertility and geographical origins in regards to nitrogen levels of the soil (Hailu, 2018).

3.5 Carbohydrate

The flours with the highest carbohydrate content were Sago Tanah and Banggai tubers. The lowest carbohydrate content was found in Sago Baruk (Table 1). Carbohydrates in the plant kingdom, in general, would correlate with photosynthesis and are closely related to the energy content of any products related to plants (Marianus *et al*., 2012). The carbohydrates of the Sago Baruk flour closely agrees with the reports of 55.83% (Marianus *et al*., 2012). Reports also portrait the Dalugha would have a high carbohydrate content of 81.45-83.55% (Faridah and Jenie, 2016; Faridah *et al*., 2019). While Sago Tanah had the highest carbohydrate content of all the flours in the range of flours in this work, it agrees with reports on *Tacca leontopetaloides* which reported a carbohydrate content of 78.19-86.07% (Ogbonna *et al*., 2017).

3.6 Fibre content

Dalugha flour from Sangihe had the highest fibre content. Starch flour from Sago had the lowest fibre contents (Table 1). The fibre content for the flours was higher than the national standard for Sago Flours that are already registered in the national standards which are 0.5% dry weight. All flours were beyond this standard. These results were consistent with a report of Sago Baruk flour having higher fibre contents (2.25%) than the standard of 0.5%, which was considered to be caused by processing factors that had also extracted secondary metabolites along and caused the rise in fibre content (Tarigan *et al*., 2018). The fibre content of Dalugha flour in these findings both Sangihe and Talaud appeared low (Table 1) compared to some other work that observed a high fibre content in Dalugha processed into flour-like products (18.55%), this is absolutely due to the differences in processing the flour especially the fact that in this finding Dalugha flour was a simple flour processing that involved sun drying and grinding to 60 mesh not modified in the sense of fermenting with lactic acid bacteria or by heat moisture treatment, in which these treatments are known to raise the fibre contents (Faridah *et al*., 2019).

3.7 Energy

Sago tanah exhibited to have the highest energy. Sago Baruk had the lowest energy of the flours (Table 2). Comparable to rice at 360 calories/100 g of servings in the findings of these flours only Sago Tanah (*Tacca leontopetaloides*) that would come close to rice at 343.33±1.53 calories/100 g, and Sago Baruk (*Arenga microcarpa*) in this finding (Table 2) was the lowest at 237.67±2.52 cal/100 g, which is close to the energy content of Sago Baruk previously observed at 253 calories/100 g (Marianus *et al*., 2012). These flours make a healthy alternative for staple food (Marianus *et al*., 2012). These energy contents are the attributes to main carbohydrates of the flours as protein and fat contents are low (Alcantara *et al*., 2013).

3.8 Starch content and amylose-amylopectin

Understanding a complete starch profile also requires a comparison of the amylose and amylopectin contents of the flours. These are the linear (amylose) and branched (amylopectic) components of the starches (SC) which would describe more on the physical properties of the flour. In Table 2 the highest amylose content was found in flours of Banggai tuber at 47.39±0.01% with an amylopectin content of 29.88±0.02%, which sums up to the total starch content 77.25±0.02%. Taro flours total starch consists of 33.43±0.02% amylose and contains more portions of amylopectin (41.88±0.03%), thus the total starch content is 75.31±0.04%. While Dalugha flour from Talaud had an amylose content of 29.63±0.01% and an amylopectin portion of 32.88±0.02%, the starch content (SC) of 65.52±0.02%. Flour from the perimedulars of Sago Baruk starch content comprises a concentration of amylose at 29.08±0.02% and 24.02±0.03% amylopectin, which totals up to 53.08±0.03%. Sago Tanah perimedular flours had a starch content with a composition of 26.38±0.02% amylose and 28.28±0.02% amylopectin, thus the total starch content was 54.63±0.03%. The Gembili flours starch had 19.81±0.02% amylose and 56.28±0.03% amylopectin and totals up to 76.10±0.10% total starch content. While Dalugha from Sangihe had a total starch content of 68.43±0.03% with the least amylose of all in their starch at 15.58±0.02% and a large portion of its starch as amylopectin (52.86±0.02%).

The starch content of the Dalugha's (Sangihe and Talaud) both (68.43±0.03% and 65.52±0.02% respectively) weren't too far off from the modified version of modified Dalugha starch by acid hydrolysis, pullanase debranching and autoclave-cooling at 64.93% starch content (Faridah and Jenie, 2016). Naturally unextracted and modified starch content of Dalugha alone was 89.58% (Faridah and Jenie, 2016; Faridah *et al*., 2019). Starch content of Taro (*Colocassia esculenta*) in the simple Taro flour made for this work was 75.31±0.04%, which agrees with current research developing extraction methods for Taro flour with starch yield in Taro flour at 76% (Aryanti *et al*., 2014). Colocassia, Cyrtosperma and most other tuber based plants are mainly grown and utilized for their carbohydrate contents and starchy tubers (corms) which supplements as a good source of staple food alternative to rice (Plucknett, 1977). Amylose and amylopectin contents would play a role in starch properties as in swelling power and solubility, where the amylose has more contribution to solubility as is the amylopectin with swelling power (Lerdluksamee *et al*., 2013). Therefore, Banggai tuber flour and flour of Taro would have a higher solubility than other flours, while Dalugha flour from Sangihe and the Gembili flour would have more swelling power than the rest of the flour. These properties are furthermore important in product development and innovations for food products based on these flours.

3.9 Starch Digestion (DS) and Resistant Starch (RS)

Comparing the digestibility and the resistances of the starch within these flours would help pictures the health benefits and its digestibility and the usability of these flours to incorporate in starch-based product development. Starch digestibility of Gembili flour in Table 2 is the highest at 51.22±0.03% of the starch in the flour, with 9.37±0.02% resistant starches. Flour of Dalugha made from Sangihe's Dalugha tubers has starch with 44.30±0.26% of it digestible and 11.37±0.03% are noted to be resistant starches. The Sago Baruk perimedular flour has starches that are 40.48±0.03% digestible and 10.73±0.02% of the starch are resistant starches. Starch from Taro flour are 38.60±0.36% digestible and 7.24±0.02% are detected to be a resistant starch. Sago Tanah perimedular flour contains starches that are 35.33±0.15% digestible and 14.96±0.02% of the starches are resistant. Banggai tuber flour is 34.33±0.03% digestible and 10.17±0.01% are resistant starches. Dalugha flour made from Talaud's Dalughas are least digestible with 28.29±0.03% digestible starches with 8.97±0.02% of the starches are resistant starches (Table 2).

Resistant starch is a type of starch that is not digested by amylase and would need some help from colon microorganisms to degrade via means of glycolysis, on the other hand, digestible starches are starches that are digested by the amylase in the digestive system (Li *et al*., 2014). Resistant and digestible starches both would contribute to the glycemic index and sugar absorption (Valencia *et al*., 2020). Gembili flour contains the most digestible starch of all the flours followed by Sangihe's Dalugha, and Talaud's Dalugha being least digestible. Even though Talaud's Dalugha was least digestible, it did not have the highest resistant starch within the batch (Table 2). These differences are not only defined by starch digestion and resistant starches alone, but further contributing factors are also involved such as the amylose/amylopectin ratio, especially in regards to the steric hindrance in the degrees of branching, and finally, the granule morphology is also necessary to be taken into account (Lerdluksamee *et al*., 2013). Other studies have also mentioned the effects of the existence of waxy/non-waxy starches (Wong *et al*., 2009).

4. Conclusion

Banggai flour had the highest starch content with a good combination of amylose and amylopectin, while the flours from Dalugha of both Sangihe and Talaud also had a decent amount of starch content. This makes the Banggai and the Dalugha tubers to be a potential source of starch food ingredient. Banggai and Dalugha are tuber plants that are easy to cultivate and abundant in the islands of North Sulawesi. The perimedulars also had quality carbohydrate and starch contents, but processing perimedulars would be more complicated than processing tuber flour or starch extraction. Collectively each starch flour (Taro, Gembili, Dalugha from both Sangihe and Talaud, Sago Tanah, Sago Baruk and Banggai) has its strengths and weakness, regardless to their differences, when compared to rice calorie-wise are a healthy alternative, especially in considering the digestibility of the starches. Thus, a deeper study on the properties of these flours and their starches are necessary to determine their true potential, especially as functional starchy foods and the probabilities of their utilization in food creations, despite it all, these flours are potential staples for the livelihoods of the island dwellers in surrounding islands of North Sulawesi, moreover potentially develop-able for non-rice staple food for food security of Indonesia.

Conflict of interest

The authors declare no conflict of interest.

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