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Chemical and Physical Properties of Flour Extracted from Taro *Colocasia esculenta* (L.) Schott Grown in Different Regions of Thailand

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ABSTRACT: Chemical and physical properties of taro *Colocasia esculenta* (L.) Schott flour extracted from different-sized taro corms cultivated in 4 different regions of Thailand were investigated. Taro chips were composed of 84.6 – 91.5 g carbohydrates/100 g flour, 5.1 – 8.7 g protein/100 g flour, 1.1-3.2 g fiber/100 g flour, 2.0 – 5.0 g ash/100 g flour, 0.4 – 0.9 g fat/100 g flour, and 317.0 – 435.8 mg calcium oxalate /100 g flour. The carbohydrate content of taro was not affected by corm size, but by cultivating location. An extraction using 0.05% (w/v) sodium hydroxide yielded purified taro flour (PTF) with lower protein content, compared with the water extraction method. PTF contained 96.9 – 98.2 g carbohydrates/100 g flour, 0.7 – 1.9 g protein/100 g flour, 0.1 – 0.3 g fat/100 g flour, 0.1 – 0.9 g fiber/100 g flour, 0.1 – 0.4 g ash/100 g flour, and 182.0 – 200.1 mg calcium oxalate /100 g flour. All PTFs had 18.8 – 22.4 % amylose, with an average degree of polymerization of 195 – 238. The starch granules were small and polygonal, with an average diameter of 1.3 – 2.2 µm. With an A-type crystalline structure, PTF had a low swelling power of 11.0 – 17.4 g/g dry flour and low solubility of 0.081 – 0.132 g/g dry flour at 80°C. The pasting temperature and peak viscosity of PTF were 78 – 87 °C, and 264 – 441 RVU, respectively.

KEYWORDS: Taro, Flour, Amylose, Degree of polymerization, Pasting property.

INTRODUCTION

Taro *Colocasia esculenta* (L.) Schott is cultivated in the tropical area. Taro corms contain considerable amount of starch (70-80 g/100 g dry taro) [1]. It has been reported that the carbohydrate content of taro cultivated in different locations varied [2]. The starch extracted from taro corms appears as fine granules in the 0.5-5 microns range, [3] and thus offers smooth-textured starch gel. Moreover, the fine granule-starch, was reported to improve binding and reduced breakage of snack products [4]. Also taro starch was reported to be more susceptible to pancreatin hydrolysis than other tuber and root starches [5].

Raw taro corms contain a considerable amount of oxalic acid ($H_2C_2O_4$) in forms of soluble oxalic acid and insoluble oxalate salts [6]. Soluble oxalic acid can form complexes with calcium, magnesium, or potassium, and hence reduces mineral availability in the diet. It has also been reported that insoluble oxalate salts cause skin irritation and a pungent odor in unwashed taro corms [7,8]. Continuing consumption of taro with a high oxalate-salt content can lead to gallstone deposition in the gall-bladder. In a careful extraction of taro starch from its corm, both soluble and insoluble forms of oxalic acid can be partially removed. Iwuoha and Kalu reported that boiling taro corm at 90 °C for 30 minutes and steeping in water at 30 °C for 24 hours can reduce the oxalate-salt content to 32.7% and 56.7% of its original content, respectively [9].

In Thailand, taro pricing is based on corm size. A mature sound taro, 6-month old at harvest and weighing up to 1.2 kilograms, is priced higher than taros of smaller corm size. The smallest taro corm can be as small as 160 grams, and is not preferred for commercial use. However, it has been reported that minute taro corms (60-100 g) are rated highly by Japanese consumers [10]. By far, no study on the effect of corm size on physical and chemical properties of taro starch has been found.

This study aimed to determine the chemical and physical properties of taro *Colocasia esculenta* (L.) Schott flour extracted from commercially large, medium, and small taro corms, which are cultivated in four locations representing the northern (Chiangmai province), central (Saraburi province), western (Kanchanaburi province), and eastern (Trad province) regions of Thailand.

Materials and Methods

Material

Fresh taro corms, in large (L), medium (M), and small (S) sizes, obtained upon harvest from a northern province (Chiangmai; CH), a central province (Saraburi; SB), a western province (Kanchanaburi; KB), and an eastern province (Trad; TR) were purchased from Talard Tai fruit and vegetable outlet in Patumtani province. Due to regional variability, the weight range of each size from different provinces was slightly different (Table 1). Fresh taro corms were peeled, washed, and sliced. Taro slices were dried in a hot air oven at 40 °C for 20 hours. The chips were then analyzed for its proximate compositions prior to subsequent analyses.

Starch Extraction

Water extraction method

Taro chips were ground and sieved through a 35-mesh sifter to obtain taro powder. One part of taro powder was dispersed in five parts of distilled water and let stand for 2 hours. The suspension was later screened through a 200-mesh and 300-mesh sifter, respectively. The suspension was centrifuged at 3000xg and 4 °C for 10 minutes, after which the supernatant was decanted. The sediment was re-suspended in five parts of distilled water. The centrifugation step was repeated 4 times. The sediment was finally dried in a hot-air oven at 40 °C for 16 hours, ground, and sieved through a 100-mesh sifter. The flour was sealed in a plastic bag and kept in a desiccator for further analyses.

Alkaline extraction method

In an alkaline extraction method, 0.05% (w/v) NaOH solution was used in place of distilled water in the first extraction. After the suspension was centrifuged at 3000xg and 4 °C for 10 minutes, the sediment was re-suspended in five parts of distilled water and the centrifugation was carried out. The washing step using distilled water was repeated 4 times. Drying procedure was carried out in the same manner as in the water extraction method.

Table 1. Taro corm sizes with respect to different cultivating areas.

Cultivating area		Corm weight (g)		
		Large (J)	Medium (M)	Small (S)
Chiangmai	(CH)	450-1050	300-400	200-300
Saraburi	(SB)	800-1100	400-500	300-400
Kanchanaburi	(KB)	675-1320	380-600	160-340
Trad	(TR)	600-1200	350-500	200-340

Chemical Analysis

Proximate composition. The proximate composition of all samples was determined following the official method of analysis [11].

Calcium oxalate content. The calcium oxalate contents of all samples were determined following the method of Iwuoha and Kalu [9].

Amylose content. The amylose contents of all samples were determined following the method of Juliano [12].

Degree of Polymerization of Amylose

To prepare starch sample for subsequent fractionation, 100 mg sample was dispersed in 1 mL ethanol and 10 mL of 1 M sodium hydroxide solution in a 50-mL volumetric flask. The volumetric flask headspace air was replaced with nitrogen gas. The flask was let stand at room temperature overnight. The sample-containing flask was then heated in a boiling water bath for 15 minutes and cooled down. The sample was later adjusted to pH 7 using 1 N hydrochloric acid. The sample volume was made up to 50 mL using 0.05% (w/v) sodium chloride solution before it was filtered through a sinter glass filter (number 3).

A volume of filtrate, containing approximately 10 mg dry starch, from the previous step was subjected to fractionation on the Sephacryl 500 HS (Phamacia Biotech, Sweden) connecting with a peristallic pump (model P-1, Pharmacia Biotech, Sweden). The column eluent was 0.05% (w/v) sodium chloride solution with an elution rate of 24 mL/h. Fractions of eluted sample were collected using a fraction collector (Model Redifrac, Phamacia Biotech, Sweden). The amylose fractions were collected and filtered through a microfilter (0.42 μm) before they were examined in a Dawn multi-angle laser photometer (Wyatt Technology Inc.,USA) with a He-Ne laser operating system at 632 nm equipped with 18 detectors at angles ranging from 3.3 to 158° followed by a refractive index concentration detector (Optilab DSP, Wyatt Technology Inc., USA) and using a *dn/dc* value of 0.152 mL/g. The average molecular weight of amylose was calculated using the following equation:

$$M_w = \frac{\sum C_i M_i}{\sum C_i} \quad (1)$$

where, C_i is the concentration of fraction I and M_i is the average molecular weight of amylose of fraction i. Upon getting M_w, the average degree of polymerization (DP_{avg}) can be calculated as following:

$$DP_{avg} = \frac{M_w}{180} \quad (2)$$

Scanning Electron Microscopy (SEM) and Granule Size Analysis

Images of taro starch granules mounted on a stub and gold-coated were recorded using a Scanning Electron Microscope (model JSM-5800 LV, JEOL U.S.A., Inc., Peabody, MA, USA) operating at 20 kV and 5000x magnification.

Surface average granule diameter of taro starch was obtained using a Laser Light Scattering Particle Size Analyser (Malvern Instruments, UK). PTFs were suspended in excess water and let stand for 1 hour before the measurement.

X-ray Diffraction Pattern

Crytallographic patterns of taro starch samples were recorded using an X-ray diffractometer (model JDX-8030, JEOL U.S.A., Inc., Peabody, MA, USA) equipped with Ni-filtered Cu K (radiation and operating at 40 kV and 30 mA). Data were recorded over an angular range of 5° to 45° (2 θ) with a step angle of 0.04°.

Swelling power and solubility determination

Known amount of dry taro flour (m_0; ~ 0.5 g) was dispersed in 15 mL of water. The dispersion was heated under mild agitation at 80 °C for 30 minutes. The gelatinized dispersion was then centrifuged at 3000xg for 15 minutes. After which, the supernatant was decanted and dried at 100 °C until a constant weight (m_s) was reached. The swelling power and solubility were calculated following Eq. 3 and 4.

$$\text{Swelling power [g/g dry flour]} = \frac{m_{sw}}{m_0(1-\text{solubility})} \quad (3)$$

$$\text{Solubility [g/g dry flour]} = \frac{m_s}{m_0} \quad (4)$$

where, m_{sw} is the weight of swollen starch granules.

Pasting Characteristics

Pasting behavior of starch dispersions was investigated using Rapid Visco Analyzer (RVA; series 4 D, Newport Scientific, Australia). The dispersions were prepared by dispersing ~3 g in taro flour (~ 14% MC) in 25 mL of distilled water. The following time-temperature profile was employed: Hold at 50 °C for 1.25 minute, ramp to 95 °C over 3.75 minutes (heating rate 12.0 °C per minute), hold at 95 °C for 2.5 minutes, cooling back to 50 °C over 3.75 minutes and hold at 50 °C for 1.25 minutes. The measurements were done in duplicates.

Results and Discussion

Chemical Properties of Taro Chips

Taro chips are composed of 84.6 – 91.5 g carbohydrate/100 g flour, 5.1 – 8.7 g protein/100 g flour, 1.1-3.2 g fiber/100 g flour, 2.0 – 5.0 g ash/100 g flour, and 0.4 – 0.9 g fat/100 g flour. The chips contained 317.0 – 435.8 mg calcium oxalate /100 g flour. When considering chemical composition of taro cultivating within the same area (data not shown), the medium-sized taro corm from each cultivating area comprised less carbohydrate and more protein content. An exception was found in SB taro which showed no significant difference in carbohydrate and protein contents in flours from taro of different corm sizes. However, there was no correlation between taro corm size and carbohydrate content or other chemical compositions. Moreover, calcium oxalate contents in taro flour from taro of different sizes were not significantly different ($p>0.05$).

It is observed that KB and TR taros had relatively higher carbohydrate content with an average value of 89.2 and 89.0 g/100 g flour, respectively, while SB taro had the lowest average carbohydrate content of 84.5 g/100 g flour. SB taro also contained the highest amount of calcium oxalate (420.9 mg/100 g flour), protein (8.3 g/100 g flour), fat (0.7 g/100 g flour), and ash (4.6 g/100 g flour). The variation was attributed to a variation in the local climate. It has been reported that taros cultivated in arid area contained more protein compared with that grown in humid area [2]. With additional information on average rainfall in the area where the taros were cultivated and in the same cultivating year (the Meteorological department, 2003), it can be seen clearly that the average rainfall (in millimeter) affected the calcium oxalate content and carbohydrate content in taro flour (Figure 1). The calcium oxalate content in taro flour increased while

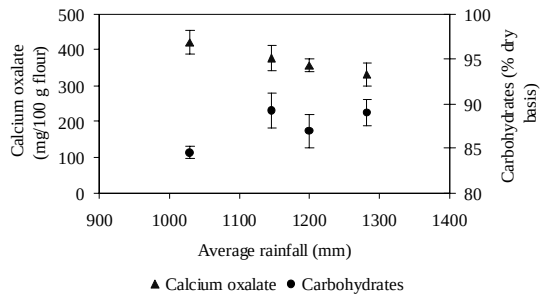

Fig 1. Average rainfall in the region where the taros were grown in 2003 versus calcium oxalate and carbohydrate contents in taro flour.

the carbohydrate content decreased with decreasing average rainfall in the area.

Extraction Process and Chemical Composition of Purified Taro Flour (PTF)

It was found that the alkaline extraction method

reduced the protein content in taro flour to approximately 1.3 g/100 g flour, while the water extraction method reduced it to 3.3 g/100 g flour. This was because of that the protein present in taro flour is alkaline-soluble protein. Therefore, the alkaline extraction method was employed for taro flour extraction in this study. It is noted that, the protein content was reduced to the lowest value of 0.7 g/100 g flour in small size KB taro. The difficulty in the extraction process arose from the mucilage content in taro corms. Several washing steps were needed to be carried out in order to remove slimy mucilage. As a result, the yield, calculated as a percentage of dry taro chips, was relatively low (30.1-47.4 g/100 g dry taro; Table 2).

From proximate analyses of PTF, it was found that the carbohydrate content in the flour extracted from different sizes of taro grown in the same area was not significantly different ($p>0.05$). The protein content in PTF ranged from 0.7 to 1.9 g/100 g flour. The result was consistent with the result on proximate composition of taro chips in that there was no relationship between taro corm size and chemical composition. Table 2 shows chemical composition of PTF from taro grown in four locations. The values shown in Table 2 are the average value from 3 sizes of taro from each cultivating area. PTF is composed of 97.1-98% carbohydrate, 0.9 – 1.7 g protein /100 g flour, 0.3-0.7 g fiber/100 g flour, 0.2-0.3 g ash/100 g flour, and 0.1-0.2 g fat /100 g flour. The flour contained 185.2 – 198.3 mg calcium oxalate/ 100 g, which was below 60% of the initial calcium oxalate content in taro chips. It can be deduced that the extraction process reduced calcium oxalate content of taro by more than 40% in general.

Amylose Content and Average Degree of Polymerization (DP_{avg})

Table 3 shows amylose content of taro starch and DP_{avg} of amylose. The values indicated that taro has low amylose content (18.8-22.4%) that is similar to taro grown in Hawaii [2]. Data on amylose content of different-sized taro corms indicated that PTF from medium-sized taro corms from each cultivating area had the lowest amylose content (data not shown). Moreover, taro starch from taro cultivated in different areas had different amylose contents ($p\leq0.05$), with SB taro starch containing the lowest amylose content (19.4%).

In addition, DP_{avg} of PTF from different areas varied in the range of 195 – 238. In comparison to DP_{avg} of amylose from Hawaiian taro starch (150-550) [2,13], the DP_{avg} of Thai taro amylose varied in a narrower range. The discrepancy was due to the difference in the variety of taro and the cultivating location.

Granule Size and Morphology

Scanning electron micrographs (Figure 2) showed that taro starch granules were small, irregular shapes, and polygonal. The surface-average diameter of taro starch granules of different-sized taro corms grown in different areas ranged from 1.3 mm to 2.2 mm. In two (SB and TR) of the taros studied, the large taro corms had a smaller average starch granule size then the smaller corms. The SB taro had the smallest average starch granule size (1.8 mm), while the KB taro had the largest average starch granule size (2.1 mm) among taros from 4 different locations.

X-ray Diffraction Pattern

X-ray diffractogram (not shown) of taro starch

Table 2. Average chemical compositions of PTF from taro of different origins.

Cultivating area	Yield (% of dried chip)	Percentage (dry basis)					Calcium oxalate(mg / 100 g) [% of initial content]
		Protein	Fat	Ash	Fiber	Carbohydrates*	
CH	30.1 ± 2.9^{C}	1.2 ± 0.2^{b}	0.2 ± 0.0^{b}	0.2 ± 0.1^{ab}	0.6 ± 0.2^{a}	97.6 ± 0.4^{b}	185.2 ± 3.8^{b}[52.0%]
SB	38.0 ± 3.0^{B}	1.7 ± 0.2^{a}	0.2 ± 0.1^{a}	0.2 ± 0.1^{bc}	0.7 ± 0.2^{a}	97.1 ± 0.3^{c}	194.7 ± 6.0^{ab}[46.3%]
KB	44.6 ± 7.8^{A}	0.9 ± 0.2^{c}	0.2 ± 0.1^{a}	0.2 ± 0.0^{c}	0.7 ± 0.2^{a}	98.0 ± 0.2^{a}	198.3 ± 12.5^{a}[52.5%]
TR	47.4 ± 4.1^{A}	1.3 ± 0.3^{b}	0.1 ± 0.0^{c}	0.3 ± 0.1^{a}	0.3 ± 0.2^{b}	98.0 ± 0.1^{a}	191.4± 15.4^{ab}[57.8%]

^{a,b,c} Mean values in each column with different superscripts are significantly different ($p \leq 0.05$).
* Carbohydrates = 100 –(Protein + Fat + Ash + Fiber).

Table 3. Amylose content and average degree of polymerization (DP_{avg}) of taro amylose.

Cultivating area	Amylose content (%)				DP_{avg} of amylose
	Large	Medium	Small	Average amylose	
CH	20.8 ± 0.6^{ab}	19.9 ± 0.2^{b}	22.4 ± 1.2^{a}	21.02 ± 1.3^{A}	207
SB	20.0 ± 0.3^{ab}	18.8 ± 0.3^{b}	19.2 ± 0.1^{a}	19.37 ± 0.6^{B}	195
KB	19.4 ± 1.0^{ab}	19.4 ± 0.2^{b}	22.3 ± 0.5^{a}	20.4 ± 1.5^{AB}	203
TR	20.5 ± 0.2^{ab}	19.7 ± 0.2^{b}	20.2 ± 0.2^{a}	20.1 ± 0.4^{AB}	238

^{a,b,c} Mean values in each row with different superscripts are significantly different ($p \leq 0.05$).
^{A,B,C} Mean values in the fifth column with different superscripts are significantly different ($p \leq 0.05$).

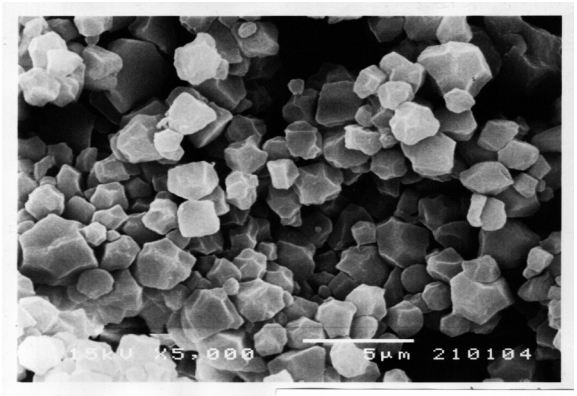

Fig 2. Taro starch granule (5000x) observed from scanning electron microscope.

Table 4. Surface average granule diameter of taro starch from four locations.

Cultivating area	Surface average granule diameter (mm)			
	Large	Medium	Small	Area average
CH	2.0 ± 0.7	2.0 ± 0.6	2.0 ± 0.5	2.0 + 0.4
SB	1.3 ± 0.4	1.9 ± 0.6	2.1 ± 0.5	1.8 + 0.5
KB	2.1 ± 0.5	2.0 ± 0.7	2.1 ± 0.8	2.1 + 0.6
TR	1.6 ± 0.5	2.2 ± 0.7	2.2 ± 0.7	2.0 + 0.7

confirmed that taro starch had an A-type crystallographic pattern which is similar to that of Hawaiian taro [2]. In general, A-type starch has double helices densely packed in an orthogonal form in the crystalline region with only 4 water molecules present in the cavity between adjacent double helices [13]. This resulted in stronger starch granules that could sustain rigorous heating and shearing conditions.

Swelling Power and Solubility

When heated in the presence of water at 80°C, PTF showed a low swelling power of 11.0-17.4 g/g dry flour and low solubility of 0.07 – 0.13 g/g dry flour. This result agreed with the previous result of x-ray diffraction study which showed that all PTFs had an A-type crystallographic pattern. The swelling data of CH, SB, and KB PTFs showed that starch from small taro corms had a higher swelling power than starch from larger corms. The average swelling power of PTFs from different locations indicated that CH taro had the lowest swelling power (11.9 ± 1.1 g/g dry flour) while KB taro had the highest swelling power (15.8 ± 1.5 g/g dry flour) at 80 °C. It was observed that swelling power of PTF was not proportional to granule size.

The solubility of taro flour from three locations (SB, KB, and TR) showed that PTF from large taro corms had higher solubility than that from small taro corms. Among all samples tested, the medium KB taro corms had the lowest solubility of 0.07 g/g dry flour. On average, KB taro exhibited the lowest solubility (0.082 g/g dry flour) while SB taro had the highest solubility (0.11 g/g dry flour). There was no correlation between the swelling power and the solubility of PTFs observed.

Table 5. Swelling power and solubility of purified taro flour heated at 80 °C.

Sample	Swelling power (g/g dry flour)	Solubility (g/g dry flour)
CH:L	11.31 ± 0.22	0.091 ± 0.005
CH:M	10.99 ± 0.04	0.099 ± 0.003
CH:S	13.27 ± 0.25	0.123 ± 0.002
SB:L	15.08 ± 0.35	0.132 ± 0.004
SB:M	14.74 ± 0.24	0.086 ± 0.005
SB:S	16.02 ± 0.51	0.098 ± 0.006
KB:L	15.85 ± 0.76	0.077 ± 0.008
KB:M	14.32 ± 0.46	0.070 ± 0.003
KB:S	17.43 ± 0.93	0.098 ± 0.005
TR:L	15.27 ± 1.05	0.088 ± 0.007
TR:M	12.75 ± 0.43	0.092 ± 0.001
TR:S	12.98 ± 0.57	0.081 ± 0.009

Pasting Characteristics

Table 6 shows pasting temperature and peak viscosity of all PTFs. It was observed that CH taro flour gelatinized at a lower temperature range (78 - 81 °C) when compared with SB (83 - 84 °C), KB (84 - 85 °C), and TR (85 - 87 °C) taro flour.

On average, KB taro flour had the lowest peak viscosity while SB taro flour had the highest peak viscosity. The higher peak viscosity of SB taro flour could be explained by its lower amylose content compared with taro flour from other locations. However, the same reason could not explain why KB taro had the lowest peak viscosity. In search for an answer to this question, it was found that the calcium oxalate content of KB starch was the highest among all. The high amount of calcium oxalate could delay water absorption in the granule and prevented amylose leaching from the starch granules. This, in turn, resulted in the lower solubility of KB taro flour as mentioned earlier. As a consequent, the peak viscosity of KB taro flour was lowered.

Conclusion

The alkaline extraction method yielded taro flour with lower protein content compared with the water extraction method. The extraction process reduced the calcium oxalate content by 46.3% of its initial

Table 6. Pasting properties of PTF from taro grown in four locations.

Sample	Peak(RVU)	Trough(RVU)	Breakdown(RVU)	Final viscosity(RVU)	Set back(RVU)	Pasting Temperature(°C)
CH:L	371 ± 3.4	187 ± 3.6	184 ± 0.1	282 ± 0.6	95 ± 3.0	81 ± 0.0
CH:M	441 ± 0.5	212 ± 2.1	228 ± 1.5	321 ± 0.4	108± 0.1	80 ± 1.2
CH:S	355 ± 5.0	158 ± 1.8	198 ± 3.1	238 ± 4.1	82 ± 0.3	78 ± 0.1
SB:L	402 ± 7.4	192 ± 0.8	211 ± 8.2	260 ± 2.8	68 ± 3.6	83 ± 1.2
SB:M	400 ± 0.3	174 ± 2.0	226 ± 2.3	241 ± 1.0	67 ± 1.0	83 ± 0.0
SB:S	371 ± 0.8	178 ± 4.6	193 ± 5.4	244 ± 1.2	66 ± 3.5	84 ± 0.1
KB:L	333 ± 0.8	145 ± 0.6	188 ± 1.4	203 ± 0.9	89 ± 0.4	84 ± 0.6
KB:M	324 ± 1.5	147 ± 1.0	176 ± 2.5	204 ± 0.4	87 ± 0.6	85 ± 0.5
KB:S	264 ± 1.4	135 ± 1.4	130 ± 0.0	196 ± 1.8	61 ± 0.4	84 ± 0.1
TR:L	366 + 2.7	177 ± 0.4	189 ± 0.4	249 ± 1.0	72 ± 1.4	84 ± 0.4
TR:M	311 ± 0.7	146 ± 0.3	164 ± 1.1	206 ± 1.1	61 ± 1.4	87 ± 2.6
TR:S	407 ± 3.0	190 ± 1.1	216 ± 4.1	265 ± 0.7	74 ± 0.4	86 ± 0.1

content. The carbohydrate content in taro flour was not affected by corm size, but cultivating location. PTF contained 96.9 – 98.28 g carbohydrate/100 g flour, 0.7 – 1.9 g protein/100 g flour, 0.1 – 0.3 g fat/100 g flour, 0.1 – 0.9 g fiber/100 g flour, 0.1 – 0.4 g ash/100 g flour, and 182.0 – 200.1 mg calcium oxalate /100 g flour. All PTFs had 18.8 – 22.4% amylose with an average degree of polymerization of 195 – 238. The starch granule was small and polygonal having an average diameter of 1.3 – 2.2 μm. With an A-type crystalline structure, the flour had a low swelling power of 11.0 – 17.4 g/g dry flour and low solubility of 0.08-0.13 g/g dry flour at 80 °C. The pasting temperature and peak viscosity of PTF were 78 – 87 °C and 264 – 441 RVU, respectively. The solubility and, thus, peak viscosity of PTFs were influenced by both amylose and calcium oxalate contents.

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