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Growth performance and starch yield potential of arrowroot (*Maranta arundinacea*) from various locations in Thailand

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Abstract. *Ieamkheng S, Santibenchakul S, Poonpaerdchon S, Soem B, Sooksawat N. 2024. Growth performance and starch yield potential of arrowroot* (Maranta arundinacea) *from various locations in Thailand. Biodiversitas 25: 3750-3757.* Arrowroot (*Maranta arundinacea* L.) is a tuberous type of medicinal that has high starch quality and good health benefits. This research studied the yield and growth characteristics of arrowroot samples from different 5 accessions in Thailand, along with their important properties for commercial use. Samples were collected from 5 field crops in Thailand: Tha Maka District, Kanchanaburi Province (Th-T-K); Sai Yok District, Kanchanaburi Province (Th-Sy-K); Ratchaburi Province (Th-RB); Chanthaburi Province (Th-Chan), and Sa Kaeo Province (Th-SK). The growth rate and yield of Thai arrowroot at 3, 6, and 9 months after planting were evaluated and the starch was extracted and characterized. During 3 months, there was only growth with no tuber yield; at 6 months, the arrowroot from Th-Sy-K had the highest growth rate and yield. The highest yields were at 9 months after planting, with the tuber weight per clump in the range of 596-2,980 g that produced 121.8-150.8 g of starch (8-10% yield). DNA fingerprinting analysis and the molecular study indicated no variation among the 5 accessions of arrowroot, indicating the uniformity and reliability of the samples. The results of the nutritional composition, the amounts of carbohydrates and amylose in the Th-Sy-K and Th-RB samples tended to increase with plant growth. At the same time, other contents, namely moisture, and lipid, decreased. The main component of the arrowroot starch was carbohydrate (87-91%), and the 9-month starch had high viscosity and heat-resistant values. In conclusion, arrowroot starch showed potential as a novel raw material for application in the food industry and possibly in cosmetic and pharmaceutical manufacturing.

Keywords: Arrowroot, genetic diversity, growth and yield, ISSR marker, starch

INTRODUCTION

Arrowroot (*Maranta arundinacea* L.) of the family Marantaceae, also known commonly as sago, is a monocotyledonous plant that can be vegetatively propagated. It is a perennial, herbaceous, annual plant that originated in Latin America and is now found locally in India and Indonesia (Nugraheni et al. 2017; Samal et al. 2018). Arrowroot is widely distributed in most regions of Thailand and is easy to plant in tropical and subtropical climates; it has a short growth period to reach a harvestable size. The roots or rhizomes are steamed or boiled and eaten as a popular snack (Amante et al. 2020; Fidianingsih et al. 2022). The arrowroot tuber contains high amounts of starch and other compounds, with the tubers or rhizomes having a normal commercial starch yield of 8-16% (Asha et al. 2015). The starch from arrowroot flour is composed of 11.9% water, 0.58% ash, 25.9% amylose, 0.14% protein, 0.84% fat, 8.7% insoluble dietary fiber, and 5.0% soluble dietary fiber (Malki et al. 2023). The carbohydrate content of arrowroot bulbs or rhizomes is in the range of 19.4-21.7% (Oktafani et al. 2018). Furthermore, arrowroot starch has similar characteristics to the starch from cassava, potato, banana, and achira (Shintu et al. 2015; Valencia et al. 2015). The extracted starch can be used to make various foods or desserts, such as bread, cookies, and ice cream, as well as being used as a flour coating. It is a beneficial food for children (Jayakumar and Suganthi 2017). Arrowroot starch has been documented as free of gluten, a protein that can cause allergies in some people as well as being high in fiber (Brito et al. 2021). Chemically, Thai arrowroot rhizomes contain benzoic acid, 4-hydroxy, chlorogenic acid, luteolin, 3′ methyl ether, ether, and 6-c-glycoside, phloretic acid, protocatechuic acid, quercetin, syringic acid, vanillic acid, beta carotene, niacin, riboflavin, and thiamin (Fidianingsih et al. 2022). In addition, the components of the stems, leaves, and roots contain important substances such as phenols, flavonoids, tannins, alkaloids, glycosides, steroids, and terpenoids (Ieamkheng et al. 2022) that can relieve the symptoms of indigestion, chronic abdominal

pain, and gastrointestinal irritation, as well as having anti-inflammatory and antioxidant effects (Rahman et al. 2015; Kusbandari and Susanti 2017).

Starch accumulates in the food storage parts of the arrowroot plant, such as tubers, roots, seeds, stems, and fruits, with carbohydrates being the major component (60-90%) and other impurities, such as protein, fat, and mineral salts, making up about 10-30% (Nogueira et al. 2018). The arrowroot rhizome (*M. arundinacea*) is a significant source of starch, with diverse uses in foods, textiles, pharmaceuticals, environmental management, and agriculture (Malki et al. 2023). However, the starch properties depend on several parameters, including pasting properties (Fan et al. 2019). Thus, the analysis and characterization of extracted starch is a key step in unlocking its potential for value-added industries such as pharmaceuticals (Shintu et al. 2015; Deswina and Priadi 2020; Ranganathan et al. 2023).

In Thailand, arrowroot is found in natural forests, especially deciduous and mixed forests, and is grown for domestic use. Therefore, this research aimed to study the relationship between the growth and yield potential of arrowroot from various sources in Thailand. The use of molecular markers to differentiate and analyze the genetic proximity of arrowroot samples from various sources will not only serve as a guide for its utilization and further conservation but also have practical implications for the cultivation and utilization of arrowroot. Furthermore, this work aimed to characterize the nutritional composition and pasting properties of the arrowroot starch extracted from arrowroot rhizomes aged 6 and 9 months that had been collected in Ratchaburi (Th-RB), Chanthaburi (Th-Chan), Sa Kaeo (Th-SK), Kanchanaburi (Tha Maka District: Th-T-K and Sai Yok District: Th-Sy-K) provinces in Thailand. The collected plants were grown in a trial field and studied at 6 and 9 months. The contents of moisture, protein, fats, ash, fiber, carbohydrates, and amylose were analyzed to determine their nutritional properties. In addition, the pasting properties of the starch were analyzed based on peak viscosity, trough viscosity, breakdown, final viscosity, setback, and pasting temperature.

MATERIALS AND METHODS

Plant varieties and cultivation

The arrowroot used in the test was grown in 5 accessions from around Thailand: Th-T-K (Tha Maka District, Kanchanaburi Province), Th-SK (Sa Kaeo Province), Th-Chan (Chanthaburi Province), Th-SY-K (Sai Yok District, Kanchanaburi Province) and Th-RB (Ratchaburi Province). The samples were planted in a field at the Department of Plant Production Technology, Faculty of Agriculture and Natural Resources, Rajamangala University of Technology Tawan-Ok, Thailand. Soil samples were collected to analyze the key nutrients, organic matter, and pH before planting. Planting plots were prepared (areas 1 × 4 m, raised 30-50 cm above ground level, with a distance between rows and plants of 50 cm and 80 cm, respectively). Arrowroot seedlings from each source were planted in a hole that contained manure. The plot was covered with straw or dry grass to maintain soil moisture. Each plot was watered once daily. Manure was added at the rate of 2,500 kg per hectare once a month after planting until 12 months.

Data collection and analysis

Arrowroot growth rate and yield potential data were collected at 9 months after planting: total plants per tiller, number of leaves per stem, clump diameter (cm), plant height (cm), leaf length (cm), leaf width (cm), fresh weight (g/tiller), number of tubers per tiller, tuber fresh weight (g/tiller), total starch (g/kg of fresh tuber) and total fiber (g), respectively. Data were analyzed using Analysis of Variance (ANOVA) at the 5% probability level. The treatment means were separated using the Least Significance Difference (LSD) at the 5% probability level ($P<0.05$).

Molecular analysis

Genomic DNA was extracted from the young leaves of the 5 accessions of arrowroot following the instructions in the Exgene™ Plant SV kit (GeneAll; Republic of Korea). Total DNA quality was checked using agarose gel electrophoresis and then quantified by measuring the optical density with a spectrophotometer at 260 nm for ISSR analysis.

ISSR analysis

The ISSR analysis was performed using 4 ISSR primers consisting of UBC 811, UBC 818, UBC 825, and UBC 827 (Asha et al. 2015). The extracted DNA was amplified in a Thermal Cycler (Bio-Rad, USA). The PCR mixture contained 8.5 mL of double distilled water (ddH_2O), 12.5 mL of 1X Polymerase Chain Reaction (PCR) buffer (One PCR; Taiwan), 2 mL of each primer, and 2 mL of DNA sample. The total reaction volume was made up to 25 mL using sterile distilled water. The PCR protocol started with an initial step at 94°C for 10 min, followed by 40 cycles of denaturation at 94°C for 1 min, primer annealing at 50-55°C for 1 min, and DNA extension at 72°C for 1 min. Then, the final DNA extension was at 72°C for another 10 min. The PCR products were analyzed based on 2% agarose gel electrophoresis in 0.5X TAE and were imaged using a gel documentation unit (Bio-Rad; USA). ISSR markers are mostly dominant markers and have higher reproducibility (Harikumar and Sheela 2019), which involve PCR amplification of DNA using single primers composed of microsatellite sequences. These primers target microsatellites that are abundant throughout the eukaryotic genome and evolve rapidly (Aji et al. 2022). Thus, the present study used these markers for the determination of genetic diversity.

Extraction of starch

The arrowroot rhizomes were collected from various provinces in Thailand and planted in the trial field and sampled at 6 and 9 months. Then, the rhizome samples were washed with clean water and dried at room temperature overnight; the extraction process involved weighing rhizomes separately (each about 1 kg) and blending with 2 L of tap water. After that, the mixture was

ground in a blender until a suspension was obtained. Next, the suspension was filtered through a thin cloth and allowed to settle. The crude starch was washed using tap water 3 times. Finally, the starch was dried in sunlight for 3 days. The starch samples were kept in separate zip-lock containers (Obioma et al. 2022).

Proximate analysis and determination of pasting properties of starch

The extracted starch samples from the 5 plant accessions were analyzed for nutritional composition (contents of moisture, protein, fats, ash, fiber, carbohydrate, and amylose) according to the official method of the Association of Analytical Chemists (Ojo et al. 2017). Specifically, the amylose content was examined using the method from Rao et al. (2014). The extracted starch was analyzed for pasting properties using a Rapid Visco Analyzer (RVA; USA). Peak viscosity, trough viscosity, breakdown, final viscosity, setback, and pasting temperature were recorded (Ajatta et al. 2016).

RESULTS AND DISCUSSION

Arrowroot growth and yield

There were no differentiating botanical characteristics among the 5 accessions. The stems formed from rhizomes that were covered with leaf bracts, lanceolate leaves, large leaf bases, pointed tips, smooth leaf plates and edges, young bright green leaves, and old dark green leaves that gradually turned yellow with the arrival of the harvest season. The arrowroot flowers were branched, consisting of two or more inflorescences. The main tuber was attached to the base of the plant, and sub-tubers broke off as the root penetrated deep into the ground. The inner flesh of the head was white with longitudinal fibers on the head (Figure 1). Notably, the arrowroot samples representing 5 accessions in Thailand showcase the diversity of the Creole cultivar in Arundinacea (Brito et al. 2021), with small and slender tubers and a large number of tubers.

There were growth differences among the arrowroot samples from the 5 accessions. Based on the results, Th-SY-K had the highest growth rate in all growth stages (Table 1) compared to the other accessions. In the first 3 months, the growth rate of arrowroot involved plant height and number of tillers. Then, at 6 months after planting, the growth rate was more than double in the leaves, and number of tillers than at 3 months (Table 1). However, the clump diameter decreased because the old leaf sheaths had fallen off. A study on the growth of arrowroot plants at 3, 6, and 9 months after planting showed that arrowroot at 3 and 6 months after planting had a high growth rate for the productive parts of the plant, with early tuber plant growth being in the stems above the soil to provide abundant leaf area and improve the output from photosynthesis (Colombo et al. 2019; Priya et al. 2023). In the present study, there was a decrease in the number of leaves at 9 months (Table 1). Then, the aboveground growth ceased so that the carbohydrates generated via photosynthesis were translocated to accumulate as food in the underground stem section.

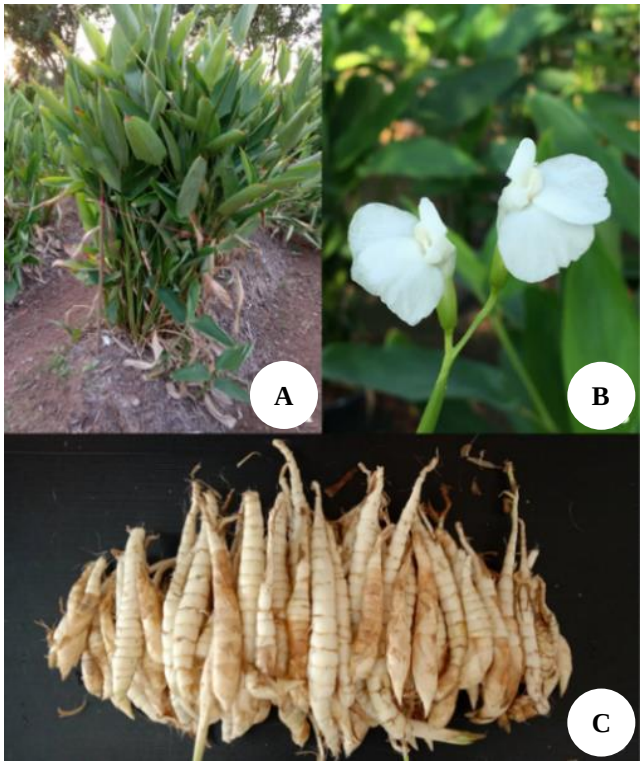

Figure 1. A. Characteristics of stem; B. Flower; and C. Tuber of arrowroot (*M. arundinacea* L.) from 5 accessions in Thailand

Table 1. Arrowroot growth rate at 3, 6, and 9 months after planting

Plant accessions	3 Months				6 Months				9 Months			
	PH (cm)	NT	CD (cm)	NL	PH (cm)	NT	CD (cm)	NL	PH (cm)	NT	CD (cm)	NL
Th-T-K	65.6c	4.2c	15.8ab	8.4ab	140a	31.8a	4.6b	45.0a	134.0b	33.2b	3.6a	18.2ab
Th-SK	54.6c	4.2c	13.4bc	7.8ab	134.2ab	24.2ab	4.6b	35.2ab	135.2b	36.2b	3.48a	19.8a
Th-Chan	74.0bc	6.2b	14.8bc	9.0ab	98.2c	12.8c	8.0b	21.4b	149.6ab	60.2a	3.0b	19.4a
Th-SY-K	96.6a	10.8a	17.2ab	10.4a	141.6a	23.0ab	4.8b	47.2a	159.0a	59.4a	2.0d	20.0a
Th-RB	76.4abc	6.6b	19.2a	9.6ab	92.4c	12.2c	12.0a	19.8b	108.2c	18.2c	2.3cd	13.8b
F-Test	*	*	*	*	*	*	*	*	*	*	*	*
CV (%)	5.72	26.24	12.20	15.90	4.13	14.90	27.08	11.73	3.17	9.99	9.47	11.50

Note: PH: Plant Height; NT: Number of Tillers; CD: Clump Diameter; NL: Number of Leaves; and *: significant at 0.05 ($P<0.05$). Lowercase letters (a, b, and c) indicate significant ($P<0.05$) differences among arrowroot growth rates from 5 accessions after growing for 3, 6, and 9 months

Table 2. Yield potential of arrowroot at 6 and 9 months after planting

Plant accessions	6 Months					9 Months				
	NT	TW (g)	TL (cm)	TS (g)	TF (g)	NT	TW (g)	TL (cm)	TS (g)	TF (g)
Th-T-K	20.2a	577a	18.8ab	15.9a	15.2	43.6a	1489.0b	20.8	121.8b	93.0b
Th-SK	14.2ab	424ab	17.8ab	21.2a	17.8	37.8b	1606.0b	18.4	150.8a	98.4ab
Th-Chan	9.8bc	314bc	23.6a	16.0a	14.4	45.2a	2930.0a	24.8	121.8b	94.8b
Th-SY-K	6.2c	235bc	18.4ab	2.6c	17.2	44.4a	1937.0ab	23.2	131.0ab	111.2a
Th-RB	4.8c	130c	15.2b	9.8b	11.1	19.6c	596.0c	22.0	144.0ab	96.7ab
F-Test	*	*	*	*	ns	*	*	ns	*	*
CV (%)	33.16	6.62	17.65	48.00	43.29	11.03	2.08	9.89	3.12	9.81

Note: NT: Number of Tubers; TW: Tuber Weight (g/clump); TL: Tuber Length; TS: Total Starch (g/kg fresh tuber); TF: Total Fiber (g/kg fresh tuber); ns: non-significant; and *: significant at 0.05 ($P<0.05$). Lowercase letters (a, b, and c) indicate significant ($P<0.05$) differences among yield potential of arrowroot from 5 accessions after growing for 6 and 9 months

Table 3. Total number of DNA and polymorphic bands of 5 accessions of arrowroot using 4 primers in ISSR analysis

Primer[1]	Sequence	T(°C)[2]	Number of DNA band			Size of PCR band (bp)
			Total	Polymorphic	Percentage (%)	
UBC811	GAG AGA GAG AGA GAG AC	53	5	2	40	200-800
UBC818	CAC ACA CAC ACA CAC AG	45	3	1	33.33	150-450
UBC825	ACA CAC ACA CAC ACA CT	52	3	1	33.33	200-800
UBC827	ACA CAC ACA CAC ACA CG	52	6	2	33.33	300-1100
Total			17	6	35%	

Note: [1]Asha et al. (2015); [2]T(°C) = Annealing temperature

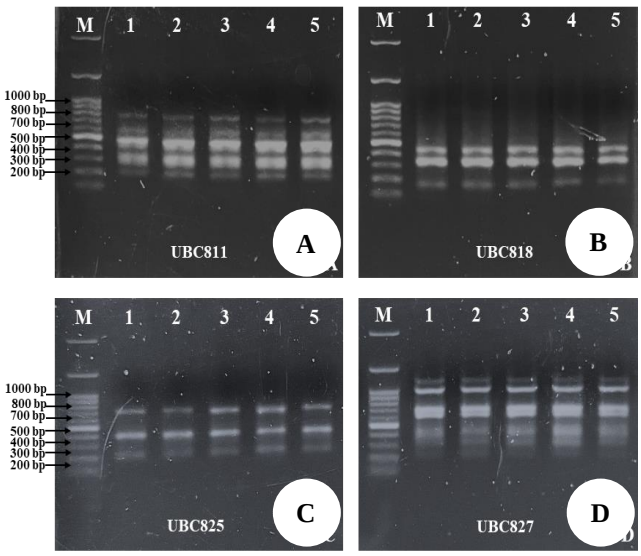

Figure 2. A. 5 accessions of arrowroot by UBC811 primer; B. UBC818 primer; C. UBC825 primer; and D. UBC827 primer. Lane M = 1 kb plus ladder (GeneDireX); lanes 1-5 = Th-T-K, Th-SK, Th-Chan, Th-SY-K and Th-RB

There were significant yield potential differences among the 5 accessions (Table 2). The arrowroot tuber weight yield from Th-T-K was the highest of the 5 Thai accessions (Table 2). The arrowroot products could be harvested and processed 6 months after planting. However, arrowroot from Th-Chan had the highest tuber weight at 9 months after planting. Overall, the results showed that the number of tubers, tuber weight, tuber length, total starch, and total fiber at 9 months were greater than those harvested at 6 months after planting (Table 2).

Analysis of arrowroot genotypic diversity

The diversity analysis of the 5 accessions of arrowroot carried out using 4 ISSR markers (UBC811, UBC818, UBC825, UBC827) produced a total of 17 bands, of which 6 were polymorphic with 35 % polymorphism (Table 3). The UBC 827 primer produced the highest number of DNA bands, while the UBC 811 and the UBC 827 primers produced the highest number of polymorphic DNA bands (2 bands each). Amplification using the UBC 811 primer resulted in the highest polymorphism at 40% (Table 3). The UBC 811 primer has been recommended for use in a genetic diversity study of the plant *Robinia pseudoacacia* L. and its closely related species (Uras et al. 2024). In the present study, visualization of the electrophoresis results using the Gel-Doc Transilluminator showed variations among these molecular markers (Figure 2). Overall, the DNA bands were in the range of 150-1,100 bp, whereas the polymorphic bands of each marker were diverse. The number of total DNA bands and the average percentage of polymorphism were lower than those reported by Asha et al. (2015) and Aji et al. (2022) due to the specific characteristics of the studied accessions and the chosen markers.

Based on the present molecular study results, there was no variation among the 5 accessions of arrowroot collected from the different provinces in Thailand (Figure 2). More specifically, the results showed a good correlation with the morphological characterization of *M. arundinacea*.

Nutritional composition of arrowroot starch

Further evaluation was undertaken on the chemical composition of the extracted starch from the 5 plant accessions and arrowroot rhizomes grown in the field trial and sampled at 6 and 9 months old. The results of the contents of moisture, protein, fats, ash, fiber, carbohydrates,

and amylose are shown in Table 4. The amount of amylose in the Th-T-K, Th-Chan, and Th-Sy-K starch tended to increase with age to 9 months. However, the amount of amylose in the Th-SK and Th-RB starch tended to decrease with age at 9 months (Table 4). The extracted starch samples from the 5 plant accessions had a low amylose content (approximately 2.9-8.5%) compared to the reported amylose content of cassava and corn starch of 21 and 28%, respectively (Puspita et al. 2019). The moisture content in the starch from the 5 plant accessions was in the range 9.46-12.45%. At age 6 months, Th-SK and Th-Chan starch had the highest moisture contents of 12.45 and 12.50%, respectively, whereas Th-Sy-K and Th-RB starch at 9 months had the lowest moisture contents of 10.29 and 9.46%, respectively (Table 4). The protein and fiber contents in the extracted starch of arrowroot rhizomes were quite low (0.05-0.28% and 0.02-0.07%, respectively) and were not significantly different among the 5 plant accessions (Table 4). The fat and ash contents were approximately 0.01-0.40 and 0.11-0.17, respectively (Table 4). The fat content at 6 months in the Th-Sy-K starch was the highest (0.40%) compared to at 9 months (0.01%), suggesting that the fat content could be converted to carbohydrate and/or amylose as observed from the increased amount of carbohydrates over the lifetime of arrowroot rhizomes (Zhai et al. 2021). In the present study, the Th-Sy-K starch had a lower fat content but a higher amylose content at 9 months compared to 6 months (Table 4). In addition, the ash content can reflect the mineral content in the extracted starch. The ash content of starch decreased at 9 months of age compared to 6 months of age, except for Th-SK starch, which increased from 0.12 to 0.17 % (Table 4). The extracted starch from arrowroot rhizomes was a notable source of high amounts of carbohydrates (87.14-90.54%; Table 4). The lowest carbohydrate contents were at 6 months in the starch from Th-SK and Th-Chan, while the highest carbohydrate contents were at 9 months in the starch from Th-Sy-K and Th-RB (89.71 and 90.54%, respectively; Table 4). These findings have significant implications for our understanding of the variation in carbohydrate content in different starches at varying ages. It seems that the Th-Sy-K starch in the rhizome at 9 months had accumulated and increased the amount of carbohydrates in the form of amylose, possibly by the transformation of fat in its metabolic pathway during plant growth and starch accumulation in the rhizome.

Pasting properties of arrowroot starch

The pasting properties of the extracted starch from the 5 plant accessions are shown in Table 5. The arrowroot rhizomes were sampled at 6 and 9 months to extract purified starch for studying the viscosity properties using the RVA. Based on the results, the starch granules absorbed water and became swollen during the gelatinization process with heating, which increased the viscosity properties of the starch. The pasting temperatures are presented in Table 5, suggesting that almost all of the extracted starch from Th-SK, Th-Chan, Th-Sy-K, and Th-RB that had been separated from the arrowroot rhizomes at 6 months had pasting temperatures (82.3-83.9°C) higher than those at 9 months (79.0-80.1°C; Table 5). Notably, the viscosity of the extracted starch decreased with an increase in arrowroot rhizome from 6 to 9 months. Furthermore, the pasting temperature of the arrowroot starch was higher than for cassava starch (52-65°C), whereas the gelatinization temperature was similar to that of rice starch (61-78°C) and glutinous corn starch (63-72°C).

The peak viscosity values of the extracted starch of the 5 plant accessions, a crucial aspect of our research, showed that the highest swelling of the starch granules was in the range 4,581.00-6,255.67 cP (Table 5). At 9 months, the arrowroot rhizomes from Th-SK and Th-Chan had a maximum viscosity value that was much lower than at the age of 6 months. Our research results also indicate that Th-Sy-K starch has the highest viscosity compared to all plant accessions, a finding that has practical implications for the food industry. This leads to the swelling and bursting of starch pellets when heated to maximum resistance, resulting in reduced starch molecules and a decrease in dough viscosity until the difference between the maximum and minimum viscosity is obtained. This demonstrates the resistance of starch granules to heating, which is a key consideration in food processing. Therefore, a higher minimum viscosity indicated that the starch had better heat-resistant properties. Table 5 shows that at 6 months, the arrowroot starch from Th-T-K, Th-Chan, and Th-Sy-K had lower breakdown values (2,872.33-3,483.33 cP) compared to at 9 months (3,859.33-4,827.67 cP). As a result, the extracted starch from the arrowroot rhizome at 9 months had better heat-resistant properties, a finding that can be directly applied in food processing.

The final viscosity is the viscosity during temperature reduction from 95 to 50°C and remains constant at this temperature. Based on the results in Table 5, the final viscosities of the extracted starch of the 5 plant accessions were close to their breakdown values. The setback value is the viscosity related to the retrogradation phenomenon of the starch. So, as the dough was cooling, the molecules of the starch granules would rearrange and become tighter, increasing the viscosity properties. Again, based on the results in Table 5, there were increasing setback values at 9 months in the Th-T-K and Th-Chan starch samples (2,539.67 and 2,502.00 cP, respectively) compared to at 6 months (1,186.00 and 707.33 cP, respectively). As the viscosity increased, the starch recovered. Therefore, the extracted starch from the arrowroot rhizomes has a good recovery value. In addition, the arrowroot starch had a gelatinization temperature of 79.0-80.9°C when heated, indicating that the boiled arrowroot starch would have a high viscosity. However, if the starch is cooled, it will return to its original shape, which is a characteristic of glutinous rice flour. In summary, arrowroot starch could be used instead of glutinous rice flour. However, further research must be carried out regarding the suitability of arrowroot starch for processing in the food, cosmetic, and pharmaceutical industries.

Table 4. Nutritional composition of extracted starch from 5 plant accessions

Plant accessions/	Amylose (%)		Moisture (%)		Protein (%)		Fats (%)		Ash (%)		Fiber (%)		Carbohydrate (%)	
Age(month)	6	9	6	9	6	9	6	9	6	9	6	9	6	9
Th-T-K	4.18±0.01d	8.41±0.01h	10.95±1.06abc	10.75±0.23abc	0.28±0.03	0.08±0.08	0.02±0.03a	0.01±0.01a	0.15±0.02abc	0.14±0.01abc	0.06±0.10	0.06±0.05	88.58±1.08abc	89.25±0.23abc
Th-SK	3.64±0.00c	2.91±0.00a	12.45±0.85bc	11.89±0.44abc	0.21±0.05	0.08±0.08	0.07±0.05a	0.06±0.09a	0.12±0.02ab	0.17±0.01c	0.03±0.04	0.07±0.07	87.15±0.94a	88.11±0.44ab
Th-Chan	3.48±0.00b	5.19±0.01e	12.50±1.03c	10.89±0.19abc	0.22±0.10	0.05±0.09	0.02±0.01a	0.11±0.10a	0.15±0.02bc	0.14±0.01abc	0.02±0.02	0.06±0.09	87.14±1.13a	89.11±0.19abc
Th-Sy-K	6.32±0.01g	8.45±0.01i	11.04±0.30abc	10.29±0.57ab	0.20±0.04	0.26±0.11	0.40±0.08b	0.01±0.02a	0.12±0.00ab	0.11±0.00a	0.04±0.04	0.06±0.03	88.32±0.39abc	89.71±0.57bc
Th-RB	5.38±0.01f	5.21±0.00e	11.45±0.71abc	9.46±1.26a	0.16±0.14	0.08±0.08	0.09±0.04a	0.13±0.12a	0.17±0.01c	0.16±0.01c	0.06±0.09	0.02±0.02	88.15±0.81ab	90.54±0.16c

Note: lowercase letters (a, b, c, d, e, f, g, h, and i) indicate significant ($P<0.05$) differences among nutritional components of extracted starch from 5 accessions after growing for 6 and 9 months. Next, 5 plant accessions: Th-T-K, Th-SK, Th-Chan, Th-Sy-K, and Th-RB, from Kanchanaburi, Sa Kaeo, Chanthaburi, Kanchanaburi, and Ratchaburi, Thailand. The values are shown as mean ±standard deviation

Table 5. Pasting properties of extracted starch from 5 plant accessions

Plant accession/	Peak viscosity (cP)		Trough viscosity (cP)		Breakdown (cP)		Final viscosity (cP)		Setback (cP)		Pasting temp. (°C)	
Age(months)	6	9	6	9	6	9	6	9	6	9	6	9
Th-T-K	6006.00±41.33e	6014.33±2.08ef	2522.67±270.40bcd	1186.67±146.03a	3483.33±292.16cd	4827.67±145.72f	3708.67±174.18abcd	3726.33±189.87abcd	1186.00±440.56a	2539.67±321.89b	82.27±0.45cd	80.88±0.85bc
Th-SK	6168.67±12.50fg	5322.00±19.97c	3070.00±29.05bcd	2190.00±770.71b	3098.67±41.04bcd	3132.00765.73bcd	3815.67±49.17bcd	3534.00±85.16ab	745.67±73.93a	1344.00±837.49a	82.53±0.03de	80.12±0.90ab
Th-Chan	6255.67±52.77g	5709.67±124.86d	3250.33±51.79cd	992.67±217.98a	3005.33±15.50bcd	4717.00±338.65ef	3957.67±55.01d	3494.67±54.78a	707.33±32.33a	2502.00±263.95b	83.35±0.05de	79.87±0.49ab
Th-Sy-K	6135.33±27.10efg	6237.67±95.52g	3263.00±34.39d	2378.33±430.62bc	2872.33±37.29bc	3859.33±429.36de	3884.67±150.19cd	3503.67±96.01a	621.67±139.11a	1125.33±483.37a	82.53±0.90de	80.08±0.10ab
Th-RB	4581.00±17.44a	4901.33±13.58b	2866.33±7.02bcd	2631.67±73.23bcd	1714.67±19.01a	2269.67±61.00ab	3725.33±18.90abcd	3602.33±46.61abc	859.00±12.17a	970.67±31.75a	83.93±0.46e	79.00±0.48a

Note: lowercase letters (a, b, c, d, e, f, g, h, and i) indicate significant ($P<0.05$) differences among pasting properties of extracted starch from 5 accessions after growing for 6 and 9 months. Next, 5 plant accessions: Th-T-K, Th-SK, Th-Chan, Th-Sy-K, and Th-RB, from Kanchanaburi, Sa Kaeo, Chanthaburi, Kanchanaburi, and Ratchaburi, Thailand. The values are shown as mean ±standard deviation

Based on the results of the present study, there were no genotypic differences among the arrowroot accessions from the 5 locations around Thailand (Figure 2). The ISSR marker revealed low genetic diversity between different plant accessions from different regions; however, additional analysis of genetic diversity and its relationship to phenotypic traits, such as starch production and starch properties, opens up a world of possibilities for further research and potential breakthroughs in the selection of good-quality arrowroot lines (Li et al. 2023). For example, based on the yield at 9 months, the number of tubers from Th-Sy-K (44.4 tubers) and the tuber weight (1,937.0 g/clump) was the best among the accessions (Table 2), whereas. These were the lowest for Th-RB, with values of 19.6 tubers and 596.0 g/clump, respectively (Table 2). Among the 5 plant accessions, the total starch (131-144 g/kg fresh tuber) and total fiber (96.7-111.2 g/kg fresh tuber) from Th-Sy-K and the Th-RB were not significantly different, while the total starch (150.8 g/kg fresh tuber) from Th-SK was the highest (Table 2). The nutritional composition of the Th-Sy-K and the Th-RB starch samples was notable since during the 6-9 months studied, the Th-Sy-K starch had the highest carbohydrate content with reduced fat but increased amylose, while the Th-RB starch contained increased carbohydrate with reduced amylose (Table 4). Thus, for application in the food industry, it seemed that the yield from the Th-SK starch may be preferable, while the carbohydrate and amylose contents from the Th-Sy-K and the Th-RB starch samples may be preferable. The pasting properties of these accessions (Th-SK, Th-Sy-K, and Th-RB starch) were also preferable for heat-resistance properties that may be applicable in the cosmetics industry.

The study of growth performance and yield potential of arrowroot indicated that in the first 3 months, there main growth was in plant height, number of tillers, clump diameter, and number of leaves rather than on any actual tuber yield. It was only at 6 months from planting that the yield became substantial. Notably, the Th-Sy-K arrowroot had the best growth rate of the accessions, with 1,937.0 g of tuber weight and 131.0 g of total starch (as high as 150.8 g of that from ThSK) at 9 months after planting. The molecular study of DNA fingerprinting analysis based on the results of DNA amplification with 4 ISSR markers (UBC811, UBC818, UBC 825, and UBC 827) indicated that there was no variation among the arrowroot collected from different provinces in Thailand. Furthermore, the results were consistent with morphological characterization belonging to *M. arundinacea*. The nutritional composition of the extract from the Th-Sy-K starch at 9 months contained 89.71% carbohydrate with 8.45% amylose, 10.29% moisture, 0.26% protein, 0.11% ash, 0.06% fiber, and 0.01% fat. The high viscosity and heat-resistant values of the extracted starch from the arrowroot rhizomes at 9 months indicated good stability and recovery, which are advantageous for use in manufacturing cosmetics or biopolymers. Furthermore, the high carbohydrate content indicated that this starch had good potential for applications in the food industry. In conclusion, arrowroot starch is a novel material that could be suitable for many industrial products.

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