BIODIVERSITAS
Volume 23, Number 3, March 2022
Pages: 1204-1210

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230303

Potential of *Maranta arundinacea* residues for recycling: Analysis of total phenolic, flavonoid, and tannin contents

SUPAPORN IEAMKHENG[1], SOMTOP SANTIBENCHAKUL[2], NAJJAPAK SOOKSAWAT[3,♥]

[1]Department of Plant Production Technology, Faculty of Agriculture and Natural Resources, Rajamangala University of Technology Tawan-ok. 43 Moo.6, Bangpra, Chonburi 20110, Thailand

[2]Department of Science and Mathematics, Faculty of Sciences and Technology, Rajamangala University of Technology Tawan-ok. 43 Moo.6, Bangpra, Chonburi 20110, Thailand

[3]Department of Agricultural Engineering and Technology, Faculty of Agriculture and Natural Resources, Rajamangala University of Technology. Tawan-ok. 43 Moo.6, Bangpra, Chonburi 20110, Thailand. Tel./fax.: +66-3313-6099, ♥email: najjapak_so@rmutto.ac.th, najjapak@gmail.com

Manuscript received: 24 January 2022. Revision accepted: 10 February 2022

Abstract. *Ieamkheng S, Santibenchakul S, Sooksawat N. 2022. Potential of* Maranta arundinacea *residues for recycling: Analysis of total phenolic, flavonoid, and tannin contents. Biodiversitas 23: 1204-1210.* The potential of *Maranta arundinacea* L. residues was evaluated for their nutrient composition as organic fertilizer and for the presence of the total phenolic, flavonoid, and tannin contents as phytochemical resources. This arrowroot was collected from seven different locations and planted under organic conditions. The leaves contain 1.28% total nitrogen (total N) and 1.71% total potassium (total K) that might be used as an organic component in fertilizer. The stems contain 3.25% moisture and a C/N ratio of 81.45 which might serve as the good mulch. The total phenolic, flavonoid and tannin contents of *M. arundinacea* differed in different plant parts (leaves, stem, rhizome residue), age (6, 9, 12 months), and sampling locations (Th-TK, Th-R, Th-SyK, Th-Kpc, Th-Chan, Th-Sk, Kh-B). The high total phenolic content was obtained from the Th-Kpc leaves at the 6-month-old plant (0.268 mg GAE)/g DW). The high total flavonoid content was obtained from the Kh-B rhizome residue at the 9-month-old plant (0.379 mg QE)/g DW). The high total tannin content was obtained from the Th-Chan rhizome residue at the 9-month-old plant (4.746 mg tannin/g DW). This study indicated that the rhizome residues were an abundant source of total tannin; that might be potential to be used in the food and medicinal industries. Leaves and stem residues might be useful in organic farming.

Keywords: Flavonoid, *Maranta arundinacea* organic, phenolic, tannin

INTRODUCTION

Maranta arundinacea L. (arrowroot or West Indian arrowroot) is a tropical herbaceous plant of about 120 cm in height. It is a starchy plant as a source of carbohydrate (or commercial starch), has been used as a functional food, and medicinal plant (Sudaryati et al. 2017). Its tuber or rhizome is edible, serving as baby food with high dietary fiber and protein (Nugraheni et al. 2017), The young rhizome can remove mucus from the intestinal wall, treat diarrhea, relieve gastric indigestion and heartburn symptoms, laxative, wound healing, and has antimicrobial activity (Rahman et al. 2015; Jayakumar and Suganthi 2017). Its tubers are rich in white starch and high fiber at all ages. The phytochemical composition of the *M. arundinacea* rhizome includes 7.6% moisture, 1.2% ash, 7,200 mg/100 g of carbohydrate, 1,200 mg/100 g of protein, and 6,480 mg/100 g of starch (Jayakumar and Suganthi 2017). The results of the biochemical analysis showed that it contains alkaloids, glycosides, and saponins. Alkaloids can be used to relieve pain and fever. Glycosides can be used to treat cough and blood circulation and saponins can be used as an anti-carcinogen and antioxidant. In addition, it has anti-inflammatory and promotes weight loss. The plant has the potential to be used in the pharmaceutical industry (Jayakumar and Suganthi 2017).

Antioxidants have beneficial health effects. Dietary consumption that contains antioxidant may lower the risk of health disorders by controlling rancidity development, retarding the formation of toxic oxidation products, maintaining nutritional quality, and extending the shelf-life of food and agricultural products. Phenolic antioxidants can be divided into two main groups: synthetic and natural. Natural phenolics can be classified as phenolic acids (i.e., gallic and caffeic acid); flavonoids (i.e., quercetin and catechin); stilbenes; coumarins; lignans; and tannins and are present in plant foods (Shahidi and Ambigaipalan 2015). Phenolic compounds have been found to have antioxidant, anti-inflammatory, antimicrobial, antimutagenic, anticarcinogenic, and other biological properties (Xu et al. 2008; Prihantini et al. 2018; Apridamayanti et al. 2021). Flavonoids are predominant in around two-thirds of the dietary phenols that commonly occur in plants and plant food (Robbins 2003). Flavonoids are effective antioxidants due to: (i) their metal-chelate potential and the arrangement of hydroxyl and carbonyl groups around the molecule; (ii) the presence of hydrogen-/electron-donating substituents that reduce free radicals, and (iii) the ability to delocalize an unpaired electron leading to the formation of a stable phenoxyl radical (Musialik et al. 2009). Tannins are categorized as hydrolyzable or condensed tannins, depending on their chemical structure. They are known to inhibit lipid peroxidation and lipoxygenases and can

scavenge hydroxyl, superoxide, and peroxyl radicals, inducing a cellular prooxidant state (Gyamfi and Aniya 2002). Edible tubers such as carrots, onions, potatoes, sweet potatoes, and beetroot are rich in these phenolic compounds and flavonoids (Shahidi and Ambigaipalan 2015).

By-products and plant residue may be abundant sources of phytochemicals. Peel residue of *Tacca leontopetaloides* tuber had abundant total phenolic (8.11 mg/g), flavonoid (20.79 mg/g), and tannin (8.68 mg/g) (Wacharatewinkul and Riangmoo 2019). The rhizome of *M. arundinacea* contains high total phenolic and flavonoid. Phenolics and flavonoids have antioxidant and free radical scavenging activity *in vitro* (Ruba and Mohan 2013). A previous study by Nishaa et al. (2013) showed that ethanol extract of arrowroot rhizome contained flavonoids, alkaloids, tannins, glycosides, steroids, phenols, cardiac glycosides, saponins, carbohydrates, and proteins. However, the reports on the phytochemical content of arrowroot leaves, stem at post-harvest, and the rhizome residue after starch extraction is still limited. Thus, the objectives of this research were to determine the potential of *M. arundinacea* residues as organic fertilizer and the presence of total phenolic, flavonoid, and tannin contents from the arrowroot plant collected from seven different locations in Thailand and Cambodia. Further recycling of these residual materials would add value and reduce the impact of waste disposal on the environment.

MATERIALS AND METHODS

Collection of *M. arundinacea* from different seven locations

Maranta arundinacea was collected from seven different locations from October 2019 to March 2020 in western, central, and eastern Thailand, and in Cambodia (Table 1).

Organic cultivation of *M. arundinacea* collected samples from seven different locations

The collected samples of *M. arundinacea* were planted on field plots at the Department of Plant Production Technology, Faculty of Agriculture and Natural Resources, Rajamangala University of Technology Tawan-ok, Thailand in April 2020. Soil preparation for arrowroot cultivation was carried out by plowing and sun-drying for a few weeks to degrade pesticides. Each plot of 1 m × 4 m was elevated 30–50 cm. The distance between rows was 50 cm and between plants was 80 cm and 25 plants from each location were grown after filling the planting hole with manure and covered the plot with dried straw or grass to maintain soil moisture. Plants were watered once a day and manure was added once a month at a rate of 400 kg per rai (1,600 square meters) for 12 months.

Starch extraction and collection of rhizome residues

The rhizomes were harvested at the age of 6, 9, and 12 months, washed with tap water and dried overnight at room temperature. One kg of rhizome from each sample was blended with 2 l of water (ratio 1:2) and filtered to collect the dissolved starch. The solid residue remaining after filtration was collected and was referred to as rhizome residue. Rhizome at age 6 months did not produce rhizome residue and some *M. arundinacea* samples at age 9 and 12 months did not produce any residue (Wacharatewinkul and Riangmoo 2019).

Determination of total nitrogen, phosphorus, potassium, moisture content, and C/N ratio of leaves and stem of *M. arundinacea*

Maranta arundinacea collected from Tamuang district, Kanchanaburi province, Thailand was harvested on the field trial plots at the university starting in October 2020. Plants were harvested at age of 6 months. Leaves, stem, and rhizome were separated. The leaves and stem were dried at 60ºC for 2-4 days and analyzed for total nitrogen (%N) using the Kjeldahl method, and for total phosphorus (%P), total potassium (%K), moisture content, and the carbon-to-nitrogen (C/N) ratio (Soon and Hendershot 2006).

Determination of total phenolic, flavonoid and tannin contents in rhizome residues of *M. arundinacea* organically grown

Preparation of plant samples

Maranta arundinacea samples collected from seven different locations were planted and harvested from the field trial plots in the university from July 2020 to April 2021. Plant samples at age of 3, 6, 9, and 12 months were harvested and the leaves, stem, and rhizome were separated. The starch of the rhizome was extracted and the residue was studied further. The leaves, stem, and rhizome residue were dried at 60ºC for 2-4 days and ground to powder. A sample (100 g) was soaked in ethanol for 48 h on a shaker. The ethanol extract was filtered through Whatman no.1 filter paper and concentrated at 40ºC using a rotary evaporator (Medini et al. 2014).

Total phenolic content

The dried ethanol extract was diluted by adding 0.5 mL of distilled water and 0.125 mL of Folin-Ciocalteu reagent. The mixture was shaken and allowed to stand for 6 min before adding 1.25 mL of 7% Na_2CO_3 and adjusting the volume to 3 mL using distilled water. The solution was incubated in the dark and absorbance was determined at 720 nm. The total phenol content was calculated as milligrams of gallic acid equivalent per gram of dry weight (mg GAE/g DW) from a calibration curve using gallic acid. Every sample has three replications. (Medini et al. 2014; Adebiyi et al. 2017).

Table 1. Seven locations of *M. arundinacea* collection

Assigned name of the sample	District	Province	Country
Th-TK	Thamuang	Kanchanaburi	Thailand
Th-R	Mueang	Ratchaburi	Thailand
Th-SyK	Sai Yok	Kanchanaburi	Thailand
Th-Kpc	Kamphaengsaen	Nakhon Pathom	Thailand
Th-Chan	Mueang	Chanthaburi	Thailand
Th-Sk	Watthana Nakhon	Sakaeo	Thailand
Kh-B	Thma Koul	Battambang	Cambodia

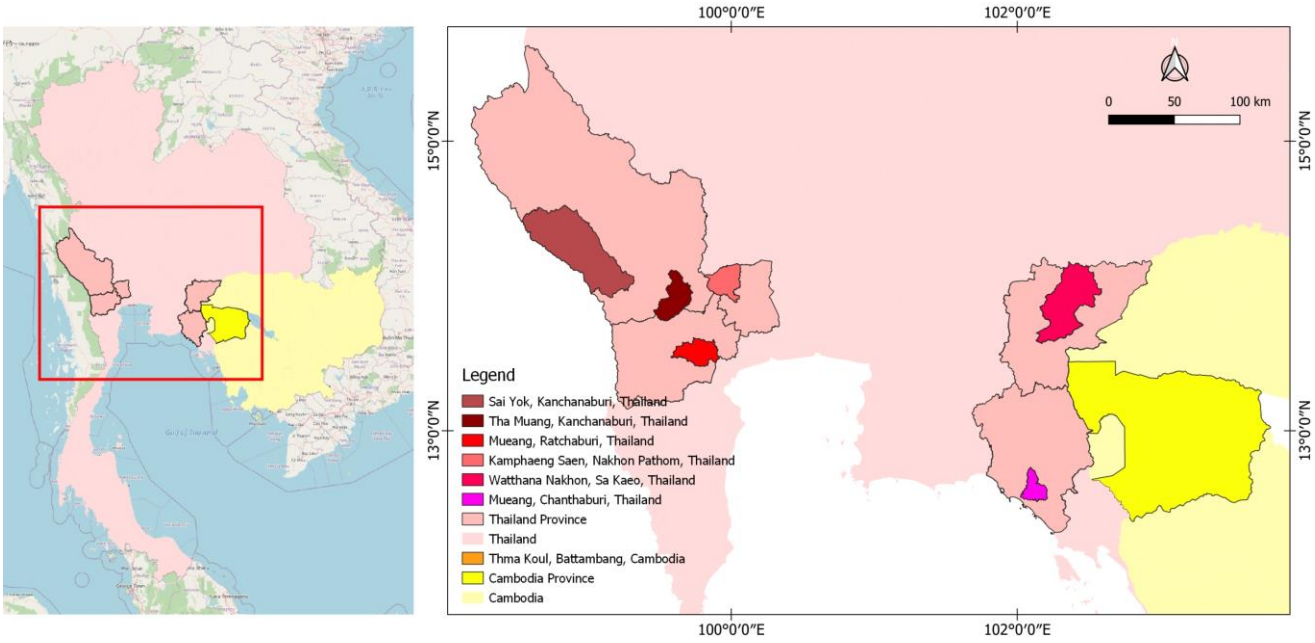

Figure 1. Study site in Thailand and Cambodia (based on Table 1)

Flavonoid content

Plant extract and standard solution of quercetin were added to 75 mL of 5% $NaNO_2$ solution and mixed for 6 min before adding 0.15 mL of 10% $AlCl_3$ and left to stand for 5 min. Then, the sample was added with 0.5 mL of NaOH, and the volume was adjusted to 2.5 mL using distilled water. The absorbance of the solution was determined at 510 nm. The total flavonoid content was calculated as milligrams of quercetin equivalent per gram of dry weight (mg QE/g DW) using the calibration curve of quercetin. The samples were analyzed in triplicate (Medini et al. 2014; Adebiyi et al. 2017).

Tannin content

Plant extract and standard solution of tannin were added to 3 mL of vanillin solution in methanol and 1.5 mL of concentrated HCl. The mixture was allowed to stand for 15 min and the absorbance was determined at 500 nm. The total tannin content was calculated as milligrams of tannin equivalent per gram of dry weight (mg tannin/g DW). The samples were analyzed in triplicate (Medini et al. 2014; Adebiyi et al. 2017).

Data analysis

All statistical analyses were performed using the SPSS software package. P values of less than 0.05 were considered statistically significant. Differences in average data were analyzed using one-way ANOVA and Tukey's HSD test. Data were presented as average ± SD values and all samples were measured in triplicate.

RESULTS AND DISCUSSION

Total nitrogen, phosphorus, potassium, moisture content, and C/N ratio of leaves and stem of *M. arundinacea*

The leaves and stem of *M. arundinacea* (Th-TK) that will be used as an organic component in fermented fertilizer were determined for the chemical composition. Table 2 shows that the leaves contained more total N (1.28%) and total K (1.71%) than the stem, whereas the stem had a higher C/N ratio (81.45) and moisture (3.25). According to the Thai standard for organic fertilizer, high-grade quality fertilizer must be composed of total N and K of more than 1%, total P of more than 2.5%, moisture content less than 30%, and a C/N ratio less than 20 (Department of Agriculture 2014). Therefore, the leaves are suitable for use as an organic component in organic fertilizers. The stems are appropriate for covering the soil after planting.

Total phenolic, flavonoid, and tannin contents in different plant parts and ages of rhizome residues of *M. arundinacea* (Th-TK)

Maranta arundinacea (Th-TK) collected from Tamuang district, Kanchanaburi province, Thailand (after being grown organically) were determined for total phenolic, flavonoid, and tannin contents in different plant parts and different ages of rhizome residues. Differences in the age of rhizome residues and plant parts had significantly different contents of total phenolic and tannin (Table 3). The highest total phenolic (0.139 mg GAE/g DW) was obtained from 6-month-old leaves, the highest total flavonoid content was obtained from 9-month-old rhizome residue (0.277 mg QE/g DW) (Table 3). However, total tannins were not significantly different among plant parts and rhizome residue ages.

Total phenolic, flavonoid, and tannin contents of rhizome residues of organically grown *M. arundinacea* were collected from seven different locations

Maranta arundinacea from different geographical locations had significantly different total phenolic, flavonoid, and tannin content regarding their plant parts and rhizome residue from different ages of the plant (Table 4, $P<0.05$). The highest total phenolic content was obtained in the leaves from plants aged 6 months, while the highest total flavonoid and tannin contents were obtained from rhizome residue originating from the 9-month-old plant (Table 4 and 5, $P<0.05$). The stem contained the lowest amounts of total phenolic, flavonoid, and tannin. Plants aged 9 months produced higher total flavonoid and total tannin contents in leaves (0.290-0.292 mg QE/g DW and 4.148-4.232 mg tannin/g DW, respectively, Table 4) compared to the stems. Rhizome residue originating from the 9-month-old plants had higher total flavonoid contents (0.379 mg tannin/g DW, Table 5). The results also showed that plants from different locations affected their phytochemical contents. The leaves from Th-Kpc originating from the 6-month-old plants had the highest total phenolic content (0.268 mg GAE/g DW, Table 4) and the leaves from Th-R originating from the 9-month-old plants produced higher total flavonoid and tannin contents (0.292 mg QE/g DW and 4.148 mg tannin/g DW, respectively, Table 4) compared to the stems. Furthermore, rhizome residue of Kh-B from 9-month-old plants had the highest total flavonoid content (0.379 mg QE /g DW, Table 5). The rhizome residue from Th-Chan at the plant age of 9 months had the highest total tannin content (4.746 mg tannin /g DW, Table 5).

Plant parts and location of plant collection affected the total phenolic content (Tables 4 and 5). Th-Kpc leaves have a high phenolic content. The flavonoid content was related to plant part (leave and rhizome residue), plant age (9 months), and location of plant collection (Th-R and Kh-B). Factors affecting the tannin content were plant-part, age of the plant, and location of plant collection. Leave and stem from Th-R samples and Kh-B rhizome residue from the 9-month-old plant had high amounts of the total flavonoid. Different parts of the plant are responsible for different functions, phytochemical production, translocation, and storage (Harding et al. 2014). This study showed that *M. arundinacea* leaves have a higher content of total phenolic, flavonoid, and tannin compounds) compared to the stems during dry season. In contrast, the *Grewia carpinifolia* stem had a lower total phenol content but a higher total flavonoid content than leaves during rainy season (Adebiyi et al. 2017). The distribution of flavonoid during development of leaves, flower, stem, and root involves enzymes and phytoregulators in the flavanone and flavone biosynthesis and has been possibly varied during plant development and seasonal circumstance (Del Bano et al. 2004; Liu et al. 2021). The present research also showed that geographical location affects the phytochemical composition of a plant species. Similarly, Rindita et al. (2020) reported the effect of environmental factors on the antioxidant activity of three species of Pteridophytes (*Histiopteris incisa*, *Nephrolepis biserrate*, and *Selaginella willdenowii)*. Rindita et al (2020) also reported that the total phenolic content of leaf extracts of three species of Pteridophytes from two different forests (shredded and opened canopy) with different abiotic factors, such as light intensity, air humidity, air temperature, soil pH, moisture, and coordinates, is also different. Differences in the chemical compounds of *M. arundinacea* from Thailand and Cambodia might be related to genetic diversity within and between species and populations (Asha et al. 2016). The genetic diversity would provide plant breeders with a genetic base for the selection of diverse parents for plant improvement of arrowroot. Thus, for further use of its residue or as a by-product in the food and pharmaceutical industries, including in organic agriculture, the collected plants with high total tannin in their rhizome residues (Th-Chan, Th-Sk, and Th-TK) should be selected for further plant improvement.

Table 2. Chemical composition of leaves and stem of *M. arundinacea* (Th-TK)

Th-TK	Leaves	Stem
Total N (%)	1.28	0.61
Total P (%)	0.22	0.31
Total K (%)	1.71	0.07
Moisture (%)	2.01	3.25
C/N ratio	37.53	81.45

Note: *M. arundinacea* sample was collected from Tamuang district, Kanchanaburi province, Thailand

Table 3. Total phenolic, flavonoid, and tannin contents in different plant parts and ages of rhizome residues of *M. arundinacea* (Th-TK)

Th-TK	Age (months)	Total phenolic (mg GAE/g dry weight of sample)	Total flavonoid (mg QE/g dry weight of sample)	Total tannin (mg tannin/g dry weight of sample)
Leaves	6	0.139±0.003a	0.131±0.012b	2.722±0.926
Stem	6	0.070±0.005c	0.072±0.003c	1.791±0.571
Rhizome residue	6	0.052±0.010d	0.023±0.001d	1.525±0.551
Rhizome residue	9	0.117±0.006b	0.277±0.002a	2.279±0.350
Rhizome residue	12	0.071±0.004c	0.137±0.003b	1.872±0.502

Note: *M. arundinacea* collected from Tamuang district, Kanchanaburi province, Thailand. Significant differences (one-way ANOVA, $P<0.05$) are indicated for mean ± SD for plant parts and ages versus each of the phytochemical contents

Table 4. Total phenolic, flavonoid, and tannin contents in the leaves and stems of *M. arundinacea* were collected from seven different locations and organically grown

Plant residue	Source	Total phenolic (mg GAE/g dry weight of sample)			Total flavonoid (mg QE/g dry weight of sample)			Total tannin (mg tannin/g dry weight of sample)		
		Age (months)			Age (months)			Age (months)		
		3	6	9	3	6	9	3	6	9
Leaves	Th-TK	0.173±0.009	0.176±0.008	0.143±0.010	0.119±0.010	0.109±0.005	0.146±0.004	2.375±0.354	1.141±0.093	1.262±0.111
	Th-R	0.157±0.010	0.175±0.000	0.192±0.017	0.127±0.010	0.136±0.004	0.292±0.018a	1.814±0.086	1.560± 0.337	4.148±0.484a
	Th-SyK	0.163±0.007	0.119±0.009	0.179±0.007	0.137±0.003	0.111±0.017	0.184±0.007bc	1.663±0.519	2.971± 0.191	3.789±0.452ab
	Th-Kpc	0.163±0.005	0.268±0.003a	0.178±0.006	0.139±0.008	0.216±0.007b	0.145±0.062	2.184±0.236	4.210± .569a	3.702±0.237ab
	Th-Chan	0.172±0.007	0.230±0.003b	0.162±0.005	0.089±0.009	0.183±0.022bc	0.044±0.002	1.509±0.202	2.551± 0.329	2.899±0.202
	Th-Sk	0.159±0.003	0.245±0.006b	0.038±0.006	0.080±0.002	0.228±0.003b	0.217±0.002b	2.175±0.460	2.624± 0.062	4.232±0.492a
	Kh-B	0.181±0.007	0.179±0.001	0.171±0.015	0.142±0.001	0.133±0.007	0.166±0.039	1.653±0.209	1.902± 0.304	3.745±0.397ab
Stem	Th-TK	0.092±0.003	0.071±0.003	0.053±0.002	0.060±0.007	0.066±0.003	0.130±0.003	1.966±0.531	1.603± 0.217	3.852±0.411ab
	Th-R	0.088±0.001	0.073±0.006	0.190±0.008	0.111±0.002	0.121±0.004	0.290±0.034a	1.410±0.181	1.110± 0.207	3.285±0.685abc
	Th-SyK	0.043±0.001	0.075±0.004	0.049±0.004	0.109±0.003	0.034±0.002	0.122±0.005	1.555±0.030	1.721± 0.389	3.061±0.555
	Th-Kpc	0.113±0.006	0.075±0.003	0.046±0.002	0.037±0.003	0.090±0.004	0.118±0.004	2.051±0.192	1.754± 0.015	3.186±0.152abcd
	Th-Chan	0.045±0.003	0.051±0.001	0.106±0.002	0.000±0.001	0.035±0.002	0.086±0.009	2.019±0.066	1.852± 0.188	2.583±0.255
	Th-Sk	0.085±0.004	0.061±0.002	0.084±0.004	0.054±0.003	0.057±0.001	0.104±0.009	1.663±0.431	1.627± 0.282	1.821±0.101
	Kh-B	0.126±0.004	0.183±0.005	0.060±0.001	0.082±0.002	0.142±0.019	0.057±0.002	2.029±0.141	2.002± 0.082	1.257±0.017

Note: Significant differences (one-way ANOVA, P<0.05) are indicated for mean ± SD for plant parts, ages, and locations versus each of the phytochemical contents. Only the group with the highest levels of total phenolic, flavonoid, and tannin contents were indicated in a, b, c, and d.

Table 5. Total phenolic, flavonoid and tannin contents in rhizome residues of *M. arundinacea* were collected from seven different locations and organically grown

Age (months)	Source	Total phenolic compound (mg GAE/g dry weight of sample)	Total flavonoid (mg QE/g dry weight of sample)	Total tannin (mg tannin/g dry weight of sample)
9 months	Th-TK	0.082±0.004d	0.158±0.004e	4.197±0.887abc
	Th-R	0.159±0.002b	0.157±0.003e	1.086±0.252d
	Th-Kpc	0.064±0.006e	0.310±0.009b	2.860±0.614c
	Th-Chan	0.097±0.002c	0.261±0.010bc	4.746±0.153a
	Th-Sk	0.171±0.004a	0.206±0.004de	4.490±0.277ab
	Kh-B	0.021±0.005f	0.379±0.054a	3.175±0.540bc
12 months	Th-R	0.102±0.002c	0.220±0.003cd	4.003±0.291abc
	Th-Sk	0.156±0.007b	0.200±0.002de	4.276±0.537ab
	Kh-B	0.162±0.003ab	0.209±0.007cde	3.755±0.164abc

Note: Significant differences (one-way ANOVA, P<0.05) are indicated for mean ± SD for plant ages, and sources versus each of the phytochemical contents.

Discussion

The result of this study indicated that the total flavonoid of rhizome residue of *M. arundinacea* is comparable to other medicinal plants, such as *Asparagus racemosus*, *Ocimum sanctum*, *Cassia fistula*, *Piper betel*, *Citrus aurantifolia*, *Catharanthus roseus*, and *Polyalthia longifolia*, which have flavonoid content ranging from 0.2–0.4 mg/g leaves (Kaur et al. 2014, Table 6). Although leaves, stems, and rhizome residue of *M. arundinacea* contained relatively low amounts of total phenolic compared with ferns, other medicinal plants, and a halophyte (*Limonium delicatulum*), however, its rhizome residue has a relatively high amount of total tannins, so it might be potential as a source of tannin (Table 6). The rhizome residue of *M. arundinacea* has a higher amount of tannin than other condiments, spices, and herbs such as turmeric (*Curcuma longa*), formulated puliogare powder, formulated rasam powder, formulated sambhar powder, formulated bisibele-bhat powder, and garlic (*Allium sativum*), which have tannin content ranging from of 1.1-2.3 mg/g (Sharma et al. 2019)

The present study indicated that rhizome residue has a relatively high content of total tannin. Tannin, both hydrolyzable and condensed, can be biosynthesized by plant metabolic pathways, where the pathway of hydrolyzable tannin is initiated in leaves from intermediate compounds of the shikimate pathway, dehydroshikimic acid, and the reaction is catalyzed by the enzyme (Ossipov et al. 2003). In contrast to condensed tannin, the process of synthesizing hydrolyzable tannin is relatively short, being more closely geared to the metabolism of carbohydrates. Therefore, the formation and accumulation of these tannins generally occur in young, and actively growing leaves (Ossipov et al. 2003).

Table 6. Total phenolic, flavonoid, and tannin contents in various plants

Plant species	Plant part	Total phenolic compound	Total flavonoid	Total tannin	Reference
M. arundinacea L. (tuber)	Leaf and rhizome residue	0.268 mg GAE/g DW	0.379 mg QE/g DW	4.746 mg tannin/g DW	*This study*
Tacca leontopetaloides (tuber)	Flour	2.70 mg/g DW	0.79 mg/g DW	2.62 mg/g DW	Wacharatewinkul and Riangmoo (2019)
	Peel	8.11 mg/g DW	20.79 mg/g DW	8.68 mg/g DW	
Dioscorea alata (tuber)	Rhizome	6.8 mg/g	12.1 mg/g	-	Sakthidevi and Mohan (2013)
Angiopteris ferox Copel (tuber)	Rhizome	35.86 mg/g	0.77 mg/g	-	Nur et al. (2019)
Plagiogyria pycnophylla (fern)	Rhizome	286.9 mg GAE/g extract	127.2 mg QE/g extract	-	Nurhasnawati et al. (2019)
Acrostichum aureum (fern)	Leaf	366.5 mg GAE/g extract	228.6 mg QE/g extract	-	
Histiopteris incisa (fern)	Leaf	18.1 mg GAE/g	-	-	Rindita et al. (2020)
Nephrolepis biserrate (fern)	Leaf	17.5 mg GAE/g	-	-	
Selaginella willdenowii (fern)	Leaf	38.7 mg GAE/g	-	-	
Moringa oleifera (fern)	Leaf	30 mg GAE/g	81 mg QE/g	-	Sulastri et al. (2018)
Asparagus racemosus (medicinal plant)	Leaf	3.65 mg/g	0.159 mg/g	-	Kaur et al. (2014)
Ocimum sanctum (medicinal plant)	Leaf	3.65 mg/g	0.205 mg/g	-	
Cassia fistula (medicinal plant)	Leaf	2.64 mg/g	0.382 mg/g	-	
Piper betel (medicinal plant)	Leaf	2.12 mg/g	0.398 mg/g	-	
Citrus aurantifolia (medicinal plant)	Leaf	3.66 mg/g	0.390 mg/g	-	
Catharanthus roseus (medicinal plant)	Leaf	2.85 mg/g	0.417 mg/g	-	
Polyalthia longifolia (medicinal plant)	Leaf	2.44 mg/g	0.271 mg/g	-	
Limonium delicatulum (halophyte)	Flowering	29.58 mg GAE/g DW	23.2 mg catechin/g DW	2.62 mg catechin/g DW	Medini et al. (2014)
	Vegetative	14.25 mg GAE/g DW	4.87 mg catechin/g DW	3.14 mg catechin/g DW	

Regulation of condensed tannin, or proanthocyanidins, biosynthesis is under complex control by multiple regulatory genes at the transcriptional level, protein transcription factors, and structural proteins and enzymes. Starting with regulation of genes encoding proteins and enzymes in the pathway of the flavonoid biosynthesis, the shikimate and glycolytic pathways lead to proanthocyanidin synthesis and modification of the branch pathway. Transportation of proanthocyanidin precursors from flavonoid biosynthetic pathway located on the endoplasmic reticulum membrane or in the cytoplasm to polymerize and accumulate proanthocyanidin in the vacuole are followed by control of the development processes for the generation of cell accumulation in specific plant tissue (He at al. 2008).

He et al. (2008) reported that environmental factors have a significant influence on the biosynthesis of condensed tannins in plants, such as light stress and shading, atmospheric change (CO_2, N_2, O_2, and O_3), temperature (day and night), exogenous plant hormone (abscisic acid, naphthaleneacetic acid, and ethylene), infection of pathogens (bacterial and fungal), UC (UV-A and UV-B) or solar radiation, nitrogen, water, and phosphorus deficiency. These environmental factors manipulate the expression of the structural genes and widely affect the functions of the transcription factors. Therefore, it confirms the variation in the phytochemical content of leaves, stems, and rhizome residue of *M. arundinacea* collected from different locations.

Maranta arundinacea collected from various locations contained different total phenolic and flavonoid contents depending on the plant part and age, and possibly due to genetic biodiversity. Compared to other plants (Table 6), the leaves and stems of *M. arundinacea* contained relatively low total phenolic and flavonoid contents but have a high content of total N, total K, and C/N ratio, making it suitable for recycling as an organic component in fertilizer. The rhizome residue is considered a waste product that has high total tannins (at plant ages of 9 and 12 months) comparable to that of *T. leontopetaloides* flour and the halophyte, *L. delicatulum* (Medini et al. 2014; Wacharatewinkul and Riangmoo 2019). In conclusion, the post-harvest leaves and stems, and rhizome residue are potential to be recycled and use in the food, pharmaceutical, and agricultural industries.

ACKNOWLEDGEMENTS

This research was fully granted from Thailand Science Research and Innovation (Grant no. TSRI 10-2565). We are thankful to Dr. Andrew Warner from Academic English Editor, Kasetsart University Research and Development Institute (KURDI), Bangkok, Thailand for English proofreading.

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