Important Medicinal Plant Families in Thailand

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Throughout the world, surveys have been conducted at the country level to answer research questions pertaining to ethnomedicinal usage patterns. This study is focused on Thailand, which has never been surveyed systematically in this way. We mined 16,000 records of medicinal plant use from 64 scientific reports, which were published from 1990 to 2014. In total, 2,187 plant species were cited as being useful for medicinal purposes. The overall aim was to reveal the relative importance of the plant families for pharmacological research. To determine the most important medicinal plant families, we use a combination of three statistical approaches: linear regression, Binomial analysis, and Bayesian analysis. At the regional level, 19 plant families repeatedly stood out as being the most important from an ethnomedicinal perspective.

Keywords: ethnomedicine, family importance, Bayesian analysis, binomial analysis, linear regression, relative regression residual

INTRODUCTION

It is well-documented in the scientific literature that plants have been used for medicinal purposes for the past 60,000 years (Solecki, 1975). Still today, millions of people around the world depend on medicinal plants for their well-being (WHO, 2002). In the tropics, medicinal plants are often used on a regular basis in rural communities where pharmaceuticals are hard to obtain or even unavailable. This is in contrast to westernized societies where medicinal plants are typically used as an alternative or supplement to prescribed medicine (WHO, 2002). Medicinal plants are important for people, not only as a primary source of medicines but also as phytochemical building blocks for development of new drugs (Fabricant and Farnsworth, 2001). It is estimated that 67% of drugs used in chemotherapy are derived from natural products (Wangkheirakpam, 2018). This applies to the discoveries of active compounds such as vincristine (Raviña, 2011), taxol (Fischer et al., 2010), and artemisinin (Tu, 2011). Moreover, medicinal plants also offer an opportunity for rural dwellers to generate a cash income (EL-Hilaly et al., 2003).

There are several factors that influence how people select plants for medicinal purposes: tradition, efficacy, abundance, accessibility, doctrine of signatures, as well as taxonomic affiliation (Bennett and Husby, 2008). Interestingly, some plant families comprise higher proportion of medicinally useful species than expected from the null model of a linear relationship between species diversity and number of medicinally useful species. Traditional use of plants for medicines is not random but determined, to a certain degree, by taxonomic affiliation (Moerman, 1996; Bennett and Husby, 2008). Various statistical tools have been applied to test the relationship between species richness and number of medicinally useful species. In an ethnomedicinal study conducted in North America at the family level, Moerman (1996) plotted the relationship between the number of medicinally useful plant species and the number of native species. Although the classic regression model is a simple and common way to test patterns of medicinal knowledge

(Moerman, 1996; Leonti et al., 2003; Bourbonnas-Spear et al, 2005; Douwes et al, 2008; Saslis-Lagoudakis et al., 2011), it suffers from a bias toward large families (Weckerle et al., 2011). Bennett and Husby (2008) used binomial analysis to overcome this bias in their test of the medicinal importance of Ecuadorian plant families. Bayesian analysis was recently introduced as an alternative to reveal over- and under-represented medicinal families (Weckerle et al., 2011). The technique performed particularly well for small data sets and showed similar results to those of the binomial analysis. Here, we combine all three above-mentioned statistical techniques and only refer to a plant family as important if all three statistical methods confirm that it includes a higher number of medicinal species than expected under the null model.

Studies around the world reveal that the medicinal importance of plant families is only partly overlapping across space. In North America, Moerman (1996) showed that *Asteraceae*, *Apiaceae*, *Ericaceae*, *Rosaceae*, and *Ranunculaceae* included higher numbers of medicinal species than expected based on their species richness. Likewise, in Ecuador medicinal plant species were overrepresented in *Zingiberaceae*, *Piperaceae*, *Lamiaceae*, *Amaranthaceae*, *Apiaceae*, and *Costaceae* (Bennett and Husby, 2008). In Campania, Italy, a study revealed that medicinal species were over-represented in *Lamiaceae*, *Rosaceae*, and *Malvaceae*. In contrast, the families *Orchidaceae*, *Caryophyllaceae*, *Poaceae*, and *Leguminosae* included fewer medicinally useful species than suggested by their total species numbers (Weckerle et al., 2011). A recent study from Hawaii revealed that not only *Leguminosae*, *Ericaceae*, *Malvaceae*, *Zingiberaceae*, and *Apocynaceae* but also *Poaceae* and *Cyperaceae* were the most important medicinal families (Ford and Gaoue, 2017). Similar studies were conducted in Belize (Bourbonnas-Spear et al., 2005), Mexico (Leonti et al., 2003), New Zealand (Saslis-Lagoudakis et al., 2011), Nepal (Saslis-Lagoudakis et al., 2011), and South Africa (Saslis-Lagoudakis et al., 2011). Recently, *Leguminosae*, *Lamiaceae*, *Euphorbiaceae*, *Apocynaceae*, *Malvaceae*, *Apiaceae*, and *Ranunculaceae* were listed as being the medicinally most important plant families on a worldwide scale (Kew, 2017).

In this study, we analyze and compare the medicinal usefulness of plant families across Thailand. The country boasts a high diversity of both plants and ethnic groups (Pooma and Suddee, 2014 and Phumthum et al., 2018). Thailand has traditionally been divided in seven phytogeographic regions in accordance with Tem Smitinand's classification (Smitinand, 1958). Based on a meta-analysis of plant species distribution records, van Welzen et al. (2011) concluded that the country should be divided into four phytogeographic regions defined as areas with a "typical, unique, and distinct plant composition": the southern, northern, eastern, and central regions. The overall plant diversity increases toward the Malay Peninsula, which has a less seasonal climate. The biodiversity in Thailand is generally under pressure from human activities, especially farming and urban development.

Within Thailand, more than 80 dialects are spoken, which belong to five linguistic families: Austronesian, Hmong-Mien, Sino-Tibetan, Tai-Kadai, and Austro-Asiatic (Premsrirat,

2004). The majority of the population in Thailand is referred to as local Thai. However, the population also comprises a number of ethnic minorities many of which have their main distribution outside Thailand in countries such as Myanmar (Moken, Kachin, and Taiyai), Yunnan (Mien, Haw, and Lue), and Tibet (Karen, Musue, and Lahu) (Phumthum and Balslev, 2018). It should be noticed that the comprehensive ethnomedicinal data underlying this study are biased toward the ethnic minorities, which have been visited most frequently by ethnobotanical researchers. Although the data may not reflect the average situation at the village level, it does capture all common medicinal plant uses (Phumthum et al., 2018) and provides insights into the diversity of plant used for medicinal purposes, not only in Thailand but also in the neighboring countries.

We will address the following research questions: which are the most important medicinal plant families locally and across Thailand? How do these compare with medicinally important families found elsewhere in the world?

MATERIALS AND METHODS

Plant Use Records
Plant use records were extracted from 64 studies reported in the scientific literature (1 book, 2 reports, 29 journal articles, and 32 master and PhD theses; for more details on how we avoided data replication, criteria for including or excluding references, and a list of references, we refer to our previous publications (Phumthum and Balslev, 2018; Phumthum et al., 2018). Data sources such as pocketbooks, local knowledge, plant labels in parks and gardens, and news articles were avoided since they are often based on inaccurate vernacular names, and they are difficult to reproduce due to lack of metadata. We only included records that cited scientific names and plants that had been identified to the species. To be considered, the data should comply with recognized ethnobotanical collection standards. Most of the scientific reports underlying this study cited voucher specimens deposited in herbaria across Thailand. In cases where journal articles had been published based on Master and PhD studies i.e., Srithi (2012), Srithi et al. (2012a), and Srithi et al. (2012b), we extracted the data strictly from the original thesis. We used data from studies conducted from 1990, when systematic ethnobotanical exploration began in Thailand, until 2014. All Masters and PhD theses were accessed *via* the website of the Thai Library Integrated System (https://www.thailis.or.th/tdc), which includes all Thai institutes of higher education. To gain insight into the variation of the most important medicinal plant families (MIMFs) at the subregional level, we divided the dataset in seven subsets based on geographic location of the villages in accordance with Phumthum and Balslev (2018).

Plant Diversity
The *Thai Plant Names* book provides list of all plant species in Thailand (Pooma and Suddee, 2014). We updated the taxonomy

using *The Plant List* website (www.theplantlist.org) and follow the family names used on the *Angiosperm Phylogeny* website (www.mobot.org). We identified no discrepancies except for the families *Lamiaceae* and *Leguminosae* on *The Plant List* website, which were named *Labiatae* and *Fabaceae* on *Angiosperm Phylogeny* website. We followed the former. The complete version of the list after updating included 9,793 plant species representing totally 276 families in Thailand. To avoid bias and random noise, we removed from the dataset all families with less than 10 species in Thailand. This reduced the number of families included in our analysis to 115 (**Table 1**) and the number of species to 9,097.

To investigate the geographic variation in MIMFs we used estimates of regional family diversity. In cases where the species diversity within a family was unknown for a specific region, we used instead the corresponding figure for the entire country as a conservative approach.

Statistical Approaches

Linear Regression and R Values

We used regression residuals to analyze a simple plot of the number of medicinally useful species against the total number of species in a family. It should be noted that this analytical approach when used for analyzing medicinal floras typically violates the statistical assumptions of homescedasticity and normality (Bennett and Husby, 2008).

In this study, we coined a new metric that we refer to as *relative regression residual* (R). It is defined as the relative difference between the *observed number of medicinally useful species* (O) and *predicted number of medicinally useful species under the model* (P):

$$R = (O - P) / P$$

R value equals zero (0) when there is a perfect fit between predicted and observed data; values below zero (-R) implies that a given family had fewer medicinal species than expected; and values above zero (+R) implies that a family had more medicinally useful species than expected. To filter random noise, which could be problematic in data sets assembled from many sources, we introduced a critical range of R values from -0.5 to 0.5 within which we considered deviation from the model of no consequence. Families with R values above 0.5 we refer to here as MIMFs.

Binomial Analysis

We used the BINOMDIST function in Microsoft Excel to conduct a binomial analysis in accordance with the method described by Bennett and Husby (2008). The dataset was identical to the one used for linear regression. Families with higher numbers of medicinal species than expected from the model were identified as MIMFs. Based on the probability that the actual number of medicinal species is equal to or lower than the number of expected medicinal species (a) and the probability that the number of medicinal species is equal to the number of expected medicinal species (b), we calculated a 95%

interval probability (p) that the number of medicinal species is more than the number of expected medicinal species as:

$$p = (1 - a) + b$$

We considered all plant families with 95% interval probabilities less than 0.05 as MIMFs.

Bayesian Analysis

We conducted a Bayesian analysis according to the principles laid down by Weckerle et al. (2014) using the BETA.INV function in Microsoft Excel. We considered all plant families with an inferior 95% probability credible interval higher than the one calculated for all species in Thailand (0.2362) as MIMFs in this analysis.

RESULTS

Regression Analysis

At the national scale, the modeled linear relationship between the number of medicinal species (P) and all species (T) within a given family was:

$$P = 0.3165T + 7.678$$

The model only explained 37% of the variability in the data ($R^2 = 0.37$) (**Figure 1**).

Although there was a positive relationship overall between the number of medicinally useful plants within a family and the number of species it comprises, it should be noted that some of the larger families actually contained fewer medicinal plants than some of the smaller families. A number of families had no record of medicinally useful species at all and consequently scored -1 for their R values. This applied to *Thelypteridaceae*, *Hymenophyllaceae*, *Podostemaceae*, *Eriocaulaceae*, *Hydrocharitaceae*, *Burmanniaceae*, and *Cupressaceae* (**Table 1**). Using the relative regression residual (R), we identified a total of 22 MIMFs across Thailand. The families with the highest R score were in decreasing order: *Asteraceae* (R = 2.7), *Leguminosae* (R = 1.5), *Annonaceae* (R = 1.3), *Lamiaceae* (R = 1.2), *Rutaceae* (R = 1.2), and *Cucurbitaceae* (R = 1.1).

Binomial Analysis and Bayesian Analysis

The binomial and Bayesian analyses identified the same 27 MIMFs (**Table 1**). The families *Rhamnaceae*, *Ranunculaceae*, *Dilleniaceae*, *Apiaceae*, *Connaraceae*, *Oxalidaceae*, *Sapindaceae*, and *Thymelaeaceae* were not identified by linear regression analysis as MIMFs. On the contrary, the families *Rubiaceae*, *Zingiberaceae*, and *Moraceae*, which were included in the MIMFs resulting from the linear regression analysis, were not among the MIMFs identified by the binomial and Bayesian analyses (**Table 1**).

Combined Analyses

At the national level, 19 plant families were identified as MIMFs by all three statistical approaches (**Table 1**). Fifteen of these were shared across all villages studied Thailand: *Asteraceae*, *Leguminosae*,
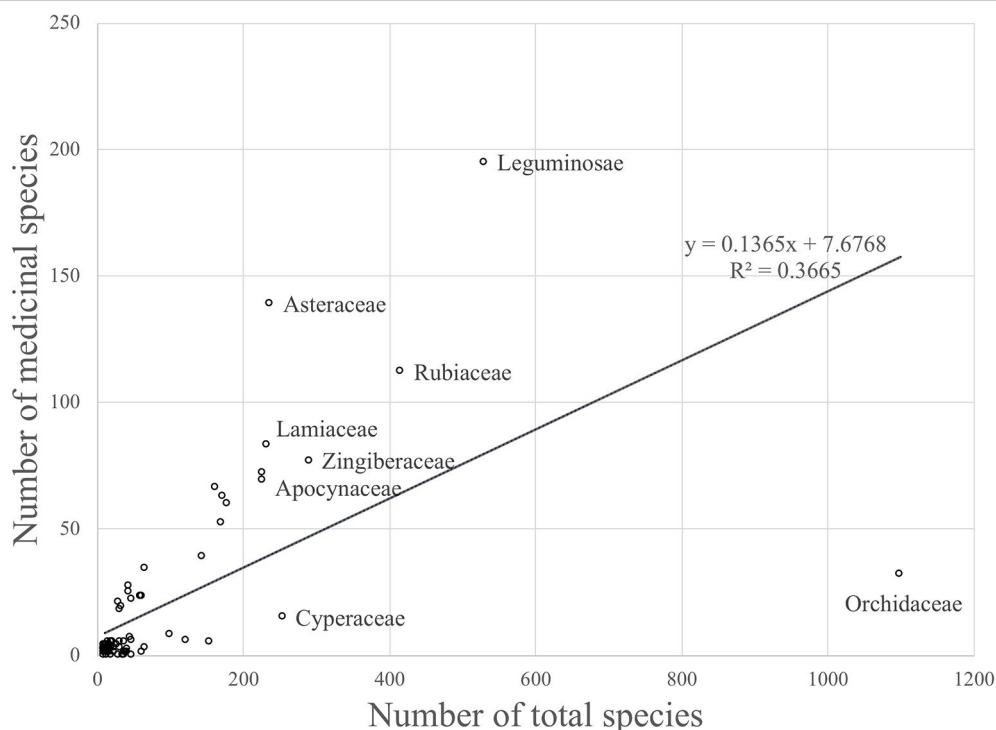
FIGURE 1 | Linear regression model that shows the relationship between the number of medicinal species and the total number of species for plant families occuring in Thailand (R^2 = 0.36646).

Combretaceae, Cucurbitaceae, Rutaceae, Menispermaceae, Lamiaceae, Amaranthaceae, Malvaceae, Solanaceae, Phyllanthaceae, Apocynaceae, Euphorbiaceae, Vitaceae, and *Acanthaceae.* The families *Annonaceae, Polygonaceae, Araliaceae,* and *Anacardiaceae* were included among the MIMFs at the national level but not shared across all villages.

Variation in MIMFs Across Regions

The regression-residual analysis revealed substantial variation in the MIMFs across the seven regions as defined by Phumthum and Balslev (2018) (**Table 2**). The highest number of MIMFs was found in the northeastern region (27) whereas the lowest number was recorded in the southeastern region (20). In the southwestern, the northern, the central, the peninsula, and eastern regions we recorded were 25, 24, 23, 23, and 21 MIMFs, respectively. The families *Leguminosae, Euphorbiaceae, Apocynaceae, Malvaceae,* and *Amaranthaceae* were shared among the MIMFs of all the regions. The families *Rutaceae, Lamiaceae, Menispermaceae, Asteraceae, Combretaceae, Acanthaceae, Phyllathaceae,* and *Rubiaceae* appeared among the MIMFs in six regions, whereas *Zingiberaceae, Moraceae,* and *Sapindaceae* appeared in five regions. Nineteen families were recorded as MIMFs in at least four regions. The total list of MIMFs across the seven regions combined included 51 plant families.

The binomial and Bayesian analyses identified the 44 MIMFs in total at the regional level. None of these families were shared across all seven regions. *Rutaceae, Leguminosae, Menispermaceae,*

Euphorbiaceae, and *Combretaceae* were identified as MIMFs in six regions; *Sapindaceae, Amaranthaceae,* and *Solanaceae,* in five regions; *Lamiaceae, Malvaceae,* and *Phyllanthaceae,* in four regions (**Table 3**).

DISCUSSION

Combining Statistical Tools in the Evaluation of the Medicinal Importance of Plant Families

The three statistical approaches used here to evaluate MIMFs at the national and regional levels in Thailand have all been used previously for analyzing medicinal floras in other parts of the world, but never in combination. Similar to Bennett and Husby (2008) and Weckerle et al. (2014), we found that the Binomial and Bayesian analyses are more sensitive to small families. By using these two statistical methods, we added the plant families *Rhamnaceae* (14 spp.), *Ranunculaceae* (20 spp.), *Dilleniaceae* (14 spp.), *Apiaceae* (25 spp.), *Connaraceae* (15 spp.), *Oxalidaceae* (11 spp.), *Sapindaceae* (45 spp.), and *Thymelaeaceae* (12 spp.) to the list of MIMFs (**Table 1**). Interestingly, the R values were biased toward the larger families and identified *Zingiberaceae* (290 spp.) and *Rubiaceae* (416 spp.) as MIMFs, whereas the Binomial and Bayesian analyses did not (**Table 1**). This result confirms previous findings that these two families are high in numbers of medicinal use reports (691 and 608 respectively) and in use value scores (5.71 and 5.02, respectively) (Phumthum et al., 2018).

TABLE 1 | Medicinal importance of all plant families in Thailand containing more than 10 species as revealed by three statistical approaches: regression residual analysis, binomial analysis and Bayesian analysis.

Family	T	M	Method					
			Regression		Binomial		Bayesian	
			P1	R	P2	Prob.	inf.	sup.
Acanthaceae	169	52	30	0.79*	38	9.53E-03*	0.2430*	0.3811
Achariaceae	11	2	9	−0.76	2	7.51E-01	0.0549	0.4841
Amaranthaceae	33	19	12	0.67*	7	1.62E-05*	0.4069*	0.7281
Amaryllidaceae	29	10	11	−0.08	7	1.01E-01	0.1993	0.5281
Anacardiaceae	61	23	15	0.53*	14	5.87E-03*	0.2660*	0.5031
Annonaceae	162	66	29	1.35*	37	2.25E-07*	0.3347*	0.4845
Apiaceae	25	14	11	0.36	6	3.19E-04*	0.3691*	0.7341
Apocynaceae	226	72	37	0.97*	51	9.81E-04*	0.2613*	0.3820
Araceae	201	27	34	−0.19	46	1.00E+00	0.0941	0.1885
Araliaceae	60	23	15	0.55*	14	4.64E-03*	0.2707*	0.5104
Arecaceae	218	23	36	−0.35	49	1.00E+00	0.0715	0.1534
Aristolochiaceae	22	5	10	−0.50	5	5.81E-01	0.1023	0.4370
Asparagaceae	80	22	18	0.26	18	1.85E-01	0.1893	0.3819
Aspleniaceae	41	1	13	−0.92	9	1.00E+00	0.0058	0.1257
Asteraceae	237	139	39	2.67*	54	1.11E-32*	0.5228*	0.6474
Athyriaceae	40	1	13	−0.92	9	1.00E+00	0.0060	0.1286
Balsaminaceae	66	3	16	−0.81	15	1.00E+00	0.0165	0.1253
Begoniaceae	41	2	13	−0.84	9	1.00E+00	0.0150	0.1616
Bignoniaceae	42	13	13	0.04	10	1.38E-01	0.1908	0.4613
Boraginaceae	28	7	11	−0.35	6	4.58E-01	0.1273	0.4354
Brassicaceae	12	4	9	−0.54	3	2.81E-01	0.1386	0.6143
Burseraceae	27	4	11	−0.62	6	8.92E-01	0.0606	0.3267
Cactaceae	11	3	9	−0.65	2	4.72E-01	0.0992	0.5719
Campanulaceae	21	5	10	−0.49	5	5.36E-01	0.1073	0.4537
Capparaceae	35	11	12	−0.05	8	1.51E-01	0.1856	0.4811
Celastraceae	55	11	15	−0.23	12	7.33E-01	0.1159	0.3243
Clusiaceae	48	12	14	−0.10	11	4.06E-01	0.1495	0.3887
Combretaceae	29	21	11	0.94*	7	1.83E-08*	0.5411*	0.8527
Commelinaceae	40	12	13	−0.02	9	1.79E-01	0.1808	0.4554
Connaraceae	15	10	10	0.11	3	3.46E-04*	0.4133*	0.8480
Convolvulaceae	114	25	22	0.14	26	6.14E-01	0.1533	0.3040
Crassulaceae	10	4	9	−0.52	2	1.73E-01	0.1675	0.6921
Cucurbitaceae	44	27	13	1.11*	10	4.28E-08*	0.4654*	0.7430
Cycadaceae	14	4	9	−0.55	3	3.97E-01	0.1182	0.5510
Cyperaceae	254	15	40	−0.63	58	1.00E+00	0.0363	0.0952
Davalliaceae	18	4	10	−0.57	4	6.10E-01	0.0915	0.4557
Dennstaedtiaceae	18	3	10	−0.68	4	8.11E-01	0.0605	0.3958
Dilleniaceae	14	10	9	0.13	3	1.45E-04*	0.4490*	0.8818
Dioscoreaceae	38	9	12	−0.25	9	5.05E-01	0.1304	0.3933
Dipterocarpaceae	67	11	16	−0.30	15	9.20E-01	0.0947	0.2710
Dryopteridaceae	62	1	16	−0.93	14	1.00E+00	0.0039	0.0853
Ebenaceae	61	18	15	0.20	14	1.33E-01	0.1956	0.4195
Elaeocarpaceae	21	5	10	−0.49	5	5.36E-01	0.1073	0.4537
Ericaceae	37	1	12	−0.92	8	1.00E+00	0.0064	0.1381
Euphorbiaceae	226	69	37	0.89*	51	4.00E-03*	0.2489*	0.3683
Fagaceae	121	6	23	−0.74	27	1.00E+00	0.0234	0.1040
Gentianaceae	38	5	12	−0.58	9	9.53E-01	0.0586	0.2743
Gesneriaceae	153	5	27	−0.81	35	1.00E+00	0.0144	0.0741
Gleicheniaceae	10	1	9	−0.88	2	9.24E-01	0.0228	0.4128
Hypericaceae	11	5	9	−0.41	2	8.11E-02	0.2109	0.7233
Icacinaceae	12	1	9	−0.88	3	9.54E-01	0.0192	0.3603
Lamiaceae	233	83	38	1.22*	53	5.30E-06*	0.2975*	0.4197
Lauraceae	112	23	22	0.06	25	7.41E-01	0.1411	0.2896
Lecythidaceae	18	4	10	−0.57	4	6.10E-01	0.0915	0.4557
Leguminosae	530	195	77	1.57*	120	1.73E-03*	0.3280*	0.4098
Linderniaceae	38	10	12	−0.17	9	3.56E-01	0.1500	0.4213
Lindsaeaceae	23	1	11	−0.90	5	9.97E-01	0.0103	0.2112
Loganiaceae	19	6	10	−0.37	4	2.49E-01	0.1539	0.5428

(Continued)

TABLE 1 | Continued

Family	T	M	Method					
			Regression		Binomial		Bayesian	
			P1	R	P2	Prob.	inf.	sup.
Loranthaceae	31	5	12	−0.55	7	8.64E-01	0.0721	0.3279
Lycopodiaceae	10	3	9	−0.64	2	4.05E-01	0.1093	0.6097
Lythraceae	32	11	12	−0.02	7	9.00E-02	0.2040	0.5183
Magnoliaceae	32	3	12	−0.73	7	9.86E-01	0.0340	0.2433
Malpighiaceae	23	3	11	−0.70	5	9.21E-01	0.0474	0.3236
Malvaceae	172	63	30	1.14*	39	2.54E-05*	0.2979*	0.4406
Marantaceae	22	6	10	−0.39	5	3.82E-01	0.1321	0.4841
Melastomataceae	99	14	20	−0.30	22	9.88E-01	0.0865	0.2237
Meliaceae	72	20	17	0.22	16	1.86E-01	0.1877	0.3909
Menispermaceae	44	25	13	0.96*	10	1.06E-06*	0.4215*	0.7036
Moraceae	144	39	26	0.51*	33	1.25E-01	0.2050	0.3489
Musaceae	13	6	9	−0.31	3	5.31E-02	0.2304	0.7114
Myristicaceae	36	8	12	−0.32	8	5.92E-01	0.1177	0.3821
Myrtaceae	121	18	23	−0.21	27	9.88E-01	0.0964	0.2231
Nepenthaceae	12	2	9	−0.77	3	7.94E-01	0.0504	0.4545
Nephrolepidaceae	10	2	9	−0.76	2	7.00E-01	0.0602	0.5178
Oleaceae	76	13	17	−0.23	17	9.07E-01	0.1031	0.2714
Orchidaceae	1099	32	151	−0.79	249	1.00E+00	0.0207	0.0408
Orobanchaceae	20	5	10	−0.48	5	4.88E-01	0.1128	0.4717
Oxalidaceae	11	7	9	−0.18	2	4.25E-03*	0.3489*	0.8483
Pandanaceae	26	6	11	−0.43	6	5.58E-01	0.1111	0.4226
Passifloraceae	16	5	10	−0.45	4	2.89E-01	0.1421	0.5596
Phyllanthaceae	178	60	30	0.99*	40	5.25E-04*	0.2717*	0.4094
Piperaceae	48	12	14	−0.10	11	4.06E-01	0.1495	0.3887
Plantaginaceae	47	6	14	−0.54	11	9.71E-01	0.0607	0.2525
Poaceae	524	52	76	−0.31	119	1.00E+00	0.0765	0.1279
Polygalaceae	25	7	11	−0.32	6	3.34E-01	0.1433	0.4779
Polygonaceae	32	18	12	0.60*	7	4.16E-05*	0.3921*	0.7189
Polypodiaceae	128	13	24	−0.45	29	1.00E+00	0.0606	0.1662
Primulaceae	115	22	23	0.00	26	8.48E-01	0.1300	0.2729
Proteaceae	13	4	9	−0.54	3	3.39E-01	0.1276	0.5810
Pteridaceae	99	8	20	−0.60	22	1.00E+00	0.0420	0.1516
Putranjivaceae	16	1	10	−0.89	4	9.84E-01	0.0146	0.2869
Ranunculaceae	20	13	10	0.35	5	6.33E-05*	0.4303*	0.8189
Rhamnaceae	14	11	9	0.24	3	1.49E-05*	0.5191*	0.9221
Rhizophoraceae	17	2	10	−0.78	4	9.25E-01	0.0358	0.3471
Rosaceae	57	14	15	−0.03	13	4.19E-01	0.1526	0.3717
Rubiaceae	416	112	62	0.83*	94	2.45E-02	0.2289	0.3139
Rutaceae	65	34	16	1.19*	15	1.98E-07*	0.4034*	0.6401
Salicaceae	35	9	12	−0.22	8	3.98E-01	0.1420	0.4220
Santalaceae	15	2	10	−0.78	3	8.86E-01	0.0405	0.3835
Sapindaceae	45	18	13	0.39	10	6.97E-03*	0.2699*	0.5463
Sapotaceae	46	7	14	−0.46	10	9.23E-01	0.0765	0.2831
Selaginellaceae	20	3	10	−0.69	5	8.65E-01	0.0545	0.3634
Smilacaceae	29	10	11	−0.08	7	1.01E-01	0.1993	0.5281
Solanaceae	47	22	14	0.67*	11	2.34E-04*	0.3329*	0.6083
Stemonaceae	14	5	9	−0.44	3	1.94E-01	0.1634	0.6162
Styracaceae	10	2	9	−0.76	2	7.00E-01	0.0602	0.5178
Symplocaceae	17	1	10	−0.89	4	9.87E-01	0.0138	0.2729
Tectariaceae	14	3	9	−0.66	3	6.48E-01	0.0779	0.4809
Theaceae	11	2	9	−0.76	2	7.51E-01	0.0549	0.4841
Thymelaeaceae	12	7	9	−0.19	3	8.21E-03*	0.3158*	0.8078
Urticaceae	76	18	17	0.06	17	4.63E-01	0.1556	0.3441
Verbenaceae	13	5	9	−0.43	3	1.52E-01	0.1766	0.6486
Violaceae	10	3	9	−0.64	2	4.05E-01	0.1093	0.6097
Vitaceae	57	22	15	0.52*	13	5.05E-03*	0.2704*	0.5163
Zingiberaceae	290	77	45	0.72*	66	6.92E-02	0.2180	0.3192

T, total number of all species; M, number of medicinal species; P1, number of medicinal species predicted by the regression model; R, R value; P2, number of medicinal species predicted by the binomial model; Prob, binomial probability; inf., inferior of 95% Bayesian interval; sup., superior of 95% Bayesian interval. A "" indicates that the family was estimated as MIMFs using the given method.*

TABLE 2 | Relative regression residuals (R values) for Thai plant families in each of seven regions in Thailand as defined by Phumthum & Balslev (2018).

Family	C	E	N	NE	P	SE	SW
Acanthaceae	0.58*	1.13*	1.44	0.81*	0.40	2.64*	1.30*
Achariaceae	−0.41	−1.00	−0.69	−1.00	−1.00	−1.00	−0.27
Amaranthaceae	2.02*	0.79*	0.89*	1.45*	1.08*	1.41*	0.74*
Amaryllidaceae	−0.47	−0.53	−0.09	1.03*	−0.28	0.23	1.41*
Anacardiaceae	0.43	0.02	0.52*	1.37*	0.12	−1.00	1.76*
Annonaceae	−0.40	2.66*	−0.10	1.33	2.42*	2.72*	0.32
Apiaceae	0.04	−0.51	0.08	0.05	1.48*	−1.00	−0.37
Apocynaceae	2.40*	2.82*	0.80*	1.22*	1.37*	2.75*	1.07*
Araceae	−0.02	−0.38	0.03	0.01	0.43	−0.33	0.35
Araliaceae	−0.57	−0.31	0.7*	−0.60	0.32	1.13*	0.39
Arecaceae	−1.07	−0.56	−0.51	−0.24	0.53*	0.91*	−0.79
Aristolochiaceae	−0.45	−0.49	−0.72	−1.00	−0.49	0.27	−1.00
Asparagaceae	−0.13	0.17	0.6*	−0.30	−0.01	0.97*	0.61
Aspleniaceae	−0.51	−1.00	−0.88	−1.00	−0.78	−1.00	−1.00
Asteraceae	1.86*	−0.18	2.07*	0.7*	0.78*	0.82*	2.00*
Athyriaceae	−0.50	−1.00	−0.88	−1.00	−0.78	−1.00	−0.46
Balsaminaceae	−0.59	−1.00	−0.80	−0.62	−0.64	−1.00	−1.00
Begoniaceae	−0.51	−0.59	−0.88	−1.00	−1.00	−1.00	−1.00
Bignoniaceae	−0.01	0.22	0.40	−0.09	−0.36	0.16	1.68*
Boraginaceae	−0.47	0.42	−0.34	−0.49	−0.52	−1.00	−0.39
Brassicaceae	0.08	−1.00	−0.85	−0.40	−0.72	−1.00	−0.28
Burseraceae	0.04	−1.00	−0.47	−0.48	−1.00	−1.00	−1.00
Cactaceae	−0.41	−1.00	−0.69	−1.00	−0.72	−1.00	−1.00
Campanulaceae	−0.44	−1.00	−0.44	−0.45	−1.00	−1.00	−1.00
Capparaceae	0.51*	0.31	−0.01	0.44	−0.32	2.59*	−0.43
Celastraceae	−0.55	0.79*	−0.36	1.06*	−0.03	0.09	−0.52
Clusiaceae	−0.03	−1.00	−0.66	−0.57	0.64*	0.13	−1.00
Combretaceae	1.53*	1.34*	0.83*	2.04*	0.20	1.46*	1.41*
Commelinaceae	0.50*	−0.59	0.19	−0.54	−0.56	−1.00	0.63*
Connaraceae	−0.42	0.68*	−0.40	0.16	0.91*	−1.00	−1.00
Convolvulaceae	1.26*	−0.06	−0.18	−0.42	−0.04	−0.13	−0.01
Crassulaceae	−0.41	−1.00	−0.37	−1.00	−0.71	−1.00	−1.00
Cucurbitaceae	0.98*	0.19	1.76*	−0.10	0.06	0.15	2.16*
Cycadaceae	−0.42	−1.00	−0.40	−1.00	−1.00	−1.00	−1.00
Cyperaceae	−1.19	−0.74	−0.65	−0.49	−0.44	−1.00	−1.00
Davalliaceae	−0.43	−1.00	−0.71	−0.44	−0.47	−1.00	−1.00
Dennstaedtiaceae	−0.43	−1.00	−0.57	−0.44	−1.00	−1.00	−1.00
Dilleniaceae	−0.42	0.70*	−0.40	0.75*	0.65*	0.33	−1.00
Dioscoreaceae	0.00	−0.58	−0.15	−0.06	−0.11	0.18	0.11
Dipterocarpaceae	−0.59	−0.03	−0.51	1.28*	−0.64	0.04	−0.12
Dryopteridaceae	−0.58	−1.00	−0.90	−1.00	−1.00	−1.00	−1.00
Ebenaceae	0.93*	1.72*	0.22	0.58*	−0.25	0.06	0.8*
Elaeocarpaceae	−0.44	0.03	−0.86	−1.00	−0.49	−1.00	−1.00
Ericaceae	−0.50	−1.00	−0.88	−1.00	−1.00	−1.00	−1.00
Euphorbiaceae	2.40*	1.55*	1.23*	1.78*	1.54*	3.37*	1.0*
Fagaceae	−0.76	−1.00	−0.71	−0.72	−0.74	−1.00	−1.00
Gelsemiaceae	−2.07	−1.00	−0.98	−1.00	−1.00	−1.00	−1.00
Gentianaceae	−0.50	−0.58	−0.64	−1.00	−0.56	−1.00	−1.00
Gesneriaceae	−0.87	−0.62	−0.81	−1.00	−0.77	−1.00	−1.00
Gleicheniaceae	−0.41	−1.00	−0.84	−1.00	−1.00	−1.00	−1.00
Hypericaceae	−0.41	0.77*	−0.53	−0.40	−0.72	−1.00	−0.27
Icacinaceae	−0.42	−1.00	−0.85	−1.00	−1.00	−1.00	−1.00
Lamiaceae	1.38*	0.24	1.74*	1.54*	1.74*	2.68*	2.24*
Lauraceae	−0.74	−0.29	0.05	0.76*	0.66*	−0.13	−1.00
Lecythidaceae	0.56*	0.07	−0.86	−0.44	−0.21	−1.00	−1.00
Leguminosae	6.93*	2.27*	2.47*	2.55*	1.30*	1.49*	2.60*
Linderniaceae	0.00	−1.00	−0.15	−0.53	−0.33	−1.00	−0.45
Lindsaeaceae	−0.45	−1.00	−0.86	−1.00	−1.00	−1.00	−1.00
Loganiaceae	0.06	0.59*	−0.43	0.11	−1.00	0.29	−1.00
Loranthaceae	0.02	−0.54	−0.49	−1.00	−0.29	0.22	−1.00
Lycopodiaceae	−0.41	−1.00	−0.69	−1.00	−0.43	−1.00	−1.00
Lythraceae	−0.48	−0.10	0.02	−0.01	−0.07	−1.00	0.76*
Magnoliaceae	−0.48	−1.00	−0.62	−1.00	−1.00	−1.00	−1.00
Malpighiaceae	−0.45	−1.00	−0.59	−1.00	−1.00	−1.00	−1.00

(Continued)

TABLE 2 | Continued

Family	C	E	N	NE	P	SE	SW
Malvaceae	6.07*	1.62*	1.24*	1.02*	0.80*	3.33*	1.02*
Marantaceae	0.05	−1.00	−0.44	−0.46	−0.23	−1.00	−1.00
Melastomataceae	−0.69	0.03	−0.44	−0.37	0.04	−0.08	−1.00
Meliaceae	−0.61	−0.07	0.23	−0.27	0.39	−1.00	0.28
Menispermaceae	0.48	1.39*	1.30*	1.69*	1.11*	4.73*	2.16*
Moraceae	1.16*	0.20	0.68*	0.01	0.55*	2.14*	1.28*
Musaceae	−0.42	−1.00	−0.24	0.77	−0.16	−1.00	−0.29
Myristicaceae	−0.49	−0.14	−0.63	−1.00	0.13	0.19	−1.00
Myrtaceae	−0.76	−0.10	−0.35	−0.44	0.19	−1.00	−0.36
Nepenthaceae	−0.42	−1.00	−1.00	−1.00	−0.44	−1.00	−1.00
Nephrolepidaceae	−0.41	−1.00	−0.69	−1.00	−1.00	−1.00	−1.00
Oleaceae	0.38	0.51*	−0.36	−1.00	−0.15	0.00	−1.00
Orchidaceae	−3.89	−0.72	−0.86	−0.95	−0.77	−1.00	−0.79
Orobanchaceae	−0.44	−0.48	−0.72	−0.45	−0.74	−1.00	−1.00
Oxalidaceae	1.09*	−1.00	0.09	−1.00	−0.43	−1.00	−1.00
Pandanaceae	−0.46	−0.52	−0.73	−0.48	0.47	0.25	−0.38
Passifloraceae	0.07	−0.45	−0.70	−1.00	−0.46	−1.00	0.38
Phyllanthaceae	2.55*	1.73*	1.25*	1.19*	1.90*	0.42	0.97
Piperaceae	−0.03	−1.00	0.23	0.30	0.44	2.37*	1.54*
Plantaginaceae	−0.03	−0.23	−0.66	−0.56	−0.17	0.13	−0.49
Poaceae	−2.05	−0.66	−0.03	0.23	−0.15	−1.00	−0.48
Polygalaceae	0.04	0.47	−0.46	−1.00	−0.50	−1.00	−1.00
Polygonaceae	0.52*	−1.00	0.9*	0.48	−0.07	−1.00	−1.00
Polypodiaceae	−0.79	−0.78	−0.37	−0.46	−0.10	−1.00	−0.69
Primulaceae	−0.24	−0.30	0.26	−0.14	−0.05	−0.14	−0.67
Proteaceae	−0.42	−0.43	−0.70	−1.00	−1.00	−1.00	−0.29
Pteridaceae	−0.69	−1.00	−0.60	−1.00	−0.41	−1.00	−1.00
Putranjivaceae	−0.43	−1.00	−1.00	−0.43	−1.00	−1.00	−0.31
Ranunculaceae	−0.44	−1.00	0.70*	−1.00	−0.74	−1.00	−1.00
Rhamnaceae	0.58*	−0.43	0.66*	1.92*	−0.72	0.33	−0.29
Rhizophoraceae	−0.43	−0.46	−1.00	−0.43	−0.46	0.31	−1.00
Rosaceae	−0.56	−0.65	0.25	−0.19	−0.62	−1.00	−1.00
Rubiaceae	1.79*	1.62*	0.74*	0.8*	1.34*	1.54*	0.14
Rutaceae	−0.58	3.61*	1.27*	2.08*	1.18*	6.32*	3.91*
Salicaceae	−0.49	−0.13	−0.26	0.44	−0.77	−1.00	−0.43
Santalaceae	−0.42	−0.44	−0.70	−0.42	−1.00	−1.00	−1.00
Sapindaceae	2.48*	0.18	0.03	1.66*	0.68*	2.42*	1.09*
Sapotaceae	−0.52	−1.00	−0.55	−0.56	−0.38	−1.00	−0.48
Selaginellaceae	−0.44	−1.00	−0.57	−1.00	−1.00	−1.00	−1.00
Smilacaceae	−0.47	−0.07	0.04	−1.00	−0.04	0.23	−1.00
Solanaceae	0.47	−0.23	1.03*	2.06*	0.86*	0.13	4.13*
Stemonaceae	−0.42	−0.43	−0.40	−0.42	−0.45	−1.00	−0.29
Styracaceae	−0.41	−0.40	−0.69	−1.00	−1.00	−1.00	−1.00
Symplocaceae	−0.43	−0.46	−1.00	−1.00	−1.00	−1.00	−1.00
Tectariaceae	−0.42	−1.00	−0.70	−1.00	−1.00	0.33	−0.29
Theaceae	−0.41	−1.00	−0.69	−1.00	−1.00	−1.00	−1.00
Thymelaeaceae	−0.42	−0.42	−1.00	0.79*	0.41	0.34	−0.28
Urticaceae	0.38	−1.00	0.47	−1.00	−0.66	0.00	−0.59
Verbenaceae	0.58*	−1.00	−0.54	−0.41	0.11	0.34	0.43
Violaceae	−0.41	−1.00	−0.69	−1.00	−1.00	−1.00	−0.26
Vitaceae	−0.06	2.87*	0.67*	0.22	0.54*	−1.00	0.42
Zingiberaceae	−0.80	0.73*	0.61*	0.99*	1.03*	−0.46	1.73*

C, central; E, eastern; N, northern; NE, northeastern; P, peninsula; SE, southeastern and SW,southwestern. A "*" indicates that the family was estimated as MIMF using this method.

Despite the fact that the three statistical approaches applied here to estimate medicinal importance of plant families all have their strength and weaknesses, our results show remarkable overlap in the results (**Table 1**). This applies especially to the national scale where we obtained robust estimates of the MIMFs due to large sample sizes. In cases where sample sizes are moderate, e.g., at smaller spatial scales, it is particularly important to combine statistical approaches to avoid inherent methodological biases.

The number of MIMFs identified by the three statistical approaches varied between 20 and 27 across the regions (**Table 2**). Of the three methodological approaches, the binomial analysis generally identified fewer MIMFs (8–20). The highest number was recovered in the northern region, the lowest

TABLE 3 | Binomial probabilities of the plant families with higher numbers of medicinal species than expected under the null model of a perfect relationship with family size.

Family	C	E	N	NE	P	SE	SW
Acanthaceae	0.488	0.055	0.000*	0.24	0.490	0.061	0.070
Achariaceae	1.000	1.000	0.455	1.00	1.000	1.000	0.285
Amaranthaceae	0.000*	0.049*	0.000*	0.001*	0.001*	0.063	0.076
Amaryllidaceae	1.000	0.713	0.091	0.002*	0.367	0.304	0.011*
Anacardiaceae	0.244	0.477	0.016	0.002*	0.299	1.000	0.010*
Annonaceae	0.920	0.000*	0.965	0.06	0.000*	0.052	0.537
Apiaceae	0.323	0.659	0.015	0.22	0.000*	1.000	0.533
Apocynaceae	0.064	0.000*	0.102	0.10	0.010*	0.064	0.145
Araceae	0.820	0.972	0.954	0.84	0.531	0.919	0.562
Araliaceae	1.000	0.725	0.002*	0.880	0.156	0.171	0.269
Arecaceae	1.000	0.995	1.000	0.95	0.454	0.508	0.999
Aristolochiaceae	1.000	0.612	0.823	1.00	0.494	0.240	1.000
Asparagaceae	0.713	0.436	0.021	0.78	0.551	0.261	0.219
Aspleniaceae	1.000	1.000	0.998	1.00	0.958	1.000	1.000
Asteraceae	0.165	0.936	0.000*	0.32	0.232	0.564	0.006*
Athyriaceae	1.000	1.000	0.997	1.00	0.954	1.000	0.704
Balsaminaceae	1.000	1.000	0.999	0.91	0.961	1.000	1.000
Begoniaceae	1.000	0.829	0.998	1.00	1.000	1.000	1.000
Bignoniaceae	0.481	0.259	0.009	0.44	0.613	0.408	0.008*
Boraginaceae	1.000	0.112	0.334	0.63	0.626	1.000	0.574
Brassicaceae	0.171	1.000	0.828	0.35	0.604	1.000	0.306
Burseraceae	0.344	1.000	0.514	0.62	1.000	1.000	1.000
Cactaceae	1.000	1.000	0.455	1.00	0.572	1.000	1.000
Campanulaceae	1.000	1.000	0.321	0.53	1.000	1.000	1.000
Capparaceae	0.102	0.182	0.096	0.12	0.488	0.009*	0.656
Celastraceae	1.000	0.081	0.780	0.004*	0.389	0.497	0.813
Clusiaceae	0.528	1.000	0.968	0.82	0.024*	0.451	1.000
Combretaceae	0.001*	0.007*	0.000*	0.000*	0.060	0.050*	0.011*
Commelinaceae	0.128	0.821	0.039	0.76	0.808	1.000	0.118
Connaraceae	1.000	0.023*	0.138	0.10	0.000*	1.000	1.000
Convolvulaceae	0.102	0.712	0.922	0.91	0.751	0.759	0.668
Crassulaceae	1.000	1.000	0.037	1.00	0.538	1.000	1.000
Cucurbitaceae	0.031*	0.283	0.000*	0.46	0.227	0.422	0.002*
Cycadaceae	1.000	1.000	0.113	1.00	1.000	1.000	1.000
Cyperaceae	1.000	1.000	1.000	0.99	1.000	1.000	1.000
Davalliaceae	1.000	1.000	0.726	0.47	0.391	1.000	1.000
Dennstaedtiaceae	1.000	1.000	0.454	0.47	1.000	1.000	1.000
Dilleniaceae	1.000	0.019*	0.113	0.001*	0.000*	0.160	1.000
Dioscoreaceae	0.448	0.805	0.257	0.39	0.312	0.378	0.316
Dipterocarpaceae	1.000	0.540	0.961	0.003*	0.964	0.567	0.601
Dryopteridaceae	1.000	1.000	1.000	1.00	1.000	1.000	1.000
Ebenaceae	0.069	0.004*	0.121	0.17	0.673	0.533	0.111
Elaeocarpaceae	1.000	0.221	0.954	1.00	0.469	1.000	1.000
Ericaceae	1.000	1.000	0.996	1.00	1.000	1.000	1.000
Euphorbiaceae	0.064	0.008*	0.002*	0.001*	0.003*	0.024*	0.009*
Fagaceae	1.000	1.000	1.000	0.99	0.999	1.000	1.000
Gelsemiaceae	1.000	1.000	1.000	1.00	1.000	1.000	1.000
Gentianaceae	1.000	0.805	0.907	1.00	0.785	1.000	1.000
Gesneriaceae	1.000	0.989	1.000	1.00	1.000	1.000	1.000
Gleicheniaceae	1.000	1.000	0.770	1.00	1.000	1.000	1.000
Hypericaceae	1.000	0.010*	0.182	0.32	0.572	1.000	0.285
Icacinaceae	1.000	1.000	0.828	1.00	1.000	1.000	1.000
Lamiaceae	0.295	0.650	0.000*	0.004*	0.001*	0.072	0.002*
Lauraceae	1.000	0.855	0.680	0.20	0.128	0.753	1.000
Lecythidaceae	0.031*	0.174	0.929	0.47	0.145	1.000	1.000
Leguminosae	0.002*	0.000*	0.000*	0.000*	0.026	0.485	0.000*
Linderniaceae	0.448	1.000	0.257	0.74	0.544	1.000	0.686
Lindsaeaceae	1.000	1.000	0.966	1.00	1.000	1.000	1.000
Loganiaceae	0.257	0.044*	0.256	0.14	1.000	0.211	1.000
Loranthaceae	0.384	0.736	0.628	1.00	0.408	0.321	1.000
Lycopodiaceae	1.000	1.000	0.406	1.00	0.167	1.000	1.000
Lythraceae	1.000	0.392	0.062	0.31	0.211	1.000	0.070

(Continued)

TABLE 3 | Continued

Family	C	E	N	NE	P	SE	SW
Magnoliaceae	1.000	1.000	0.832	1.00	1.000	1.000	1.000
Malpighiaceae	1.000	1.000	0.626	1.00	1.000	1.000	1.000
Malvaceae	0.000*	0.006*	0.001*	0.15	0.141	0.021*	0.147
Marantaceae	0.291	1.000	0.354	0.54	0.222	1.000	1.000
Melastomataceae	1.000	0.603	0.987	0.87	0.609	0.709	1.000
Meliaceae	1.000	0.589	0.178	0.72	0.165	1.000	0.367
Menispermaceae	0.149	0.010*	0.000*	0.000*	0.001*	0.000*	0.002*
Moraceae	0.186	0.568	0.082	0.75	0.273	0.105	0.069
Musaceae	1.000	1.000	0.024	0.001*	0.067	1.000	0.327
Myristicaceae	1.000	0.451	0.886	1.00	0.126	0.362	1.000
Myrtaceae	1.000	0.754	0.989	0.93	0.548	1.000	0.881
Nepenthaceae	1.000	1.000	1.000	1.00	0.223	1.000	1.000
Nephrolepidaceae	1.000	1.000	0.406	1.00	1.000	1.000	1.000
Oleaceae	0.330	0.216	0.909	1.00	0.674	0.613	1.000
Orchidaceae	1.000	1.000	1.000	1.00	1.000	1.000	1.000
Orobanchaceae	1.000	0.577	0.779	0.51	0.786	1.000	1.000
Oxalidaceae	0.001*	1.000	0.000*	1.00	0.195	1.000	1.000
Pandanaceae	1.000	0.673	0.888	0.61	0.011*	0.277	0.547
Passifloraceae	0.221	0.498	0.663	1.00	0.336	1.000	0.082
Phyllanthaceae	0.022*	0.004*	0.001*	0.10	0.000*	0.649	0.168
Piperaceae	0.528	1.000	0.056	0.24	0.063	0.021*	0.014*
Plantaginaceae	0.520	0.594	0.964	0.81	0.466	0.444	0.761
Poaceae	1.000	1.000	1.000	0.93	1.000	1.000	1.000
Polygalaceae	0.323	0.086	0.451	1.00	0.564	1.000	1.000
Polygonaceae	0.088	1.000	0.000*	0.10	0.211	1.000	1.000
Polypodiaceae	1.000	0.996	0.994	0.94	0.846	1.000	0.980
Primulaceae	0.834	0.867	0.403	0.77	0.759	0.762	0.970
Proteaceae	1.000	0.428	0.547	1.00	1.000	1.000	0.327
Pteridaceae	1.000	1.000	0.998	1.00	0.942	1.000	1.000
Putranjivaceae	1.000	1.000	1.000	0.44	1.000	1.000	0.386
Ranunculaceae	1.000	1.000	0.000*	1.00	0.786	1.000	1.000
Rhamnaceae	0.019*	0.452	0.000*	0.000*	0.661	0.160	0.347
Rhizophoraceae	1.000	0.519	1.000	0.46	0.364	0.191	1.000
Rosaceae	1.000	0.914	0.081	0.60	0.932	1.000	1.000
Rubiaceae	0.466	0.002*	0.399	0.39	0.019*	0.412	0.878
Rutaceae	1.000	0.000*	0.000*	0.000*	0.003*	0.000*	0.000*
Salicaceae	1.000	0.437	0.342	0.12	0.933	1.000	0.656
Santalaceae	1.000	0.475	0.627	0.41	1.000	1.000	1.000
Sapindaceae	0.000*	0.294	0.153	0.000*	0.017*	0.018*	0.046*
Sapotaceae	1.000	1.000	0.890	0.81	0.674	1.000	0.754
Selaginellaceae	1.000	1.000	0.527	1.00	1.000	1.000	1.000
Smilacaceae	1.000	0.347	0.036	1.00	0.165	0.304	1.000
Solanaceae	0.165	0.594	0.000*	0.000*	0.007*	0.444	0.000*
Stemonaceae	1.000	0.452	0.113	0.39	0.279	1.000	0.347
Styracaceae	1.000	0.350	0.406	1.00	1.000	1.000	1.000
Symplocaceae	1.000	0.519	1.000	1.00	1.000	1.000	1.000
Tectariaceae	1.000	1.000	0.589	1.00	1.000	0.160	0.347
Theaceae	1.000	1.000	0.455	1.00	1.000	1.000	1.000
Thymelaeaceae	1.000	0.403	1.000	0.001*	0.001*	0.139	0.306
Urticaceae	0.330	1.000	0.050	1.00	0.980	0.613	0.901
Verbenaceae	0.017*	1.000	0.258	0.37	0.013*	0.150	0.056
Violaceae	1.000	1.000	0.406	1.00	1.000	1.000	0.263
Vitaceae	0.590	0.000*	0.003*	0.32	0.059	1.000	0.244
Zingiberaceae	0.989	0.244	0.432	0.22	0.095	0.973	0.015*

C, central; E, eastern; N, northern; NE, northeastern; P, peninsula; SE, southeastern and SW, southwestern. A "" indicates that the family was estimated as MIMF using this method.*

in the southeastern region. The fact that none of the families were estimated as MIMF throughout all regions (**Table 3**) is an artifact of missing information, *viz.*, when the species diversity of a family was unknown for a specific region, we substituted it with the family diversity for the entire country. Since we used the same datasets throughout the analyses, this cannot, however, explain the differences between the three analytical approaches. The use of R values at the regional scale interestingly resulted in uniform results across scales, as for both the number and overlap of MIMFs are concerned (**Tables 1** and **2**).

TABLE 4 | Important medicinal families identified in ethnomedicinal studies from other parts of the world.

Family	North America I	Nepal	South Africa Cape	New Zealand	Beliz I	Mexico	Beliz II	Southern Africa	North America II	Korea	Guatamala	India	Ecuador I	Italy	Ecuador II	Hawaii
Acanthaceae					*											
Aceraceae									*	*						
Adiantaceae					*											
Amaranthaceae													*		*	
Amaryllidaeceae			*													
Anacardiaceae		*	*					*	*		*					
Apiaceae	*								*	*	*				*	
Apocynaceae		*						*		*	*		*	*		
Araceae					*		*			*			*			
Araliaceae				*					*	*	*					
Arecaceae													*			
Asparagaceae			*													
Asteraceae	*	*	*	*	*	*	*	*	*		*	*				
Betulaceae									*							
Bignoniaceae													*			
Boraginaceae								*			*		*			*
Brassicaceae											*					
Campanulaceae										*						
Caprifoliaceae	*								*		*			*		
Caryophyllaceae				*							*					
Celastraceae			*													
Clethraceae											*					
Clusiaceae		*														
Combretaceae		*														
Commelinaceae																
Convolvulaceae		*	*					*		*						*
Cornaceae									*							
Costaceae															*	
Cucurbitaceae		*												*		
Cyclanthaceae													*			
Dioscoreaceae											*					*
Ebenaceae			*													
Elaeagnaceae									*							
Ericaceae	*								*	*	*					*
Euphorbiaceae		*				*		*	*			*	*			
Fagaceae	*									*	*					
Gentianaceae										*	*					
Geraniaceae			*	*						*						
Gesneriaceae													*			
Grossulariaceae									*							
Iridaceae										*	*					
Juglandaceae									*							
Lamiaceae	*	*	*			*			*	*	*			*	*	
Lauraceae										*						
Leguminosae		*				*	*	*	*							
Liliaceae										*	*					

(Continued)

TABLE 4 | Continued

Family	North America I	Nepal	South Africa Cape	New Zealand	Beliz I	Mexico	Beliz II	Southern Africa	North America II	Korea	Guatamala	India	Ecuador I	Italy	Ecuador II	Hawaii
Loranthaceae													*	*		
Lythraceae		*									*					
Magnoliaceae								*								
Malpighiaceae													*			
Malvaceae		*	*	*				*					*	*		*
Melanthaceae														*		
Melastomataceae		*					*									
Meliaceae											*					
Menispermaceae													*			
Monimiaceae				*									*			
Moraceae		*						*						*		*
Myricaceae								*								
Myrtaceae				*												*
Nyctaginaceae											*					
Oleaceae		*														
Onagraceae										*	*					
Orobanchaceae								*								
Pandanaceae																*
Papaveraceae										*						
Pedaliaceae								*								
Pinaceae	*															
Piperaceae				*	*	*									*	
Plantaginaceac								*								
Plumbaginaceae								*								*
Poaceae			*													*
Podocarpaceae				*												
Polygonaceae		*										*				
Primulaceae														*		
Ranunculaceae	*							*		*	*	*				
Rhamnaceae											*					
Rosaceae	*	*						*			*			*		*
Rubiaceae		*	*	*	*		*									
Rutaceae		*								*						
Salicaceae	*							*						*		
Sapindaceae																*
Smilacaceae								*								*
Solanaceae		*	*	*				*			*	*		*		*
Symplocaceae		*														
Urticaceae		*											*	*		
Valerianaceae											*					
Verbenaceae		*		*						*	*		*			
Violaceae														*		
Vitaceae		*						*								
Zingiberaceae		*											*		*	*

Most Important Medicinal Families (MIMFs)

At the national scale, the combined statistical analyses identified 19 plant families as being MMIFs: *Asteraceae, Leguminosae, Combretaceae, Cucurbitaceae, Rutaceae, Annonaceae, Menispermaceae, Lamiaceae, Amaranthaceae, Malvaceae, Polygonaceae, Solanaceae, Phyllanthaceae, Apocynaceae, Euphorbiaceae, Araliaceae, Vitaceae, Anacardiaceae,* and *Acanthaceae* (**Table 1**). Many of these families have also been identified as MIMFs in other Asian countries such as Nepal (Saslis-Lagoudakis et al., 2011.) and South Korea (Moerman and Pemberton, 1999). The Nepali folk medicine shares most MIMFs with Thailand: *Malvaceae, Lamiaceae, Apocynaceae, Asteraceae, Cucurbitaceae,* and *Euphorbiaceae*. This is most probably due to the fact that the Nepali and the northern Thai flora contain some of the same phytogeographic elements. The flora of South Korea, which is located at subtropical and temperate latitudes, is different. Although some overlap with Thai MIMFs such as *Lamiaceae, Apocynaceae,* or *Leguminosae,* many temperate families such as *Aceraceae, Campanulaceae,* and *Ericaceae* are medicinally important in the South Korean folk medicine (**Table 4**).

Within Thailand, it is noticeable that the list of MIMFs from the different regions is so similar despite the fact that the regional floras are composed of different phytogeographic elements. This is particularly obvious, when the northern and the peninsular regions are compared. The northern region contains a Indo-Burmese phytogeographic element, whereas the peninsular region has a pronounced Malayan element (van Welzen et al., 2011). Fifteen plan families were shared between the list of MIMFs identified from northern region (27) and the peninsular region (23), respectively: *Leguminosae, Euphorbiaceae, Apocynaceae, Malvaceae, Amaranthaceae, Rutaceae, Lamiaceae, Menispermaceae, Asteraceae, Phyllanthaceae, Rubiaceae, Zingiberaceae, Moraceae, Solanaceae,* and *Vitaceae*. This corresponds to a 60% overlap (**Table 2**). Our results indicate that although there are pronounced regional differences in the flora throughout Thailand, the MIMFs remain remarkably similar.

At the global scale, at least 90 plant families were cited as most important across 16 studies conducted in North America, Nepal, South Africa, New Zealand, Belize, Mexico, South Korea, Guatemala, India, Ecuador, Italy, and Hawaii (**Table 4**). Of these, 21 families were identified as most important repeatedly in at least four countries. Those were *Asteraceae* (11 countries), *Lamiaceae* (9), *Solanaceae* (8), *Malvaceae* (7), *Apocynaceae* (6), *Euphorbiaceae* (6), *Rosaceae* (6), *Anacardiaceae* (5), *Apiaceae* (5), *Leguminosae* (5), *Convolvulaceae* (5), *Ericaceae* (5), *Ranunculaceae* (5), *Rubiaceae* (5), *Verbenaceae* (5), *Araliaceae* (4), *Moraceae* (4), *Piperaceae* (4), *Zingiberaceae* (4), *Araceae* (4), *Boraginaceae* (4), and *Caprifoliaceae* (4) (**Table 4**). On this background, it is interesting that families of global medicinal importance such as *Asteraceae, Leguminosae, Rutaceae, Lamiaceae, Malvaceae, Solanaceae, Apocynaceae, Euphorbiaceae, Araliaceae,* and *Anacardiaceae* are also found among the MIMFs both at the national and regional scales in Thailand (**Tables 1, 2,** and **4**). Shared knowledge concerning the effect of certain plant species on the human physiology have either been discovered independently or as a result of cultural exchange. To confirm this, we need detailed, comparative anthropological studies through space and time.

CONCLUSION

This study fills a gap in our ethnomedicinal knowledge about Thailand and the Southeast Asian region in general. By using three different analytical approaches, we recovered the MIMFs in Thailand and revealed substantial differences at the regional level. Ten of the MIMFs in Thailand are also listed as important elsewhere in the world: *Asteraceae, Leguminosae, Rutaceae, Lamiaceae, Malvaceae, Solanaceae, Apocynaceae, Euphorbiaceae, Araliaceae,* and *Anacardiaceae*. We consider these families particularly promising for the pharmacological industry because their widespread use is most probably due to their content of physiologically active compounds.

We recommend that statistical approaches are combined especially when dealing with small to moderate sample sizes to avoid inherent methodological biases. It should be noted that regression residuals as used in this study to identify MIMFs apparently are less sensitive to artifacts caused by unequal family sizes. Differences in the MIMFs identified across the regions in Thailand are determined by both floristic and cultural factors. Recovering ethnomedicinal usage patterns in Thailand and elsewhere will inform natural resource management and guide pharmacologists in their constant search for chemical compound with hitherto, unknown physiological effects, which can be used as a starting point for developing new drugs.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript/supplementary files.

AUTHOR CONTRIBUTIONS

MP conceived the idea, collected and analyzed data, and wrote the manuscript. HB supervised the research and wrote the manuscript. AB supported the analyses, wrote the manuscript, and supervised the research.

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