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Research article

Exploration of the nutritional and carotenoids profiles of vegetables in Thai cuisine as potential nutritious ingredients

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ABSTRACT

Missing information on plant origin control and nutritional data on herbs, spices and vegetables could lead to sample quality deficit and misusage of the plant database. In this study, twenty vegetables that were collected and managed based on the recommendations of the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand, were investigated regarding their proximate mineral, vitamin and carotenoid contents using the standard procedures of the Association of Official Analytical Chemists (AOAC). The results showed that these plants (100 g dry weight) exhibited similar energy levels (337.11–420.48 kcal), which were mainly distributed from high carbohydrate content (21.01–88.17 g), while protein (3.14–66.07 g) and fat (0.00–10.33 g) levels were quite low. As a form of carbohydrate, dietary fiber was found to be high in *Cymbopogon citratus* (DC.) Stapf (*Cy. citratus*) and *Solanum torvum* Sw. (*So. torvum*) (57.00–59.54 g). Interestingly, *Senegalia pennata* subsp. *insuavis* (Lace) Maslin, Seigler & Ebinger (*S. pennata*) exhibited exceptionally high protein content, which was between 2.3 and 3.1 times higher than its carbohydrates. High mineral contents were detected in *S. pennata*, *Ocimum africanum* Lour. (*O. africanum*), *Ocimum basilicum* L. (*O. basilicum*), *Ocimum gratissimum* L. var. *macrophyllum* Briq. (*O. gratissimum*) and *Coriandrum sativum* L. (*Co. sativum*), while *Mentha cordifolia* Opiz ex Fresen (*M. cordifolia*) was observed to be a good source of vitamin C (381.36–547.47 mg). High carotenoids were mostly found in *Eryngium foetidum* L. (*E. foetidum*), *O. gratissimum*, *Co. sativum* and *O. basilicum* (75.23–119.96 mg). Interestingly, the location of sample collection seemed to have minimal effect on the nutritional and carotenoid compositions. The results of this study provide reliable information concerning the nutritional and carotenoid contents in plant sources with control of origin, which could be used in the future for food development with specific nutritional requirements.

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1. Introduction

Evidence from around the world has shown that increased morbidity is caused by chronic diseases including obesity, cancer, diabetes, hypertension and cardiovascular disease. It has been estimated that chronic illnesses account for around 45.9% of all ailments. Furthermore, the COVID−19 pandemic has compelled people to care more about their health status [1]. A plant−based diet is one of the healthiest trends nowadays. In support, the global plant−based diet market cap was estimated at 29.4 billion U.S. dollars in 2020. This figure is expected to increase to 52.5 and 161.9 billion U.S. dollars in 2023 and 2030, respectively [2], suggesting the high demand for this type of diet. It has been demonstrated that food plants (vegetables and fruits) are crucial sources of health−promoting agents, including nutritive and non−nutritive compounds. The major nutritive compounds present in food plants include fiber, vitamins, minerals and carotenoids, while phytochemicals are classified as non−nutritive compounds. Several pieces of evidence illustrate that the consumption of food plants positively impacts human health, such as hypertension [3], cardiovascular disease [4] and type II diabetes [5]. Thus, the consumption of 400 g of fruits and vegetables per person/day has been highly recommended by the World Health Organization (WHO) [6].

Thai cuisine is typically made with a variety of herbs and vegetables that exhibit nutrient−rich and health−promoting properties. For example, *Allium sativum* L. or garlic is used in almost every dish and even in chili paste. Garlic is rich in potassium and iron. Consequently, there are previous reports regarding its various benefits to human health, such as blood pressure−lowering effects [7], anti−hyperlipidemia effects by decreasing cholesterol and low−density lipoprotein [8], and anti−atherosclerotic disease properties [9]. *Coriandrum sativum* L. or coriander is an important ingredient because of its unique aroma. *Co. sativum* has been described as having abundant carotenoids, which are naturally occurring nutritive agents found in colored vegetables. A group of carotenoids is considered a mandatory nutrient for all mammals. These carotenoids cannot be synthesized by humans; thereby, foods are their major sources [10]. It has been suspected that 30−40 types of carotenoids are found in human blood, including lycopene, lutein, β-carotene and zeaxanthin [11]. Carotenoids play a vital role in human health, such as supporting eye health, as well as cognitive and heart functions [10]. Therefore, preventing carotenoid deficiency, especially among the elderly, must be strongly considered [10]. Moreover, plant−based foods are also known to be rich in dietary fiber, a type of undigested carbohydrate. Several meta−analyses have indicated that the intake of dietary fiber could increase stool frequency in constipation patients [12], decrease cholesterol and low−density lipoprotein, and reduce fasting blood glucose and hemoglobin A1c (HbA1c) in patients with type 2 diabetes mellitus, suggesting the benefits of dietary fiber consumption for diabetic management [13].

Thai cuisine is renowned for its healthy dishes comprising a wide variety of herbs, spices and vegetables in interesting combinations. While plants have been studied regarding their nutritive compositions and carotenoid contents, little data exists concerning their control of origin (correct plant species or cultivars, cultivation area and harvesting time). Furthermore, several previous studies researched the nutritive data of whole plants, even though only some parts of these plants can be consumed. The lack of origin control and missing data on edible parts could lead to insufficient sample quality management as well as unreliability, misinterpretation, and misapplication of the plant database. To resolve potential problems as well as enhance the representation of the nutritional compositions of commonly−consumed plants used in Thai cuisine, we collaborated with the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand, to provide plant samples with well−controlled quality, as mentioned above. The edible parts of twenty plants cultivated in two major areas of Thailand were examined to determine their nutritive values and carotenoid contents. The plants were selected based on their common usage in Thai recipes, including *Allium cepa* Aggregatum Group (*A. cepa*), *Allium fistulosum* L. (*A. fistulosum*), *Allium sativum* L. (*A. sativum*), *Alpinia galanga* (L.) Willd. (*Al. galangal*), *Boesenbergia rotunda* (L.) Mansf. (*B. rotunda*), *Curcuma mangga* Valeton & Zijp (*C. mangga*), *Capsicum annuum* L. (*Ca. annuum*), *Citrus hystrix* DC. (*Ci. hystrix*), *Coriandrum sativum* L. (*Co. sativum*), *Cymbopogon citratus* (DC.) Stapf (*Cy. citratus*), *Eryngium foetidum* L. (*E. foetidum*), *Mentha cordifolia* Opiz ex Fresen (*M. cordifolia*), *Ocimum africanum* Lour. (*O. africanum*), *Ocimum basilicum* L. (*O. basilicum*), *Ocimum gratissimum* L. var. *macrophyllum* Briq. (*O. gratissimum*), *Psophocarpus tetragonolobus* (L.) DC. (*P. tetragonolobus*), *Senegalia pennata* subsp. *insuavis* (Lace) Maslin, Seigler & Ebinger (*S. pennata*), *Solanum melongena* 'Kermit' (*So. melongena*), *Solanum torvum* Sw. (*So. torvum*), and *Zingiber officinale* Roscoe (*Z. officinale*). We expect that data from the present study could be useful as a valuable nutritional database since the results came from plant samples with a well−controlled origin, which might lead to the development of nutrient−rich diets in the future.

2. Materials and methods

2.1. Sample preparation and extraction

Twenty herbs and vegetables including *A. cepa*, *A. fistulosum*, *A. sativum*, *Al. galangal*, *B. rotunda*, *C. mangga*, *Ca. annuum*, *Ci. hystrix*, *Co. sativum*, *Cy. citratus*, *E. foetidum*, *M. cordifolia*, *O. africanum*, *O. basilicum*, *O. gratissimum*, *P. tetragonolobus*, *S. pennata*, *So. melongena*, *So. torvum* and *Z. officinale* were cultivated until appropriate harvesting time. Approximately 3 kg of each sample were randomly collected from the field and cleaned, after which the edible parts were collected. The physical appearances of edible parts are shown in Supplementary Table S1. These plant samples were collected and deposited at the Bangkok Herbarium (BK), Bangkok, Thailand, for voucher specimens (Supplementary Table S2). The mature and edible parts of these samples included the bulbs of *A. cepa* and *A. sativum*, leaves of *A. fistulosum*, *Co. sativum*, *E. foetidum*, *M. cordifolia*, *O. africanum*, *O. basilicum* and *O. gratissimum*, fruit peel of *Ci. hystrix*, stalks of *Cy. citratus*, whole fruits of *Ca. annuum*, *P. tetragonolobus*, *So. melongena* and *So. torvum*, young leaves of *S. pennata* and rhizome of *Al. galangal*, *B. rotunda*, *C. mangga* and *Z. officinale* as shown in Supplementary Table S2 were collected and managed according to the recommendation of the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand.

The plant samples were cleaned with deionized water and air−dried for 3 h. The samples were then divided into 2 groups; one for nutritional analysis as fresh samples and the other for carotenoid determination as dry samples. To prepare dry samples without loss of bioactive compounds from heat treatment, the samples were freeze-dried at −50 °C and 0.086 mbar in a Heto PowerDry PL9000 Freeze Dryer (Heto Lab Equipment, Allerod, Denmark) for 72 h. The powdery samples were achieved by grinding the dry samples in a Philips 600W Grinder (Philips Electronics Co., Ltd., Jakarta, Indonesia) and kept at −20 °C before analyzing their carotenoid profiles.

The colors of the fresh samples were analyzed using a ColorFlex EZ Spectrophotometer (Hunter Associates Laboratory, Reston, VA, USA). The results were expressed as CIELAB units, in which L* represented dark (0) to lightness (100), a* represented green (−) to red (+) colors, and b* represented blue (−) to yellow (+) colors as shown in Supplementary Table S3. The moisture contents of dry samples were also examined using a Halogen HE53 moisture analyzer (Mettler Toledo AG, Greifensee, Switzerland), as shown in Supplementary Table S4. The percentages of edible portions are also shown in Supplementary Table S4.

2.2. Analysis of nutritional compositions

Nutritional compositions including energy, ash, moisture content, macronutrients (protein, carbohydrates and fats) and micronutrients (minerals and vitamins) were examined according to the standard procedures following the Association of Official Analytical Chemists (AOAC) [14]. All experiments were performed in an accredited laboratory at the Institute of Nutrition, Mahidol University with ISO/IEC 17025:2017.

2.2.1. Proximate compositions

The analyses of proximate compositions were performed as previously reported [15] with modifications as indicated in Sahasakul et al. (2022) [16]. Briefly, the moisture content was determined following AOAC 931.04, in which the sample was dried in a Memmert UNE 500 hot−air oven (Memmert, Eagle, WI, USA) until achieving a constant weight. Protein content was examined following the Kjeldahl method and a conversion factor of 6.25 (AOAC 991.20), while fats content was determined through acid hydrolysis and solvent extraction (AOAC 922.06). Ash content was analyzed using incineration of organic matter (AOAC 930.30). Total carbohydrates were calculated from moisture content, protein, fats and ash, as shown in Eq. (1). The energy was calculated from the Atwater factor of total carbohydrates, protein and fats as shown in Equation (2). As a part of carbohydrates, total dietary fiber was analyzed using an enzymatic–gravimetric method (AOAC 985.29).

$$\text{Total carbohydrates} = 100 - \text{moisture} - \text{protein} - \text{fats} - \text{ash} \quad (1)$$

$$\text{Energy} = (\text{total carbohydrates} \times 4) + (\text{protein} \times 4) + (\text{total fats} \times 9) \quad (2)$$

2.2.2. Minerals

Contents of macrominerals including calcium, sodium and potassium were determined from ash residue following AOAC 985.35 utilizing an atomic absorption spectrophotometer (a Thermo S series flame from Thermo Electron Corporation, Cambridge, UK), while the contents of magnesium and microminerals including iron and zinc were analyzed following AOAC 984.27 with a utilization of an inductively coupled plasma optical emission spectroscope (an Optima 4200DV series from PerkinElmer, Waltham, MA, USA).

2.2.3. Vitamins

Vitamin C contents were determined as previously reported [17] with the utilization of high−performance liquid chromatography (HPLC). The samples were extracted with 10% (*v/v*) metaphosphoric acid before loading onto an ODS column (5 μm, 250 × 4.6 mm, Zorbax from Agilent Technologies, Santa Clara, CA, USA) attached to the HPLC system consisting of a Waters 515 pump (Waters Corporation, Milford, MA, USA) and a UV−975 UV/Vis detector (JASCO International Co., Ltd., Tokyo, Japan). Vitamin C was detected at 254 nm with an isocratic solvent system of 0.5% (*v/v*) KH_2PO_4 and a flow rate of 0.8 mL/min.

2.3. Determination of carotenoid profile

The carotenoid profile was determined according to a well−established protocol as previously reported [18]. Briefly, the powdery samples were extracted using 80% (*v/v*) aqueous ethanol at a 1:10 (*w/v*) ratio. The mixture was incubated at 37 °C for 2 h before being centrifuged in a Hettich® ROTINA 38R centrifuge (Andreas Hettich GmbH, Tuttlingen, Germany) at 3800×*g* for 15 min. Carotenoids in the supernatant were determined utilizing an Agilent 1100 HPLC system equipped with a photodiode array detector (Agilent Technologies). The extracts were loaded onto a 5 μm, 150 × 4.6 mm YMC carotenoid−C30 reverse phase column (YMC Co., Ltd., Kyoto, Japan), and the separation of carotenoids was visualized at 450 nm using the gradient mobile phases consisting of methyl *tert*-butyl ether (solvent A) and methanol containing 2% (*v/v*) ammonium acetate (solvent B) and a flow rate of 0.6 mL/min. The authentic carotenoid standards were acquired from Sigma−Aldrich (St. Louis, MO, USA), including capsanthin (>95.0% HPLC), lutein (>96.0% HPLC), zeaxanthin (>95.0% HPLC), β-cryptoxanthin (>97.0% TLC), α-carotene (>95.0% HPLC) and β-carotene (>95.0% HPLC).

2.4. Statistical analysis

Experiments were carried out in triplicate ($n = 3$). The results were expressed as mean ± standard deviation (SD). To evaluate the

statistical significance of the indicated values for the same plant between sources 1 and 2, an unpaired *t*-test with significant differences at $p < 0.05$ was used (Tables 1–4), while one-way analysis of variance (ANOVA) and Duncan's multiple comparison test were used to determine the significant differences between plant samples at $p < 0.05$ (Supplementary Tables S7–S9).

Principal component analysis and hierarchical cluster analysis of nutritive components and carotenoids were performed using XLSTAT (Addinsoft Inc., New York, NY, USA).

3. Results

The results on nutritional compositions and carotenoid profiles were expressed as per 100 g fresh weight (FW), as shown in Supplementary Tables S5 and S6, respectively, while the comparison of nutritive values including proximate compositions (Table 1), minerals (Tables 2 and 3), vitamins (Table 3) and carotenoids (Table 4) in twenty plant samples collected from different sources was carried out as per 100 g dry weight (DW).

3.1. Proximate compositions

Proximate compositions including carbohydrates, dietary fiber, protein, fats, energy and ash were analyzed in all plant samples collected from different sources (Table 1). Among all macronutrients (protein, fats and carbohydrates), all plants potentially exhibited higher contents of carbohydrates (21.01−90.65 g/100 g DW) than protein (3.14−66.07 g/100 g DW) and fats (0−10.33 g/100 g DW), respectively, except for *S. pennata*, which contained higher protein content than carbohydrates. Comparing the same plant samples collected from different sources, the percentages of variation in carbohydrate contents varied (1−41%), with the highest value detected in *O. basilicum*. This result indicated that plant sources had a significant influence on carbohydrate contents in *O. basilicum*; a plant collected in one source (source 2) exhibited 1.7-fold higher content than one collected in the other (source 1). On the contrary, the collection area had little impact on the carbohydrate contents in *E. foetidum*, *O. africanum* and *P. tetragonolobus* with only a 1% variation between sources. Besides, *Cy. citratus* and *C. mangga* collected from both sources exhibited the highest carbohydrate contents among all plant samples (1.1−4.3-fold higher than others), while *S. pennata* exhibited the lowest content.

As one component of carbohydrates, dietary fiber contents in the same plant samples collected from different sources (12.13−59.54 g/100 g DW) varied from 1 to 38%. *Z. officinale* exhibited the highest variation of dietary fiber contents between sources, while *B. rotunda*, *Cy. citratus*, *E. foetidum* and *So. torvum* exhibited only 1−2% variation. Among all plant samples, *Cy. citratus* and *So. torvum* collected from both sources exhibited 1.1−4.8-fold higher dietary fiber contents than others, while *A. cepa* had the lowest.

The protein contents in the same plant samples collected from different sources were diverse with between 3 and 35% variation. *Cy. citratus* exhibited the highest variation of protein contents between sources, suggesting a significant impact of collecting sources on the protein contents of this plant. On the other hand, little impact on collecting sources was observed in the protein contents of *Co. sativum*, *Ci. hystrix*, *E. foetidum* and *P. tetragonolobus* with only a 3−4% variation. Among all plant samples, *S. pennata* from both sources exhibited the highest protein contents (1.9−21.0-fold higher than others), while the lowest contents were observed in *Cy. citratus* and *C. mangga*.

Fat contents were found to be the lowest among all 3 macronutrients. However, high variation in fat contents in the same plant samples collected from different sources was observed (up to 100%), especially *A. sativum*, *Al. galangal* and *E. foetidum*, with no fats being found in one of the collecting sources and *P. tetragonolobus* with no fats in either source. Among all plant samples, *Ca. annuum* from both sources exhibited the highest fat contents (up to 129-fold higher than others).

Even though the plant samples collected from different sources exhibited a wide variety of carbohydrates, protein and fat contents, these plants exhibited similar energy (337.11−420.48 kcal/100 g DW) with *Ca. annuum* exhibiting only 1.1−1.2-fold higher energy than others. Besides, low variations in the plant samples collected from different sources were also detected (0−8%).

Ash ranging from 3.24 to 23.36 g/100 g DW was used for the calculation of carbohydrate and mineral contents. The results indicated that variations of 0–64% were observed in the plant samples collected from different sources. *Z. officinale* collected from different sources exhibited the highest variation of ash contents, while only 0−1% variations were observed in *B. rotunda* and *O. basilicum*. Among all plant samples, *Co. sativum* collected from both sources exhibited the highest ash contents (1.2−7.2-fold higher than others), while *A. sativum* provided the lowest.

3.2. Minerals

Both macro- and microminerals in all plant samples were analyzed (Tables 2 and 3, respectively). Macrominerals such as calcium, phosphorus and magnesium are components in bones, while sodium and potassium act as electrolytes. Among all macrominerals, the plant samples potentially exhibited higher potassium contents (1112.43−7838.41 mg/100 g DW) than others. Comparing the collection sources, the plant samples exhibited a wide range of variation (0−61%) in potassium contents. *Al. galanga* collected from different sources exhibited the highest variation, while only 0−1% variations were detected in *Ci. hystrix*, *M. cordifolia* and *P. tetragonolobus*. Among all samples, *Co. sativum* collected from both sources exhibited the highest potassium content (1.5−7.0-fold higher than others), while the lowest was observed in *Al. galanga*.

Similar to potassium, another mineral with a main biological function as an electrolyte is sodium (41.73−934.01 mg/100 g DW), which was found to possess a wide range of variation (0−79%). The highest variation was detected in *O. basilicum,* and the lowest was detected in *E. foetidum*. Besides, *Co. sativum* collected from both sources exhibited the highest sodium contents among all plant samples

Table 1
Proximate compositions of vegetables and herbs (per 100 g dry weight).

Samples	Energy (kcal)		Protein (g)		Fats (g)		Carbohydrates (g)		Fiber (g)		Ash (g)	
	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2
A. cepa	375.30 ± 6.61	381.61 ± 5.56	20.85 ± 0.06	14.55 ± 0.12 *	0.27 ± 0.06	0.35 ± 0.00	72.36 ± 1.83	80.08 ± 1.51	12.13 ± 0.06	13.22 ± 0.29 *	6.52 ± 0.00	5.03 ± 0.00
A. fistulosum	363.35 ± 13.97	372.93 ± 18.57	20.62 ± 0.08	14.60 ± 1.07 *	2.41 ± 0.00	1.41 ± 0.00	64.79 ± 3.57	75.45 ± 5.71	34.00 ± 1.62	32.93 ± 0.43	12.18 ± 0.00	8.54 ± 0.07 *
A. sativum	383.53 ± 0.60	387.47 ± 1.34	23.00 ± 0.17	20.55 ± 0.06 *	0.00 ± 0.00	0.08 ± 0.00	72.88 ± 0.32	76.13 ± 0.39 *	15.37 ± 0.49	22.67 ± 0.02 *	4.12 ± 0.08	3.24 ± 0.04 *
Al. galanga	368.60 ± 21.47	370.12 ± 11.43	13.12 ± 1.46	10.35 ± 0.09	2.31 ± 0.11	0.00 ± 0.00 *	73.85 ± 4.16	82.18 ± 2.94	49.84 ± 1.91	53.21 ± 0.26	6.84 ± 0.00	7.47 ± 0.17 *
B. rotunda	373.37 ± 51.86	369.09 ± 21.76	8.13 ± 0.24	6.85 ± 0.09	2.41 ± 0.00	1.30 ± 0.00	80.39 ± 13.20	82.49 ± 5.35	14.65 ± 0.47	14.87 ± 0.55	9.33 ± 0.05	9.36 ± 0.05
C. mangga	375.57 ± 8.34	386.68 ± 17.28	5.86 ± 0.37	4.87 ± 0.11	1.44 ± 0.06	1.61 ± 0.06	84.79 ± 1.85	88.17 ± 4.56	22.86 ± 0.80	20.31 ± 0.83	7.91 ± 0.19	5.34 ± 0.00 *
Ca. annuum	420.33 ± 0.23	420.48 ± 0.90	13.37 ± 0.12	16.80 ± 0.05 *	9.87 ± 0.04	10.33 ± 0.04	69.50 ± 0.09	65.07 ± 0.36 *	41.92 ± 0.38	40.93 ± 1.03	7.26 ± 0.05	7.79 ± 0.10 *
Ci. hystrix	355.41 ± 14.27	365.18 ± 29.69	14.42 ± 0.16	14.97 ± 0.49	1.13 ± 0.58	0.72 ± 0.00	71.89 ± 4.71	74.70 ± 6.94	47.30 ± 0.51	53.63 ± 0.69 *	12.56 ± 0.63	9.61 ± 0.18 *
Co. sativum	347.45 ± 2.88	337.11 ± 56.52	30.29 ± 1.61	29.31 ± 0.09	3.36 ± 0.17	6.26 ± 0.09 *	49.01 ± 1.27	40.89 ± 14.02	37.19 ± 1.87	40.58 ± 0.44	17.34 ± 0.42	23.36 ± 0.09 *
Cy. citratus	374.03 ± 39.69	382.06 ± 20.77	4.86 ± 0.21	3.14 ± 0.08 *	0.44 ± 0.03	0.77 ± 0.04	87.66 ± 10.19	90.65 ± 5.36	58.22 ± 7.92	59.54 ± 0.48	7.04 ± 0.16	5.45 ± 0.06 *
E. foetidum	350.40 ± 29.18	364.44 ± 29.04	21.38 ± 1.19	20.64 ± 0.36	0.00 ± 0.00	2.11 ± 0.07 *	66.22 ± 6.10	65.72 ± 7.06	48.31 ± 4.21	47.61 ± 1.82	12.40 ± 0.14	11.53 ± 0.00 *
M. cordifolia	381.40 ± 17.81	375.46 ± 8.83	28.71 ± 0.83	26.73 ± 0.39 *	4.10 ± 0.00	3.52 ± 0.09	57.40 ± 3.62	59.21 ± 2.01	40.75 ± 0.16	38.75 ± 0.61 *	9.78 ± 0.26	10.54 ± 0.13 *
O. africanum	368.69 ± 50.80	362.84 ± 54.57	28.30 ± 0.36	25.48 ± 1.06 *	3.35 ± 0.12	4.12 ± 0.34	56.34 ± 13.14	55.96 ± 13.34	41.27 ± 1.66	43.36 ± 0.34	12.01 ± 0.18	14.40 ± 0.00 *
O. basilicum	353.08 ± 11.23	351.76 ± 34.22	32.48 ± 1.65	24.99 ± 0.59 *	2.24 ± 0.13	1.81 ± 0.00	50.75 ± 1.45	85.87 ± 7.97 *	44.11 ± 0.93	48.09 ± 0.32 *	14.53 ± 0.20	14.33 ± 0.05
O. gratissimum	367.92 ± 12.93	372.76 ± 5.91	22.44 ± 0.94	29.30 ± 0.04 *	2.71 ± 0.08	6.56 ± 0.00 *	63.46 ± 4.00	49.11 ± 1.52	47.59 ± 1.02	58.47 ± 0.53 *	11.41 ± 0.08	15.02 ± 0.04 *
P. tetragonolobus	370.42 ± 13.31	364.79 ± 8.97	32.02 ± 0.12	31.01 ± 0.34 *	0.00 ± 0.00	0.00 ± 0.00	60.59 ± 3.45	60.19 ± 1.91	54.71 ± 0.83	45.12 ± 0.56 *	7.39 ± 0.48	8.80 ± 0.11 *
S. pennata	406.21 ± 3.89	384.94 ± 4.55	60.15 ± 0.19	66.07 ± 1.61 *	6.96 ± 0.04	4.07 ± 0.69	25.74 ± 1.24	21.01 ± 2.02	25.02 ± 0.08	19.75 ± 1.61 *	7.15 ± 0.00	8.85 ± 0.64 *
So. melongena	368.70 ± 4.50	379.84 ± 3.75	17.24 ± 0.98	13.86 ± 0.07 *	1.80 ± 0.00	2.65 ± 0.07	70.88 ± 0.15	75.14 ± 0.85 *	30.77 ± 3.00	36.77 ± 1.63	10.08 ± 0.15	8.35 ± 0.07 *
So. torvum	385.68 ± 16.94	389.16 ± 25.76	13.18 ± 0.04	14.75 ± 0.24*	1.83 ± 0.04	3.80 ± 0.12 *	79.13 ± 4.36	74.00 ± 6.47	57.45 ± 0.31	57.00 ± 0.94	5.86 ± 0.04	7.46 ± 0.43 *
Z. officinale	353.56 ± 34.70	386.26 ± 55.72	8.32 ± 0.31	11.73 ± 0.00*	2.19 ± 0.00	1.41 ± 0.09	75.14 ± 8.36	81.67 ± 13.74	36.58 ± 4.34	22.79 ± 0.78 *	14.35 ± 0.15	5.19 ± 0.09 *

All data were expressed as mean ± standard deviation (SD) of triplicate experiments ($n = 3$); * indicates significant different proximate contents ($p < 0.05$) in the same plant sample collected between different sources using unpaired $t-$test.

Table 2
The contents of macrominerals that act as electrolytes in vegetables and herbs (per 100 g dry weight).

Samples	Sodium (mg)		Potassium (mg)		Calcium (mg)		Phosphorus (mg)		Magnesium (mg)	
	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2
A. cepa	75.54 ± 0.11	41.99 ± 1.88 *	2280.17 ± 79.96	1737.25 ± 23.47 *	151.47 ± 1.11	141.96 ± 0.86 *	625.64 ± 0.61	486.93 ± 20.53 *	101.02 ± 4.83	87.19 ± 2.66
A. fistulosum	113.50 ± 5.69	97.53 ± 3.36 *	3407.52 ± 42.00	2588.99 ± 209.28 *	1519.82 ± 2.60	1014.29 ± 7.36 *	534.98 ± 26.16	433.13 ± 41.57	192.07 ± 6.34	172.63 ± 0.71
A. sativum	57.85 ± 1.10	43.62 ± 1.70 *	1451.31 ± 9.55	1191.66 ± 3.59 *	49.25 ± 0.43	31.44 ± 0.30 *	605.80 ± 3.21	437.16 ± 13.20 *	63.61 ± 0.21	49.38 ± 1.56 *
Al. galanga	114.07 ± 43.51	79.12 ± 1.91	2853.50 ± 665.85	1112.43 ± 17.67 *	139.43 ± 0.00	135.46 ± 1.21 *	420.35 ± 17.31	296.63 ± 9.01 *	391.65 ± 34.51	474.28 ± 4.94
B. rotunda	53.03 ± 0.90	81.87 ± 5.39 *	2599.93 ± 49.40	3361.43 ± 187.35 *	141.99 ± 1.04	109.06 ± 1.52 *	399.97 ± 21.24	310.27 ± 12.54 *	182.30 ± 6.10	175.32 ± 9.27
C. mangga	85.27 ± 3.28	96.11 ± 1.00 *	2711.63 ± 18.42	1860.71 ± 47.18 *	162.15 ± 0.62	146.88 ± 1.00 *	386.84 ± 64.96	318.90 ± 8.67	131.29 ± 5.93	123.93 ± 2.89
Ca. annuum	84.64 ± 0.54	146.72 ± 8.74 *	2679.49 ± 13.49	2490.14 ± 1.83 *	88.86 ± 1.23	112.12 ± 3.53 *	438.33 ± 3.26	455.06 ± 23.14	158.24 ± 1.40	46.12 ± 2.73 *
Ci. hystrix	43.62 ± 6.60	164.31 ± 3.17 *	1336.23 ± 25.03	1339.28 ± 23.88	3987.45 ± 74.98	1845.74 ± 1.97 *	273.13 ± 70.39	275.98 ± 4.25	239.69 ± 9.27	254.05 ± 9.68
Co. sativum	457.11 ± 6.11	934.01 ± 14.63 *	7050.99 ± 208.87	7838.41 ± 100.06 *	1511.94 ± 45.64	1278.62 ± 10.25 *	585.00 ± 20.02	741.70 ± 27.08 *	204.80 ± 11.03	87.48 ± 0.18 *
Cy. citratus	63.49 ± 1.93	71.26 ± 2.74 *	2463.45 ± 91.50	1880.72 ± 120.77 *	178.74 ± 20.69	208.30 ± 0.20	509.91 ± 19.75	442.06 ± 18.35 *	117.76 ± 0.21	93.44 ± 3.91 *
E. foetidum	240.28 ± 1.82	239.17 ± 2.84	3679.61 ± 218.94	4255.89 ± 151.83 *	1059.47 ± 85.23	1318.63 ± 14.48 *	672.72 ± 11.22	497.35 ± 13.90 *	207.74 ± 10.80	207.72 ± 2.91
M. cordifolia	177.26 ± 4.19	125.96 ± 3.67 *	2912.23 ± 3.88	2881.27 ± 27.88 *	1157.16 ± 10.46	1178.74 ± 10.23	507.03 ± 10.93	441.25 ± 13.68 *	359.06 ± 16.78	360.85 ± 6.95
O. africanum	309.42 ± 0.95	80.96 ± 0.43 *	2783.42 ± 29.12	2586.58 ± 29.48 *	1774.88 ± 35.99	2190.97 ± 156.59 *	589.33 ± 20.66	572.82 ± 3.56	445.08 ± 0.89	695.13 ± 24.81 *
O. basilicum	204.21 ± 66.92	43.35 ± 9.30 *	3318.18 ± 119.94	2842.08 ± 12.78 *	1898.32 ± 0.00	2394.33 ± 20.10 *	739.95 ± 5.35	782.91 ± 5.99 *	434.21 ± 52.87	412.82 ± 24.65
O. gratissimum	183.38 ± 36.04	131.89 ± 0.04	2755.26 ± 330.05	3711.59 ± 40.99 *	1895.57 ± 348.42	2251.99 ± 42.88	1088.39 ± 42.97	653.53 ± 4.40 *	438.89 ± 19.33	454.23 ± 6.78
P. tetragonolobus	142.44 ± 35.53	89.21 ± 3.70	2565.97 ± 35.30	2542.03 ± 12.00	730.84 ± 33.87	643.70 ± 14.92 *	537.82 ± 0.95	652.34 ± 14.36 *	295.55 ± 17.95	286.12 ± 1.79
S. pennata	80.71 ± 3.47	111.87 ± 2.16 *	1903.47 ± 10.30	2448.28 ± 76.46 *	255.77 ± 1.55	172.77 ± 1.98 *	1349.45 ± 78.05	1090.70 ± 10.77 *	233.53 ± 1.77	238.32 ± 3.50
So. melongena	96.87 ± 3.90	86.04 ± 3.68	3235.65 ± 44.71	2680.44 ± 4.39 *	239.26 ± 10.95	242.72 ± 0.00	522.28 ± 23.93	523.51 ± 24.83	185.09 ± 7.43	184.84 ± 6.44
So. torvum	41.73 ± 1.39	68.45 ± 7.17 *	2065.41 ± 81.32	2166.70 ± 35.33	358.57 ± 0.42	525.98 ± 6.51 *	319.80 ± 6.10.	478.21 ± 29.13 *	164.29 ± 3.66	181.95 ± 5.37
Z. officinale	169.33 ± 3.41	60.90 ± 4.75 *	4709.64 ± 43.84	2358.34 ± 12.79 *	258.60 ± 25.56	154.98 ± 0.95 *	592.77 ± 31.60	326.88 ± 13.39 *	264.62 ± 3.72	258.03 ± 3.46

All data were expressed as mean ± standard deviation (SD) of triplicate experiments ($n = 3$); * indicates significant different proximate contents ($p < 0.05$) in the same plant sample collected between different sources using unpaired $t-$test.

Table 3
The contents of microminerals and vitamin C in vegetables and herbs (per 100 g dry weight).

Samples	Iron (mg)		Zinc (mg)		Vitamin C (mg)	
	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2
A. cepa	2.91 ± 0.11	2.57 ± 0.04	1.53 ± 0.06	1.53 ± 0.04	23.60 ± 0.72	16.86 ± 1.02 *
A. fistulosum	5.34 ± 0.08	4.49 ± 0.07	1.78 ± 0.08	2.83 ± 0.14 *	113.15 ± 5.52	80.45 ± 1.50 *
A. sativum	2.97 ± 0.04	1.66 ± 0.10 *	3.42 ± 0.04	2.94 ± 0.18 *	4.49 ± 0.11	8.32 ± 0.08 *
Al. galanga	3.97 ± 0.22	3.25 ± 0.09	3.97 ± 0.67	7.65 ± 0.43 *	31.24 ± 1.69	ND
B. rotunda	6.96 ± 0.00	8.74 ± 0.18 *	2.74 ± 0.00	1.21 ± 0.05 *	13.98 ± 0.76	10.04 ± 0.65 *
C. mangga	1.70 ± 0.06	1.41 ± 0.00	2.40 ± 0.06	1.30 ± 0.06 *	ND	10.45 ± 0.22
Ca. annuum	4.24 ± 0.09	4.88 ± 0.16	1.81 ± 0.11	0.15 ± 0.00 *	8.29 ± 0.00	4.74 ± 0.28 *
Ci. hystrix	9.18 ± 0.00	4.96 ± 0.00 *	0.97 ± 0.00	0.83 ± 0.00	38.94 ± 0.83	299.13 ± 19.48 *
Co. sativum	10.62 ± 0.59	8.74 ± 0.26 *	2.94 ± 0.08	0.99 ± 0.00 *	118.30 ± 1.02	197.20 ± 7.82 *
Cy. citratus	2.10 ± 0.05	1.06 ± 0.04 *	3.46 ± 0.21	1.94 ± 0.00 *	21.00 ± 3.65	26.63 ± 0.16
E. foetidum	40.77 ± 0.42	27.07 ± 0.15 *	4.37 ± 0.42	2.37 ± 0.15 *	36.36 ± 0.21	38.39 ± 2.18
M. cordifolia	54.04 ± 1.34	34.73 ± 1.31 *	4.03 ± 0.10	4.57 ± 0.17 *	381.36 ± 25.01	547.47 ± 15.91 *
O. africanum	9.00 ± 0.41	36.55 ± 0.34 *	5.15 ± 0.06	5.79 ± 0.19 *	150.65 ± 9.77	27.93 ± 1.64 *
O. basilicum	9.11 ± 0.73	7.83 ± 0.48 *	7.62 ± 0.20	5.56 ± 0.16 *	82.66 ± 3.77	68.32 ± 2.09 *
O. gratissimum	7.13 ± 0.21	17.05 ± 0.53 *	4.59 ± 0.07	2.90 ± 0.08 *	75.93 ± 0.43	122.34 ± 1.07 *
P. tetragonolobus	6.97 ± 1.31	8.09 ± 0.00 *	2.94 ± 0.12	3.33 ± 0.67	55.71 ± 0.36	51.31 ± 2.58
S. pennata	10.72 ± 0.68	9.37 ± 0.28 *	6.48 ± 0.19	7.06 ± 0.05 *	210.14 ± 10.94	230.97 ± 6.99
So. melongena	3.66 ± 0.08	3.10 ± 0.00	1.54 ± 0.08	2.30 ± 0.00 *	43.24 ± 2.18	28.91 ± 0.00 *
So. torvum	3.38 ± 0.23	3.41 ± 0.12	1.53 ± 0.08	1.38 ± 0.08	31.34 ± 1.04	29.72 ± 1.33
Z. officinale	3.50 ± 0.00	4.03 ± 0.00	2.74 ± 0.15	2.99 ± 0.09	45.45 ± 2.32	26.27 ± 0.86 *

All data were expressed as mean ± standard deviation (SD) of triplicate experiments ($n = 3$); * indicates significant different mineral or vitamin contents ($p < 0.05$) in the same plant sample collected between different sources using unpaired t−test; ND: not detected.

(1.5−22.2-fold higher than others), while *A. cepa* and *So. torvum* had the lowest.

Being the main mineral for bone components, calcium contents in the same plant sample collected from different sources (31.44−3987.45 mg/100 g DW) exhibited 1−54% variations. Interestingly, one source of *Ci. hystrix* provided 2.2-fold higher calcium than another source, causing the highest variation of calcium contents in this plant. It was also the highest calcium provider among all plant samples being investigated. However, ignoring the exceptionally high calcium content in *Ci. hystrix* from one source, *O. basilicum* and *O. gratissimum* collected from both sources contained generally high calcium contents. On the other hand, *A. sativum* was a poor source of calcium with the lowest amount detected.

Phosphorus contents detected in the plant samples collected from different sources ranged from 273.13 to 1349.45 mg/100 g DW. While possessing the highest variation in calcium contents, *Ci. hystrix* only exhibited a 1% variation in phosphorus contents. A similar result was observed in *So. Melongena*; a 0% variation in phosphorus contents was detected. Besides, *Ci. hystrix* possessed the least amount of phosphorus despite being a good calcium provider, while *S. pennata* exhibited the highest contents (1.2−4.9-fold higher than others).

As for magnesium (49.38−695.13 mg/100 g DW), its variations ranged from 0 to 71% with *Ca. annuum* exhibiting the highest value, while *E. foetidum*, *M. cordifolia* and *So. melongena* had the lowest. Comparing among plant samples, *O. africanum* exhibited the highest magnesium contents (1.1−15.1-fold higher than others), while the lowest contents were detected in *A. sativum*.

Different levels of two microminerals including iron and zinc were detected among the plant samples collected from different sources (Table 3). Comparing these microminerals, higher iron contents (1.06−54.04 mg/100 g DW) in all plant samples were observed with a wide range of variation (1−75%). *O. africanum* exhibited the highest variation of iron contents, in which the one collected from one source exhibited 4.1-fold higher iron content than the one from the other. The opposite result was observed in *So. torvum*, in which only 1% variation was detected despite being collected from different sources. Among all plant samples, *M. cordifolia* collected from both sources was a good iron provider, which exhibited 1.1−34.5-fold higher iron contents than others.

Similar results were observed in zinc contents (0.83−7.62 mg/100 g DW), in which wide variations of 0–92% were detected in the plant samples collected from different sources. *Ca. annuum* exhibited the highest variation of zinc content between sources, while *A. cepa* had the lowest. Besides, *O. basilicum* and *S. pennata* collected from both sources provided high zinc contents when comparing among the plant samples, while *Ci. hystrix* was a poor zinc provider.

3.3. Vitamins

Vitamin C (4.49−547.47 mg/100 g DW) was detected in all plant samples collected from both sources except for *Al. galangal* and *C. mangga*, in which vitamin C contents were only detected in one of the collecting sources (Table 3). Variations between collecting sources of these plant samples ranged from 5 to 87%. *Ci. hystrix* exhibited the highest variation such that the one collected from one source provided 7.7-fold higher vitamin C contents than the one collected from the other source. Opposite results were observed in *E. foetidum* and *So. torvum*, in which only 5% variations were detected between collecting sources. Among all plant samples, *M. cordifolia* collected from both sources was a good vitamin C provider with 1.8–115.5-fold higher vitamin C content than others.

Table 4
The contents of carotenoids in vegetables and herbs (per 100 g dry weight).

Samples	Capsanthin (mg)		Lutein (mg)		Zeaxanthin (mg)		β-Cryptoxanthin (mg)	
	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2
A. cepa	ND	ND	0.12 ± 0.01	0.06 ± 0.01 *	ND	ND	ND	ND
A. fistulosum	ND	ND	29.46 ± 0.79	19.05 ± 1.28 *	ND	ND	ND	ND
A. sativum	ND	ND	0.01 ± 0.00	0.03 ± 0.00	ND	ND	ND	ND
Al. galanga	ND	ND	0.05 ± 0.00	0.11 ± 0.01 *	ND	ND	ND	ND
B. rotunda	ND	ND	0.06 ± 0.01	0.06 ± 0.01	ND	ND	ND	ND
C. mangga	ND	ND	ND	ND	ND	ND	ND	ND
Ca. annuum	19.59 ± 2.66	24.74 ± 0.54	ND	ND	20.42 ± 0.76	11.23 ± 0.18 *	12.33 ± 0.43	10.83 ± 0.35 *
Ci. hystrix	ND	ND	0.12 ± 0.01	0.06 ± 0.01 *	ND	ND	ND	ND
Co. sativum	ND	ND	54.31 ± 0.24	60.34 ± 10.69	ND	ND	2.16 ± 0.24	ND
Cy. citratus	ND	ND	0.30 ± 0.04	0.32 ± 0.02	ND	ND	ND	ND
E. foetidum	ND	ND	65.34 ± 5.44	58.41 ± 8.36	ND	ND	ND	ND
M. cordifolia	ND	ND	42.35 ± 6.06	43.82 ± 1.00	ND	ND	ND	ND
O. africanum	ND	ND	37.27 ± 1.02	39.86 ± 2.87	ND	ND	ND	ND
O. basilicum	ND	ND	68.07 ± 1.57	54.87 ± 0.46 *	ND	ND	ND	ND
O. gratissimum	ND	ND	42.74 ± 4.63	50.11 ± 11.53	ND	ND	ND	ND
P. tetragonolobus	ND	ND	12.42 ± 0.81	6.73 ± 0.38 *	ND	ND	ND	ND
S. pennata	ND	ND	23.31 ± 3.11	26.82 ± 2.15	ND	ND	ND	ND
So. melongena	ND	ND	5.31 ± 0.07	3.91 ± 0.77	ND	ND	ND	ND
So. torvum	ND	ND	5.11 ± 0.09	8.02 ± 1.60	ND	ND	ND	ND
Z. officinale	ND	ND	0.14 ± 0.02	0.31 ± 0.01 *	ND	ND	ND	ND

Samples	α-Carotene (mg)		β-carotene (mg)		Total carotenoids (mg)	
	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2
A. cepa	ND	ND	0.06 ± 0.02	ND	0.18 ± 0.02	0.06 ± 0.01 *
A. fistulosum	0.28 ± 0.00	0.29 ± 0.00	25.11 ± 0.03	21.34 ± 3.39	54.84 ± 0.76	40.68 ± 2.11 *
A. sativum	ND	ND	ND	ND	0.01 ± 0.00	0.03 ± 0.00
Al. galanga	ND	0.03 ± 0.00	0.09 ± 0.01	0.12 ± 0.01	0.14 ± 0.02	0.26 ± 0.00 *
B. rotunda	ND	ND	ND	ND	0.06 ± 0.01	0.06 ± 0.01
C. mangga	ND	ND	ND	ND	ND	ND
Ca. annuum	ND	ND	14.60 ± 1.46	14.83 ± 0.24	47.36 ± 2.65	36.89 ± 0.78 *
Ci. hystrix	2.48 ± 0.11	2.87 ± 0.57	7.81 ± 0.33	12.89 ± 1.59	31.09 ± 1.66	38.43 ± 4.64
Co. sativum	ND	1.00 ± 0.06	34.72 ± 0.26	58.62 ± 0.36 *	91.20 ± 0.74	119.96 ± 11.11
Cy. citratus	0.01 ± 0.00	ND	0.17 ± 0.01	0.16 ± 0.01	0.48 ± 0.05	0.48 ± 0.02
E. foetidum	ND	1.18 ± 0.01	34.09 ± 2.98	36.20 ± 4.66	99.43 ± 8.42	95.79 ± 13.01
M. cordifolia	ND	ND	41.01 ± 1.93	40.18 ± 0.87	83.36 ± 7.99	84.00 ± 0.14
O. africanum	4.26 ± 0.77	4.33 ± 0.32	41.92 ± 6.22	38.86 ± 1.68	83.44 ± 5.96	83.05 ± 4.23
O. basilicum	ND	0.12 ± 0.01	51.28 ± 2.03	48.68 ± 1.60	119.35 ± 0.47	103.67 ± 2.05 *
O. gratissimum	5.66 ± 0.24	ND	26.84 ± 1.79	43.81 ± 2.33 *	75.23 ± 6.66	93.91 ± 13.86 *
P. tetragonolobus	0.54 ± 1.15	0.05 ± 0.13	10.06 ± 0.14	4.25 ± 0.48 *	23.02 ± 0.72	12.13 ± 0.99 *
S. pennata	0.54 ± 0.00	0.52 ± 0.02	12.60 ± 1.27	17.50 ± 1.63	36.44 ± 4.38	44.83 ± 3.80
So. melongena	ND	ND	2.63 ± 0.02	2.52 ± 0.25	7.94 ± 0.09	6.43 ± 1.02
So. torvum	0.12 ± 0.01	1.65 ± 0.22 *	2.48 ± 0.05	2.76 ± 0.15	7.71 ± 0.03	12.43 ± 1.97
Z. officinale	0.02 ± 0.00	0.03 ± 0.00	0.17 ± 0.01	0.31 ± 0.00 *	0.33 ± 0.04	0.66 ± 0.01 *

All data were expressed as mean ± standard deviation (SD) of triplicate experiments ($n = 3$); * indicates significant different carotenoid contents ($p < 0.05$) in the same plant sample collected between different sources using unpaired $t-$test; ND: not detected.
All data were expressed as mean ± standard deviation (SD) of triplicate experiments ($n = 3$); * indicates significant different carotenoid contents ($p < 0.05$) in the same plant sample collected between different sources using unpaired $t-$test; ND: not detected.

3.4. Carotenoids

Using authentic standards of carotenoids including capsanthin, lutein, zeaxanthin, β-cryptoxanthin, α-carotene and β-carotene, the HPLC analysis indicated that the plant samples exhibited different types and degrees of carotenoids (Table 4 and Supplementary Fig. S1). Among all investigated carotenoids, most of the plant samples potentially contained the highest contents of β-carotene, followed by lutein and α-carotene, while capsanthin, zeaxanthin and β-cryptoxanthin were very specific to particular plants. Being the most abundantly found in the plant samples (0.06−58.62 mg/100 g DW), the variations of β-carotene contents in the plant samples collected from different sources ranged from 2 to 58%. *P. tetragonolobus* exhibited the highest variation, in which the plant from one source exhibited 2.4-fold higher content than the one from the other source. *Ca. annuum* and *M. cordifolia*, on the other hand, exhibited only a 2% variation. Among all plant samples, *O. basilicum* from both collecting sources potentially exhibited high β-carotene, while a similar result was observed in *Co. sativum* from only one collecting source. However, no β-carotene was detected in *A. sativum*, *B. rotunda* or *C. mangga* collected from either source, and *A. cepa* from one of the collection sources.

The second most abundantly found carotenoid (0.01−68.07 mg/100 g DW), lutein, in the plant samples collected from different sources, exhibited 0−67% variations. *A. sativum* with a trace amount of lutein contents exhibited the highest variation between collecting sources (one exhibited 3-fold higher than the other), while *B. rotunda* is the lowest. Among all plant samples, *Co. sativum*, *E. foetidum* and *O. basilicum* collected from both sources are good lutein providers. On the other hand, none was detected in *C. mangga* and *Ca. annuum* from both collecting sources.

As for α-carotene (0.01−5.66 mg/100 g DW), it was detected in *A. fistulosum*, *Ci. hystrix*, *O. africanum*, *P. tetragonolobus*, *S. pennata*, *So. torvum* and *Z. officinale* collected from both sources and *Al. galangal*, *Co. sativum*, *Cy. citratus*, *E. foetidum*, *O. gratissimum* and *O. basilicum* from one of the collecting sources. The variations in α-carotene contents detected in the plant samples from both collecting sources were varied (1.6−92.7%) with *So. torvum* exhibiting the highest variation (one exhibited 13.8-fold higher than the other) and *O. africanum* the lowest. Among plant samples, *O. africanum* from both collecting sources is a good α-carotene provider.

Interestingly, only *Ca. annuum* collected from both sources contained capsanthin (19.59−24.74 mg/100 g DW) and zeaxanthin (11.23−20.42 mg/100 g DW), while none was detected in other plant samples. The variation between collecting sources of capsanthin in *Ca. annuum* was 20.8%, while that of zeaxanthin was 45%. Besides, β-cryptoxanthin was also detected in *Ca. annuum* collected from both sources (10.83−12.33 mg/100 g DW), while a trace amount (5.0−5.7-fold lower than those of *Ca. annuum*) was also detected in *Co. sativum* from one of the collecting sources. The variation between collecting sources of β-cryptoxanthin in *Ca. annuum* was only 12.2%.

For total carotenoid contents as calculated from the sum of each carotenoid content, it was found that *Co. sativum* (91.20−119.96 mg/100 g DW), *E. foetidum* (95.79−99.43 mg/100 g DW) and *O. basilicum* (103.67−119.35 mg/100 g DW) from both collecting sources were good providers of carotenoids. On the other hand, no carotenoids were detected in *C. mangga,* while trace amounts were detected in *A. cepa*, *A. sativum*, and *Al. galangal*, *B. rotunda*, *Cy. citratus* and *Z. officinale* (less than 1 mg/100 g DW).

3.5. Correlation analysis by principal component analysis (PCA) and hierarchical cluster analysis (HCA)

Because this study involves a large amount of numerical data regarding nutritive values as well as mineral and carotenoid levels, we used a statistical technique known as principal component analysis (PCA) to condense the data into figures (Figs. 1 and 2) for easier interpretation. The PCA, a dimensionality−reduction technique, is well known for its ability to transform a large quantity of data into a smaller amount while retaining accuracy. The mean values of all nutritional compositions and carotenoid contents obtained from all plant samples collected from different sources were included in the analysis.

Fig. 1A and B illustrate biplots of the proximate compositions of all plant samples, which were randomly positioned within the PC1, PC2 and PC3 axes. The combination of PC1 (41.09%), PC2 (29.53%) and PC3 (17.44%) was 88.06%, implying a good representation of the PCA results. The PC1 consists of protein, fats and carbohydrates, while the PC2 consists of energy and ash, and the PC3 contains only dietary fiber. Interestingly, not only the plant samples but also the variables (energy, fats, protein, dietary fiber, carbohydrates and ash) were randomly placed within the graph with no trend of clustering. These results indicated that the relationship between the plant samples and proximate compositions could not be established. In addition, two collecting sources of the same plant species seemed to cluster together, such as *Ca. annuum*, *O. africanum*, *Cy. citratus*, etc., indicating that the collecting sources of the plant samples may not be a major factor contributing to the proximate values, particularly in the present study.

The relationship between the plant samples and vitamin C and minerals was further elucidated using the same analysis. Fig. 1C and D shows that PCA divided the data into three axes as the proximate data. The combination of three PCs was 72.92%, which was still a good representation of vitamin C and mineral contents. In the biplots, the PC1 was closely related to magnesium, calcium, iron and vitamin C, while the PC2 was closely related to sodium and potassium, and the PC3 was more related to phosphorus and zinc. Fig. 1B and C were able to divide the samples into two clusters. For example, cluster 1, which was in the blue circle, contained *S. pennata*, *O. africanum*, *O. basilicum*, *O. gratissimum*, *Co. sativum*, *M. cordifolia*, etc., indicating that the plant samples in cluster 1 were high in minerals and vitamin C. In contrast, several plants were located outside the circle, which can be interpreted as them being low in minerals and vitamin C. Again, it appeared that the sources of plant samples may not be a major factor contributing to the minerals and vitamin C contents, as shown in Fig. 1A and B.

The relationship between all plant samples and carotenoid contents was also subjected to PCA analysis. In Fig. 2, the results show only PC1 and PC2, which represent 85.75% of all data. The PC1 contained lutein, β-carotene, total carotenoids and α-carotene, while the PC2 contained capsanthin, β-cryptoxanthin and zeaxanthin. In the analysis, PCA rendered three groups of clusters. Cluster 1 was in the blue circle consisting of, for example, *E. foetidum*, *O. gratissimum*, *Co. sativum* and *O. basilicum*. These plants were high in lutein,

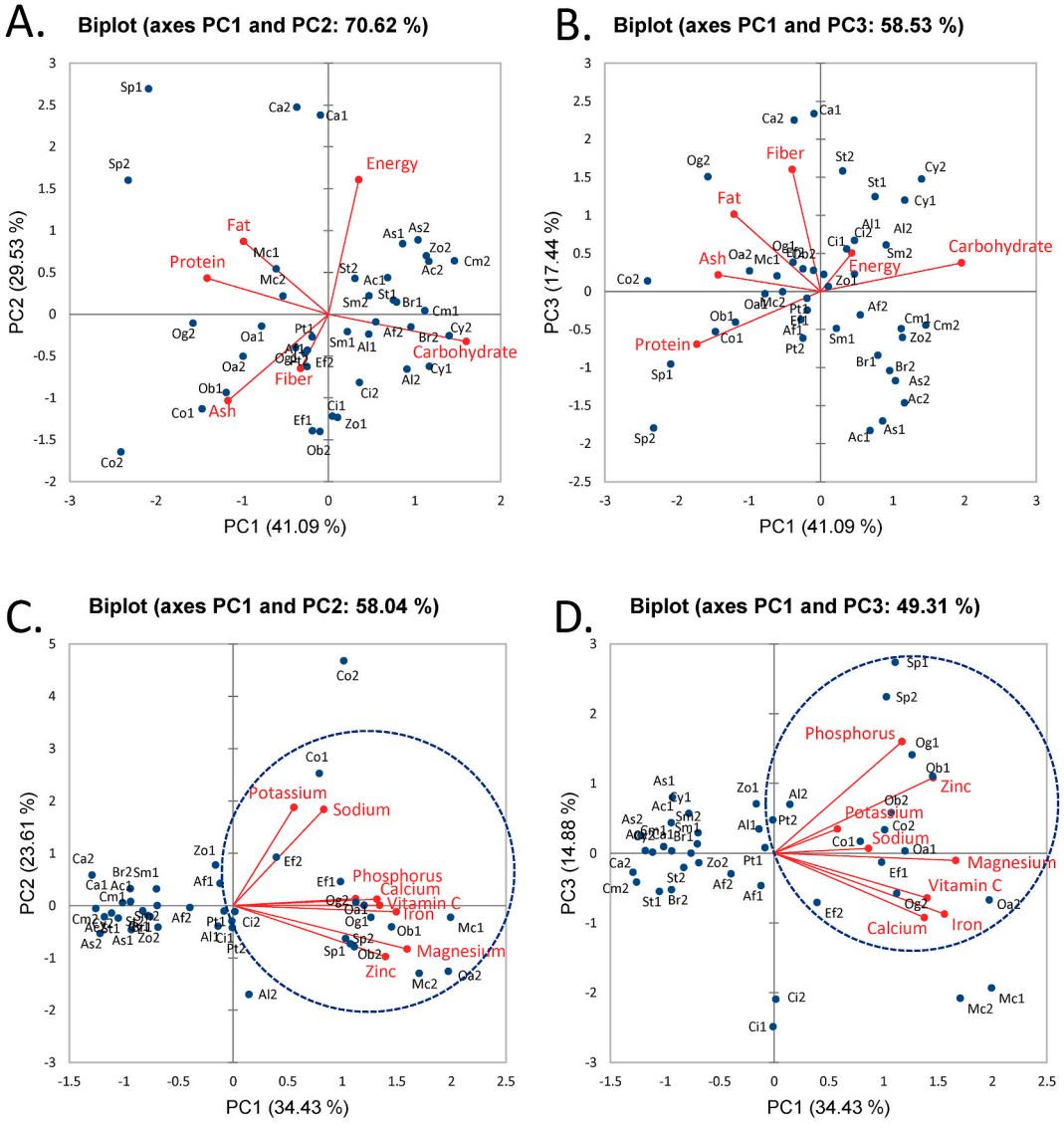

Fig. 1. Biplots of the principal component analysis (PCA) from the mean values of all vegetables in the present study, with (A, B) showing the PCA analyzed from the mean values of the proximate data (ash, carbohydrates, energy, fats, fiber and protein) of all vegetables, (A) showing the plot between PC1 (41.09%) and PC2 (29.53%), and (B) showing the plot between PC1 (41.09%) and PC3 (17.44%). The PCA (C, D) was analyzed from the mean values of the minerals (calcium, iron, magnesium, potassium, phosphorus, sodium and zinc) and vitamin C of all vegetables, while (C) shows the plot between PC1 (34.43%) and PC2 (23.61%), and (D) shows the plot between PC1 (34.43%) and PC3 (14.88%). Abbreviations – Ac: *A. cepa*; Af: *A. fistulosum*; Al: *Al. galangal*; As: *A. sativum*; Br: *B. rotunda*; Cm: *C. mangga*; Ca: *Ca. annuum*; Ci: *Ci. hystrix*; Co: *Co. sativum*; Cy: *Cy. citratus*; Ef: *E. foetidum*; Mc: *M. cordifolia*; Oa: *O. africanum*; Ob: *O. basilicum*; Og: *O. gratissimum*; Pt: *P. tetragonolobus*; Sm: *So. melongena*; Sp: *S. pennata*; St: *So. torvum*; Zo: *Z. officinale*; 1 from source 1; 2 from source 2.

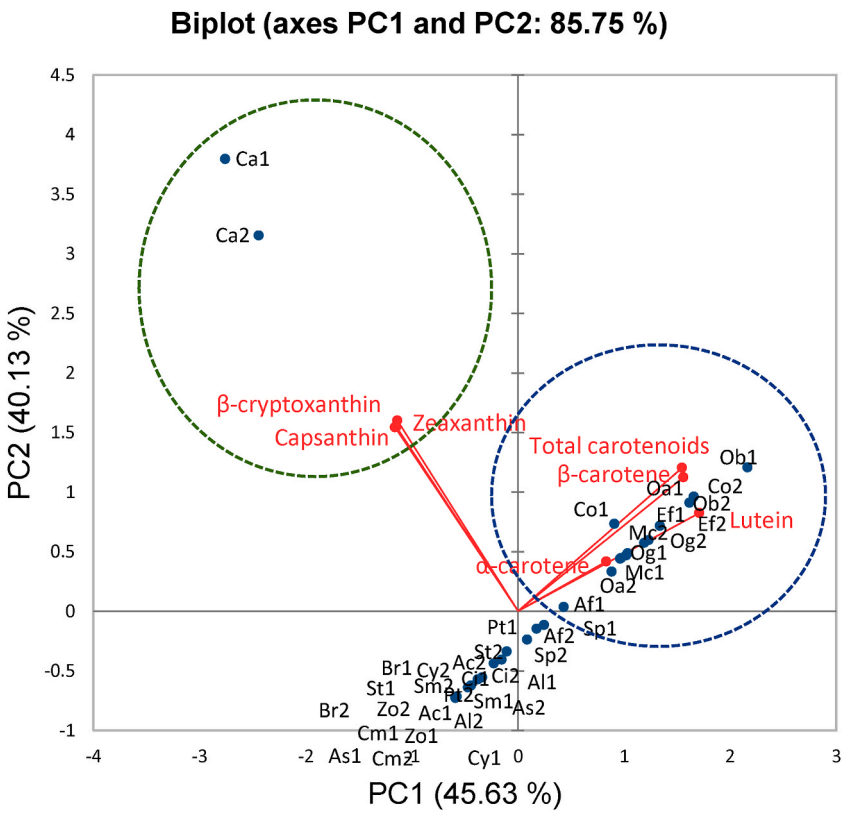

Fig. 2. The biplots of principal component analysis (PCA) from mean values of carotenoids (capsanthin, lutein, zeaxanthin, β-cryptoxanthin, α-carotene, β-carotene and total carotenoids) of all vegetables. Abbreviations; Ac: *A. cepa*; Af: *A. fistulosum*; Al: *Al. galangal*; As: *A. sativum*; Br: *B. rotunda*; Cm: *C. mangga*; Ca: *Ca. annuum*; Ci: *Ci. hystrix*; Co: *Co. sativum*; Cy: *Cy. citratus*; Ef: *E. foetidum*; Mc: *M. cordifolia*; Oa: *O. africanum*; Ob: *O. basilicum*; Og: *O. gratissimum*; Pt: *P. tetragonolobus*; Sm: *So. melongena*; Sp: *S. pennata*; St: *So. torvum*; Zo: *Z. officinale*; 1 from source 1; 2 from source 2.

β-carotene, total carotenoids and α-carotene, whereas only *Ca. annuum* was located in the red circle, suggesting that this plant was uniquely high in capsanthin, β-cryptoxanthin and zeaxanthin. Many plant samples were classified into the third group, which showed a poor relationship with carotenoids. Again, the sources of plant samples did not affect the carotenoid content in these plant samples, as shown by the proximate and mineral data (Fig. 1A–D).

We analyzed the data further using hierarchical cluster analysis (HCA). This algorithm assembles similar samples into clusters, thereby clustering the samples with similar properties. In this analysis, the proximate, minerals, vitamin C and carotenoid contents were included. The results showed that most of the vegetables obtained from different sources were located in close proximity, such as *Co. sativum*, *A. sativum*, *So. torvum*, *P. tetragonolobus*, *E. foetidum* and *Ci. hystrix* (Fig. 3). These data indicated that, while these plants were cultivated from different areas, their proximate, minerals, vitamin C and carotenoids were mostly not significantly varied. Intriguingly, some samples such as *M. cordifolia*, *Z. officinale*, *A. cepa* and *C. mangga* collected from different sources were not clustered, implying that these plants exhibited different proximate, minerals, vitamin C and carotenoids, despite being of the same species. These could be examples of the cultivation effect on these plants.

4. Discussion

The edible parts of twenty herbs and vegetables commonly consumed in Thai cuisine were collected under origin control (species or cultivars, cultivation area and harvesting time as indicated in Supplementary Tables S1 and S2) according to the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand, and investigated in an attempt to establish a reliable database concerning nutritional compositions and carotenoid profiles for future applications in food development or diets with specific health purposes. The results indicated that the proximate values and carotenoid contents in most plant samples were not influenced by collecting sources, particularly in the present study. Besides, all investigated plant samples exhibited similar energy levels, which were mostly calculated from carbohydrate and protein contents, while trace amounts of fats were detected. Among all investigated plant samples, it was found that (i) *S. pennata* was a good protein provider; (ii) *Cy. citratus* and *So. torvum* were good sources of dietary fiber; (iii) *S. pennata*, *O. africanum*, *O. basilicum*, *O. gratissimum* and *Co. sativum* exhibited high overall mineral contents; (iv) *M. cordifolia* was high in vitamin C, and (v) carotenoids were mostly found in *E. foetidum*, *O. gratissimum*, *Co. sativum* and *O. basilicum*.

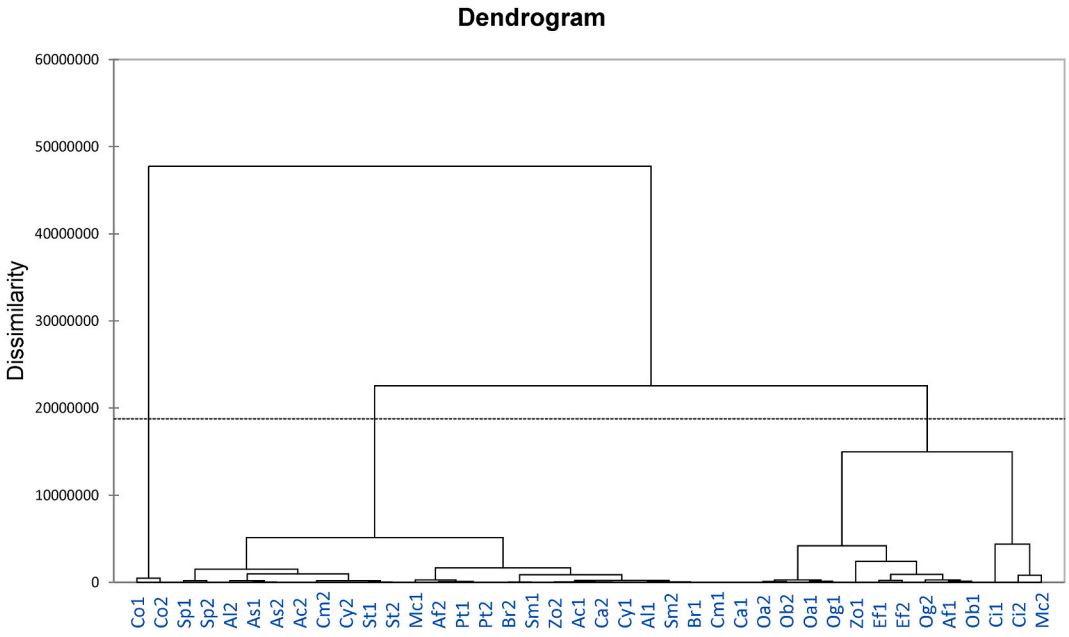

Fig. 3. The dendrogram of hierarchical cluster analysis (HCA) derived from the mean data of the proximate data (ash, carbohydrates, energy, fats, fiber and protein), minerals and vitamin C (calcium, iron, magnesium, potassium, phosphorus, sodium, vitamin c and zinc) and carotenoids (capsanthin, lutein, zeaxanthin, β-cryptoxanthin, α-carotene, β-carotene and total carotenoids) of all vegetables. Abbreviations; Ac: *A. cepa*; Af: *A. fistulosum*; Al: *Al. galangal*; As: *A. sativum*; Br: *B. rotunda*; Cm: *C. mangga*; Ca: *Ca. annuum*; Ci: *Ci. hystrix*; Co: *Co. sativum*; Cy: *Cy. citratus*; Ef: *E. foetidum*; Mc: *M. cordifolia*; Oa: *O. africanum*; Ob: *O. basilicum*; Og: *O. gratissimum*; Pt: *P. tetragonolobus*; Sm: *So. melongena*; Sp: *S. pennata*; St: *So. torvum*; Zo: *Z. officinale*; 1 from source 1; 2 from source 2.

Among all plant samples, the young leaves of *S. pennata* contained the highest amount of protein (60.15−66.07 g/100 g DW). *S. pennata* (synonym: *Acacia pennata*) or climbing wattle is a traditional Thai vegetable in the Fabaceae family. A similar amount of protein content was found in the tender leaves and stems of *S. pennata* (51.4 g/100 g DW) [19]. Based on Thai Recommended Daily Intakes (Thai RDIs) [20], 100 g of fresh *S. pennata* provides protein at 20−23% of Thai RDIs. Moreover, it is recommended that males and females aged 19−30 years consume 61.3 g and 53.0, respectively, of protein when considering Thai Dietary Reference Intakes (Thai DRIs) [21]. This is based on the recommendation of 1 g of protein per 1 kg body weight for the Thai population of both sexes aged 19 and older [21]. While the US guideline recommends protein consumption of 0.8 g/kg body weight per day, the Recommended Daily Allowances (RDAs) of protein for American males and females aged 19 years and older are 56 g and 46 g per day, respectively [22]. Therefore, 100 g of fresh *S. pennata* provides protein at 17−21% of Thai DRIs and 18−25% of US RDAs. In Asia and Thailand, there are several edible Acacia plants with feathery shoots including *S. pennata* (common name: climbing wattle), *S. rugata* (common name: soap-pod), and *A. leucocephala* (common name: horse-tamarind) [23–25]. The nutritive values of these 3 plants can be found in the Thai Food Composition Database (Thai FCD). The raw climbing wattle (Food code D29) had similar levels of energy, protein, carbohydrates, fiber, ash, most minerals, and vitamin C to those found in our study. However, the database exhibited 2.5-fold higher sodium content than ours (238.64 mg/100 g DW), and 2-fold lower fat and zinc (2.95 g and 3.35 mg/100 g DW) compared to ours [26]. Our study reported higher iron and protein contents (1.5 and 2-fold higher) and 6.5-fold higher vitamin C than soap-pod leaves (Food code D329), while the database exhibited 1.7 and 2.6-fold higher fiber and carbohydrates (38.98 and 61.02 g/100 g DW, respectively) and 2.2-fold higher calcium (474.58 mg/100 g DW) than ours [26]. The raw tender tips of horse-tamarind (FCD, food code D3) exhibited 1.5-fold lower protein (43.19 g/100 g DW), 3.5-fold lower fats and vitamin C (1.57 g and 61.90 mg/100 g DW, respectively), and 2.3-fold lower phosphorus (542.86 mg/100 g DW). However, the database showed 2-fold higher carbohydrates (48.86 g/100 g DW) and 1.6-fold and 2.9-fold higher sodium and calcium (157.14 mg and 614.29 mg/100 g DW, respectively) [26]. These variations might be due to the different genotypes, locations, weather, climate, and analysis methods.

The stalk of *Cy. citratus* and the fruit of *So. torvum* contained the highest amount of fiber (58.22−59.54 and 57.00−57.45 g/100 g DW, respectively). *Cy. citratus* or lemongrass is a traditional Thai herb in the Poaceae family. It provides fiber at 32−42% of Thai RDIs per 100 g FW. The Thai DRIs recommend healthy adults consume 25−38 g of fiber daily [21]. At the same time, the US guideline recommends fiber intake of 14 g per 1000 kcal per day, which translates to males and females aged 19−30 years taking in 34 and 28 g per day, respectively [22]. Therefore, 100 g of fresh lemongrass provides fiber at 21−42% of Thai DRIs and 23−37% of US RDAs. However, lemongrass has a fibrous texture and is usually cut, smashed, and added to various Thai dishes such as Tom Yum (spicy lemongrass soup), for flavor and not consumed as a whole unless thinly sliced or chopped in a food processor as an ingredient in traditional recipes like Khao Yam Pak Tai (Thai Southern spicy rice salad mixed with herbs and vegetables). Therefore, the fiber value is not available in Thai FCD (FCD, Food code N18) or the U.S. Department of Agriculture (USDA), Food Data Central (FDC, FDC ID 168573) [26,27].

Another plant with high dietary fiber, *So. torvum* or Turkey berry, is a traditional Thai vegetable in the Solanaceae family. As a rich source of fiber, 100 g of *So. torvum* provides fiber equivalent to 41–42% of Thai RDIs, 27–42% of Thai DRIs, and 30–38% of US RDAs. Compared to Thai FCD, raw Turkey berry (Food code D122) has similar amounts of energy, protein, and carbohydrates to those found in our study (384.3 kcal, 14.50 g, and 72.62 g/100 g DW, respectively), except for fiber, for which the database showed 1.2 times higher content (71.20 g/100 g DW) [26]. While they are in the same Solanum species, our result demonstrated that on a fresh basis, *So. torvum* had 3.2 times higher fiber content than *So. melongena*. In contrast, a previous study demonstrated that fiber content was slightly higher in *So. melongena* than *So. torvum* (3.91 and 3.81 g/100 g FW, respectively) [28]. Apart from *So. torvum* (Food code D122), the Thai FCD database contains three commonly consumed eggplants including *So. xanthocarpum* (Food code D120) and two different types of *So. melongena* (Food code D123, D124) [26]. Moreover, *So. melongena* is also found in the USDA database (FDC ID 169228) [27]. Energy levels (324.7–387.46 kcal/100 g DW), protein (12.70–15.55 g/100 g DW), and carbohydrates (73.01–77.92 g/100 g DW) were comparable in these plants. When compared to our results and databases, *So. melongena* from the current study had the highest potassium content (2-fold higher than the lowest). *So. melongena* (Food code D123) had the highest vitamin C content (329.90 mg/100 g DW, 12-fold higher than the lowest). Fats, fiber, calcium, phosphorus, and magnesium were the highest in *So. torvum* (Food code D122) (3.98 g, 71.20 g, 952.88 mg, 691.10 mg, and 277.49 mg/100 g DW, respectively). The highest sodium, iron and zinc concentrations were found in *So. xanthocarpum* (Food code D120) (117.02, 5.85, and 2.45 mg/100 g DW, respectively) [26,27]. These variations could be attributed to differences in genotypes, cultivation sites, environments, and sample preparation.

Interestingly, the leaves of *Co.* sativum, *O. africanum*, *O. basilicum*, *O. gratissimum* and *S. pennata* exhibited high overall mineral contents. *Co. sativum* (commonly called coriander or cilantro) is a traditional Thai vegetable in the Apiaceae family. In comparison to Thai FCD, coriander (Food code D87) exhibited 1.9-fold lower sodium and phosphorus contents (sodium: 373.83 and phosphorus: 345.79 mg/100 g DW) and 1.6-fold lower calcium and potassium contents (calcium: 850.47 and potassium: 4747.66 mg/100 g DW) than ours, while the FCD database showed 2.4-fold higher magnesium content than our findings (355.14 mg/100 g DW) [26]. However, the USDA database (FDC ID 169997) showed a 2.3-fold higher amount of magnesium (333.33 mg/100 g DW) than what we reported. Interestingly, calcium contents from both databases were similar (Thai FCD: 850.47 mg and USDA: 859.0 mg/100 g DW), and these numbers were 1.6 times lower than in our study [26,27]. Sodium and potassium are essential for water and electrolyte balance [29]. Sodium from natural food is essential to our body. However, the frequent consumption of modern diets, sauces and seasoning, and processed foods can cause excess sodium intake. The National Academies of Sciences, Engineering, and Medicine reported adequate intakes (AIs) of sodium in adults of 1500 mg/d [29]. In Thailand, both RDIs and DRIs of sodium recommend limiting sodium intake to less than 2000 mg/d [20,21], while US guidelines set the chronic disease risk reduction level (CDRR) of sodium intake at less than 2300 mg [29]. Since plants are not major sources of sodium and even though the leaves of *Co. sativum* contain the highest sodium content per dry weight, its fresh leaves (as per 100 g FW) provide sodium equivalent to only 2–4% of Thai RDIs and DRIs, and 3–5% of US AIs. Similarly, since the Thai RDIs of potassium is equal to 3500 mg/d [21], and US AIs for males and females aged 19 years and older are 3400 and 2600 mg/d, respectively [29], fresh *Co. sativum* provides potassium equivalent to 17–18% of Thai RDIs and 17–19% and 23–24% of US AIs for males and females aged 19 years and older, respectively.

Among all plants, 3 *Ocimum* species including *O. africanum* (common name: hoary basil), *O. basilicum* (common name: sweet basil), and *O. gratissimum* (common name: cumin) are traditional Thai herbs in the Lamiaceae family. *O. africanum* contains the highest magnesium content, whereas calcium has the highest amount of *O. basilicum*, closely followed by *O. gratissimum*. Compared to Thai FCD, hoary basil (Food code N155) exhibited similar amounts of macrominerals to those found in our study, except for sodium content, which was 3-fold higher than our findings. While sweet basil (Food code N37) had similar mineral contents to our study, cumin (Food code N39) showed 2.4-fold and 1.8-fold lower calcium and phosphorus contents, respectively, than in our study [26]. Based on Thai RDIs and RDAs, 100 g of fresh hoary basil provides magnesium at 15–29% of Thai RDIs and 17–30% and 21–41% of Thai RDAs for males and females aged 19–30 years, respectively. This amount is also equivalent to 13–26% and 17–33% of US RDAs for males and females aged 19–30, respectively. Per 100 g FW, sweet basil provides calcium at 25–40% of Thai RDIs. The same amount offers 25–40% of Thai AIs and 20–32% of US RDAs for both sexes aged 19–50. In the same trend, cumin provides calcium at 43–48% of Thai RDIs and Thai AIs, and 34–39% of US RDAs.

As mentioned previously, the climbing wattle (Food code D29) had similar levels of proximate contents to those found in our study. For mineral contents, however, sodium in the database was 2.5 times higher than in our study [26]. This plant contained the highest amount of phosphorus, providing 21–32% of Thai RDIs as well as 24–36% of Thai and US RDAs for those aged 19 years and older.

Among all plant samples, *M. cordifolia* or mint is a traditional Thai herb in the Lamiaceae family with the highest amount of vitamin C content. Compared with the Thai FCD (Food code N40), the database showed similar proximate contents but 4.6-fold lower vitamin C (1316.67 and 100.00 mg/100 g DW, respectively) than our study [26]. While vitamin C is essential for all humans, some mammals do not possess the ability to synthesize vitamin C due to the lack of gulonolactone oxidase enzymes [30]. Vitamin C is a good electron donator, so it is an effective antioxidant [30]. As a rich source of vitamin C, 100 g of *M. cordifolia* provides vitamin C equivalent to 87–148% of Thai RDIs, furnishing 52–89% and 61–104% of Thai RDAs for males and females aged 19 years and older, respectively, and 58–98% and 69–118% of US RDAs for males and females aged 19 years and older, respectively. These amounts are safe since the tolerable upper intake level (UL) is 2000 mg/d [30]. Vitamin C is heat labile and water–soluble. Thus, significant amounts are lost during food preparation and cooking [31]. Many examples of Thai cuisine sprinkle fresh mint leaves on top, such as Yam, Larb, and Phla (spicy Thai–style salad); consuming raw mint can provide maximum vitamin C.

As mentioned, carotenoids are crucial nutritive agents with positive effects on human health. In this study, the top four plant samples with high total carotenoid contents were *O. basilicum*, *Co. sativum*, *E. foetidum* and *O. gratissimum*. Conversely, vegetables with edible rhizomes, including *C. mangga*, *A. sativum* and *B. rotunda*, exhibited extremely low carotenoids. Leafy vegetables appeared to exhibit higher carotenoids than the rhizomes. Indeed, it has been proposed that carotenoids act as photoprotection during

photosynthesis [32], and in support, *O. basilicum* cultivated in a field showed higher amounts of certain carotenoids, such as lutein and β-carotene, compared with one planted in a greenhouse [33]. In the plant samples for this study, lutein and β-carotene were found in abundance. For example, *O. basilicum* (100 g DW) possessed 54.87−68.07 and 48.68−51.28 mg of lutein and β-carotene contents, respectively, while *E. foetidum* (100 g DW) exhibited 58.41−65.31 and 34.09−36.20 mg of lutein and β-carotene contents, respectively. Previous studies also reported the same range of lutein and β-carotene contents presented in our *O. basilicum* and *E. foetidum* [33, 34]. In contrast, capsanthin, zeaxanthin and β-cryptoxanthin were uniquely found in *Ca. annuum*, in which the plant (100 g DW) exhibited 14.60−14.83 mg β-carotene, 10.83−12.33 mg β-cryptoxanthin, 19.59−24.74 mg capsanthin and 11.23−20.42 mg zeaxanthin. Kim and colleagues reported that red−colored *Ca. annuum* from eight cultivars exhibited β-carotene, β-cryptoxanthin, capsanthin and zeaxanthin in the range of 0.83–2.73, 0.13−0.59, 3.98−31.8, and 3.61−24.05 mg per 100 g DW, respectively, indicating the carotenoid−richness of *Ca. annuum* planted in Thailand. β-carotene can be converted into β-cryptoxanthin and zeaxanthin by the enzymatic reaction of β-carotene hydroxylase (BCH) [35]. However, plants with high β-carotene including *Co. sativum*, *O. basilicum* and *M. cordifolia* also showed undetectable levels of β-cryptoxanthin and zeaxanthin, implying the role of BCH activities in each plant for β-cryptoxanthin and zeaxanthin biosynthesis. Besides, β-carotene has provitamin A activity and antioxidant activities [36], while lutein exhibited antioxidant activities and age−related macular degeneration [37]. Thus, the consumption of green leafy vegetables, such as *O. basilicum*, *E. foetidum* and *O. gratissimum*, may help to enhance the flavor of food as well as maintain physical fitness.

5. Conclusions

In this study, our group provided a significant amount of useful data concerning the nutritive values and carotenoid contents of 20 vegetables that are commonly used in Thai cuisine. All samples were well−controlled from the beginning, including species verification, cultivation area and process, harvesting time, voucher specimen, and herbarium management by the Ministry of Agriculture and Cooperatives, Thailand, in order to provide reliable and citable data for those vegetables. Further, the data could be used for a food database and applied in functional food or plant−based food sectors. All of these are strengths of our study. However, this study was limited to only 20 samples. Due to the redundancy of the samples, other Thai vegetables cannot be included in the present study. Furthermore, total fiber should be assessed as soluble and insoluble fiber, which may improve the sample's usability.

Declarations

Uthaiwan Suttisansanee: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Parunya Thiyajai: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Woorawee Inthachat: Analyzed and interpreted the data.

Kanchana Pruesapan, Khanitha Wongwathanarat: Contributed reagents, materials, analysis tools or data.

Somsri Charoenkiatkul: Conceived and designed the experiments.

Yuraporn Sahasakul, Piya Temviriyanukul: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e15951.

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