Kasetsart J. (Nat. Sci.) 48 : 214 - 226 (2014)

Lipophilic and Hydrophilic Antioxidant Capacities of Vegetables, Herbs and Spices in Eighteen Traditional Thai Dishes

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ABSTRACT

A selection of 18 local dishes commonly consumed in four regions of Thailand and 42 types of vegetables as their ingredients were analyzed for their total antioxidant capacity (TAC) and total phenolic content (TPC). The TAC was calculated by combining the hydrophilic oxygen radical absorbance capacity (H-ORAC) and the lipophilic oxygen radical absorbance capacity (L-ORAC). The H-ORAC values of all vegetables ranged from 2.87 to 607.17 µmol Trolox equivalents (TE) per gram, whereas the L-ORAC values ranged from 0.17 to 262.02 µmol TE.g^{-1}. The TAC values paralleled the H-ORAC values in most vegetables because H-ORAC makes up more than 90% of TAC. All of the vegetables analyzed contained total phenolic contents ranging from 0.29 to 10.03 mg gallic acid equivalent per gram of fresh weight (GAE.g^{-1}). The H-ORAC, L-ORAC and TPC of all dishes showed wide ranges, from 9.82 to 44.37 µmol TE.g^{-1}, from 0.41 to 4.85 µmol TE.g^{-1} and from 0.56 to 2.22 mg GAE.g^{-1}, respectively. To make an overall evaluation, the TAC and TPC consumed per serving size must be considered. The TAC and TPC of all dishes per serving ranged from 901 to 7,237 µmol TE and from 49 to 326 mg GAE, respectively. Fifty percent of the studied dishes were found to contain a TAC level greater than 3,000 µmol TE per serving. This means that a single food item of these dishes could achieve the recommended daily allowance of antioxidants currently recommended by the United States Department of Agriculture at 3,000 to 5,000 µmol TE.

Keywords: antioxidants, local vegetables, oxygen radical absorbance capacity (ORAC), Thai foods, total phenolic content

INTRODUCTION

Traditional foods from every region of Thailand are currently of interest because of their potential health benefits. Each region of the country has its own local foods consisting of various kinds of indigenous vegetables, herbs and spices. These ingredients could contribute natural antioxidants for health benefits. Epidemiological studies have shown that a diet rich in phytochemicals and antioxidants performs a protective role in health and disease, and frequent consumption of fruits and vegetables reduces the incidence of chronic diseases such as cancer and cardiovascular disease (Riboli and Norat, 2003). Several previous studies demonstrated that local Thai vegetables exhibited functional properties, such as antitumor, antimutagenicity and antioxidant activity (Murakami *et al.*, 1995; Nakahara *et al.*, 2002; Chanwitheesuk *et al.*, 2005; Tangkanakul *et al.*, 2006). The leaves, shoots, fruits or rhizomes of vegetables are eaten fresh or cooked. After cooking,

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Received date : 05/07/13 Accepted date : 06/12/13

vegetables present in assayed foods still provide considerable antioxidant capacity as measured by the 2,2-diphenylpicrylhydrazyl (DPPH) free radical scavenging assay (Tangkanakul *et al*., 2006). Data on the antioxidant capacity of indigenous Thai vegetables and other foods, as analyzed using oxygen radical absorbance capacity (ORAC) assay, is limited. ORAC assay has been selected for antioxidant capacity measurement because of its advantages related to biological systems (Cao and Prior, 1998; Prior and Cao, 1999). Antioxidants possibly are hydrophilic or lipophilic compounds, such as ascorbic acid and tocopherol, respectively. Polyphenols, a general term for the major compounds that respond to antioxidant activity in foods, are either hydrophilic or lipophilic compounds (Rice-Evans *et al.*, 1997). The objective of this study was to investigate the hydrophilic oxygen radical absorbance capacity (H-ORAC), the lipophilic oxygen radical absorbance capacity (L-ORAC) and total phenolic content (TPC) of foods from all regions of Thailand, together with their vegetable ingredients.

MATERIALS AND METHODS

Materials

2,2′-Azobis(2-amidinopropane) dihydrochloride (AAPH) was purchased from Wako Pure Chemical Industries, Ltd., Japan. 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) and fluorescein sodium salt were obtained from Sigma-Aldrich (St. Louis, MO, USA). Folin–Ciocalteu reagent was obtained from Merck (Darmstadt, Germany). Ascorbic acid was purchased from Fisher Scientific UK Ltd. (Loughborough, UK). All other chemicals used were of analytical grade.

Preparation of food

Eighteen commonly consumed Northern, Northeastern, Central and Southern Thai dishes were selected for this study. All foods were prepared according to the authentic recipes from each region of Thailand (Kasemboonyakorn, 2012). Four traditional dishes from each of the North, Northeast and South and six from the Central region were selected.

Northern foods consisted of: *kaeng kanoon on* (KKnoon), a soup containing young jackfruits; *kaeng phak gad jaw* (KPJaw), a soup containing flowering cabbage; *kua kae gai* (KuaKG), stir-fried vegetables with chicken, *cha om*, *cha plu* and long coriander; and *pad phak chiang da* (PChD), stir-fried *phak chiang da* with egg. Samples of Northeastern cuisine were: *kaeng naw mai bai ya nang* (KNMai), a spicy soup containing bamboo shoots in juice from *bai ya nang*; *om kai* (OmK), a soup without coconut milk, containing various kinds of vegetables; *lap pla duk* (LPD), spicy grilled fish salad; and *sup ma khua por* (SuMaK), boiled eggplant spicy salad. The four Southern dishes were: *kaeng nhua bai cha plu* (KBaiCP), soup with coconut milk, containing wild betel leaves; *pad sator* (PSTor), stir-fried petai beans; *kaeng tai pla* (KTai), a soup containing various kinds of vegetables; and *pla tod kha min* (PlaTod), deep-fried marinated fish with turmeric. The six foods from the Central region consisted of: *kaeng pa gai* (KPaG), a soup without coconut milk, containing various kinds of vegetables; *kaeng mhoo tae po* (KTaePo), swamp cabbage in red curry with pork; *pha naeng nhua* (PNN), beef in creamy curry sauce containing coconut milk, as well as fresh and dried herbs and spices; *pad phak wan ban* (PWan), stir-fried *phak wan ban* with oyster sauce; *yum tua poo* (YumTua), winged bean spicy salad; and *yum ma khuea yao* (YuMK), long eggplant spicy salad.

The percentage distributions of various ingredients used in each recipe are given in Table 1. The vegetables, herbs and spices used to prepare the foods were purchased from three markets in Bangkok: Prachanivej, Ramintra and Muang Thong Thani. The purchased amounts varied from 1 to 2 kg.

Table 1 List of ingredients in selected local Thai foods. The proportion of major ingredients is calculated based on weight.

Traditional Thai foods (abbreviation), and major ingredients (%)	Plant content (%)
Northern foods	
Kaeng kanoon (KKnoon)	
Green jackfruit (19.7), garlic (1.2), shallot (1.0), dried chili (0.5), lemongrass (0.6), galangal (0.2), wild tomato (6.6), *cha om* (2.0), *cha plu* (0.7), shrimp paste (0.3), salt (0.1), pork ribs (11.2), pork (1.8), fish sauce (1.6), water (52.5)	32.5
Kaeng phak gad jaw (KPJaw)	
Flowering cabbage (30.9), garlic (2.1), shallot (1.4), shrimp paste (0.5), salt (0.1), tamarind paste (1.7), fish sauce (1.6), vegetable oil (1.4), pork belly (5.5), pork ribs (6.8), water (48.0)	36.1
Kua kae gai (KuaKG)	
Dried chili (1.0), garlic (2.5), shallot (3.2), long yard bean (8.6), eggplant (brinjal) (6.4), plate brush eggplant (4.3), hummingbird flower (3.2), ivy gourd leaves (3.2), *cha om* (3.2), *cha plu* (2.1), long coriander (2.1), chicken (15.0), roasted rice (2.7), vegetable oil (2.1), shrimp paste (0.3), fish sauce (1.6), water (38.5)	39.8
Pad phak chiang da (PChD)	
Phak chiang da (24.4), garlic (3.7), chili (1.0), egg (59.0), oyster sauce (4.4), soy sauce (1.2), sugar (0.2), vegetable oil (6.1)	29.1
Northeastern foods	
Kaeng naw mai bai ya nang (KNMai)	
Bamboo shoot (18.2), shallot (0.8), chili (0.4), lemongrass (0.4), hairy basil leaves (1.3), *cha om* (2.1), pumpkin (12.7), corn (5.6), *bai ya nang* (2.2), fermented fish (4.0), fish sauce (1.6), glutinous rice (2.0), water (48.7)	43.7
Om kai (OmK)	
Sponge gourd (14.4), shallot (0.9), garlic (0.5), chili (0.5), lemongrass (0.5), hairy basil leaves (1.4), dill (4.8), flowering cabbage (9.7), wild betel leaves (1.9), roasted glutinous rice (1.4), fish sauce (1.1), fermented fish (2.7), chicken meat (13.2), water (47.0)	34.6
Lap pla duk (LPD)	
Shallot (4.6), dried chili (0.9), young galangal (2.6), long coriander (4.8), spring onion (4.9), mint leaves (2.9), kaffir lime leaves (0.2), grilled catfish meat (33.8), roasted rice (2.4), fermented fish (9.4), fish sauce (3.5), water (30.0)	20.9
Sup ma khua por (SuMaK)	
Eggplant (brinjal) (37.4), shallot (1.7), garlic (0.9), chili (0.8), spring onion (1.8), mint leaves (0.7), fermented fish (2.2), fish sauce (2.1), striped snakehead fish (5.7), water (46.7)	43.3

Traditional Thai foods (abbreviation), and major ingredients (%)	Plant content (%)
Southern foods	
Kaeng nhua bai cha plu (KBaiCP) Wild betel leaves (9.9), garlic (3.6), shallot (2.0), chili (0.7), dried chili (0.5), pepper (0.1), lemongrass (0.7), galangal (0.4), turmeric (0.4), kaffir lime leaves (0.1), shrimp paste (1.0), salt (0.4), beef (22.0), coconut milk (27.4), fish sauce (1.6), palm sugar (1.1), vegetable oil (0.5), water (27.6)	18.4
Pad sat or (PSTor) Petai beans (43.0), garlic (3.3), chili (3.0), shrimp paste (2.1), prawn (12.9), minced pork (8.6), vegetable oil (3.4), soy sauce (1.7), fish sauce (2.1), palm sugar (1.7), lime juice (0.9), water (17.3)	50.2
Kaeng tai pla (KTai) Garlic (3.1), shallot (1.6), chili (0.8), dried chili (0.4), lemongrass (1.2), galangal (0.3), kaffir lime peels (0.1), turmeric (0.2), pepper (0.1), shrimp paste (1.0), kaffir lime leaves (0.4), eggplant (brinjal) (12.8), long yard bean (9.6), bamboo shoot (8.0), pea eggplant (2.4), cashew nut (3.2), tamarind paste (1.2), palm sugar (0.8), grilled fish (3.2), fermented fish viscera (9.6), water (40.0)	45.4
Pla tod kha min (PlaTod) Fish meat (87.5), turmeric (3.5) garlic (3.5) salt (0.7) vegetable oil (4.8)	7.0
Central foods	
Kaeng pa gai (KPaG) Garlic (1.9), shallot (1.1), chili pepper, red/green (1.1), bird chili (1.0), dried chili (0.5), lemongrass (1.1), galangal (0.7), fingerroot (3.3), kaffir lime peels (0.2), coriander root (0.2), pepper (0.2), coriander seeds (0.1), eggplant (brinjal) (7.6), bamboo shoot (6.6), long beans (4.7), pea eggplant (2.8), holy basil (1.9), young peppercorn (1.9), kaffir lime leaves (0.2), chicken meat (14.2), fish sauce (2.7), sugar palm (0.5), salt (0.2), shrimp paste (0.5), vegetable oil (1.9), water (42.9)	37.1
Kaeng mhoo tae po (KTaePo) Swamp cabbage (19.0), garlic (2.0), shallot (0.9), dried chili (0.6), lemongrass (0.6), galangal (0.3), kaffir lime peels (0.3), kaffir lime leaves (0.2), kaffir lime juice (0.8), fish sauce (1.9), sugar palm (3.5), tamarind paste (1.0), salt (0.5), shrimp paste (0.6), pork (10.2), dried fish (0.6), coconut milk (31.7), water (25.3)	25.7
Pha naeng nhua (PNN) Garlic (2.1), shallot (2.1), dried chili (0.8), chili pepper, red (0.4), galangal (0.2), lemongrass (0.5), kaffir lime leaves (0.3), coriander seed (0.3), cumin (0.1), roasted ground nut (0.2), salt (0.3), shrimp paste (0.2), pepper (0.1), nutmeg (0.04), palm sugar (2.6), fish sauce (1.8), beef (35.1), coconut milk (35.1), water (17.8)	7.1

Traditional Thai foods (abbreviation), and major ingredients (%)	Plant content (%)
Pad phak wan ban (PWan)	
Phak wan ban (70.0), garlic (3.5), oyster sauce (9.3), sugar (0.5), vegetable oil (7.3), water (9.4)	73.5
Yum tua poo (YumTua)	
Winged bean (38.7), shallot (7.8), garlic (2.7), dried chili (0.6), salt (0.2), pork (8.7), prawn (9.3), tamarind paste (1.9), lime juice (1.5), palm sugar (5.8), fish sauce (2.9), coconut milk (11.6), grated coconut meat (4.8), roasted groundnut (0.6), water (2.9)	58.6
Yum ma khuea yao (YuMK)	
Long eggplant (56.0), shallot (4.5), garlic (2.2), chili (1.7), lime juice (5.0), fish sauce (5.3), sugar (3.4), dried shrimp (1.1), minced pork (15.8), water (5.0)	69.4

Sample preparation and extraction

The vegetables were cleaned and cut into small pieces before freeze drying. Food samples for analysis were prepared by removing inedible portions (for example, pork bones), then homogenized using a Waring blender (Dynamics Corporation of America; New Hartford, CT, USA) and freeze dried. The dried foods were ground into a fine powder and kept at -80 °C for further analysis.

Powder samples (1 g) were extracted with 10 mL of hexane/dichloromethane (1:1 ratio) according to previously published procedures (Wu *et al.*, 2004; Isabelle *et al.*, 2010). Each mixture was vortexed for 30 s, followed by sonication for 5 min with temperature maintained at 37 °C, and then centrifugation at 2,500 rpm for 5 min. The extraction was repeated twice. The combined extracts were dried with centrifugal vacuum concentrators (miVAC Duo Genevac; Gardiner, NY, USA), reconstituted with 10 mL of acetone and then vortexed for 30 s. The extracts were kept at -80 °C in individual glass vials each with a rubber stopper and aluminum cap until they were used to measure the L-ORAC.

For H-ORAC preparation, the residue from the hexane/dichloromethane was dried under nitrogen and extracted three times with 8 mL acetone/water/acetic acid (AWA; 70:29.5:0.5). Acetone is applied since it is one of the effective solvents for extracting phenolic compounds and has a very small effect on the ORAC assay (Cao *et al.*, 1995; Hayouni *et al.*, 2007). After addition of the solvent, the tube was vortexed for 30 s, followed by sonication at 37 °C for 5 min. The tube was shaken once in the middle of the sonication step to suspend the sample. The mixture was then centrifuged and the supernatant was collected in a 25 mL volumetric flask; AWA was added to obtain a final volume of 25 mL. This solution was kept at -80 °C in a glass vial with rubber stopper and aluminum cap and was used to measure the H-ORAC and the TPC.

Oxygen radical absorbance capacity assay

The ORAC assay was carried out according to Huang *et al.* (2002) on a microplate reader (Infinite M200; Tecan, Männedorf, Switzerland) equipped with an injection pump. Fluorescence conditions were as follows: excitation, 485 nm; emission, 520 nm; number of cycles, 35; cycle time, 210 s; shaking mode, 8 s orbital shaking before each cycle; injection speed, 300 $\mu L.s^{-1}$. The area under the curve (AUC) was calculated following the method of Wu *et al.* (2004). Data were expressed as micromole

Trolox equivalents (μmol TE) per gram serving. The ORAC value or total antioxidant capacity (TAC) was calculated by summing the H-ORAC and L-ORAC. ORAC assay is the current method widely used by researchers to study on a wide spectrum of plant from leaf to nut or even oily samples such as olive oils (Wu *et al.*, 2004; Ninfali *et al.*, 2005). Foods cooked with or without oil would be appropriate for this analysis.

Total phenolic content

The TPC was determined using Folin–Ciocalteu reagent, as adapted from Singleton and Rossi (1965). Gallic acid was used as a standard. TPC measurements of food samples were performed on the AWA extracts and were calculated on the basis of the standard curve for gallic acid. The results were expressed as milligrams or grams gallic acid equivalent (GAE) per gram of fresh weight (GAE.g^{-1} FW).

Statistical analysis

The results were analyzed using the Microsoft Excel statistical analysis program (Version 2007; Microsoft, Redmond, WA, USA). Data were expressed as mean ± standard deviation (SD) for vegetables having a sample number larger than 2.

RESULTS AND DISCUSSION

Total antioxidant capacity and total phenolic content of plants

The L-ORAC and H-ORAC were determined using oxygen radical absorbance capacity (ORAC) assay, with fluorescein as the fluorescent probe and 2,2′-azobis (2-amidinopropane) dihydrochloride as a peroxyl radical generator.

The TAC of 42 plants are shown in Table 2. They were divided into three groups: leafy, fruits/pods and culinary herbs/spices. All plants exhibited a TAC ranging from 14.33 to 166.28, 3.06 to 89.10 and 6.17 to 869.18 μmol TE.g^{-1} FW, respectively. Turmeric possessed the most potent antioxidant activity (869.18 μmol TE.g^{-1} FW) followed by cumin (342.27 μmol TE.g^{-1} FW) and young pepper (271.07 μmol TE.g^{-1} FW). Possible antioxidants in *chiang da* were vitamin E and gymnemic acid (Chanwitheesuk *et al.*, 2005; Geethika, 2009). Antioxidants reported in other local vegetables were naringenin in wild betel, piperine in young pepper, rosmarinic acid and sinapic acid in hairy basil and holy basil (Mittal and Gupta, 2000; Subramaniam *et al.*, 2003; Trakoontivakorn *et al.*, 2012).

In this study, the plant that had the highest L-ORAC level was turmeric (262.02 μmol TE.g^{-1} FW), followed by young pepper (84.94 μmol TE.g^{-1} FW), fingerroot (48.81 μmol TE.g^{-1} FW), kaffir lime peel (36.72 μmol TE.g^{-1} FW), *ka yaeng* (35.78 μmol TE.g^{-1} FW), cumin (34.15 μmol TE.g^{-1} FW) and coriander seed (25.82 μmol TE.g^{-1} FW). All of these herbs and spices are commonly used as ingredients in chili paste for the preparation of Thai dishes. Although they are a good source of antioxidant activity, they are not consumed in large quantities due to their strong odor, and instead are used in relatively small amounts as ingredients in food recipes. Turmeric also provided the highest reading of the H-ORAC (607.17 μmol TE g^{-1} FW). The major active components of turmeric are curcuminoids, which include curcumin, demethoxycurcumin and bisdemethoxycurcumin; curcumin acts as a superoxide radical scavenger (Reddy and Lokesh, 1994; Ruby *et al.*, 1995) and as a singlet oxygen quencher (Das and Das, 2002).

The TAC of the leafy and fruit/pod vegetables was mainly contributed by the H-ORAC, which made up more than 90%. Most leafy vegetables were typically ranked high in TAC and TPC compared to fruit/pod vegetables. Plants used as herbs/spices come from various parts of the plant (leaf, fruit, rhizome or seed). Contrary to the results for leafy and fruit/pod vegetables, the L-ORAC levels of the eight herbs/spices contributed from 22 to 84% of TAC, which was

Table 2 Total antioxidant capacity (TAC), lipophilic (L-ORAC), hydrophilic (H-ORAC) and total phenolic contents (TPC) of 42 vegetables[a].

Common name or Thai name	Scientific name	n	L-ORAC [b] (μmol TE.g^{-1} FW) (min, max)	H-ORAC [b] (μmol TE.g^{-1} FW) (min, max)	TAC [c] (μmol TE.g^{-1} FW)	L-ORAC / TAC (%)	H-ORAC / TAC (%)	TPC [d] (mg GAE.g^{-1} FW)
Leafy vegetables								
Cha om	*Acacia pennata*	3	0.85 ± 0.11 (0.72, 0.92)	51.96 ± 2.43 (49.57, 54.42)	52.81	1.6	98.4	6.13
Chiang da	*Gymnema inodorum*	5	1.54 ± 0.27 (1.17, 1.80)	164.73 ± 24.17 (124.90, 189.99)	166.28	0.9	99.1	5.67
Flowering cabbage	*Brassica chinensis*	3	0.66 ± 0.24 (0.44, 0.92)	13.67 ± 1.45 (12.70, 15.33)	14.33	4.6	95.4	0.84
Ivy gourd	*Coccinia grandis*	3	2.58 ± 0.81 (2.02, 3.51)	43.93 ± 8.20 (37.38, 53.13)	46.51	5.5	94.5	2.27
Phak wan ban	*Sauropus androgynus*	4	1.41 ± 0.27 (1.19, 1.70)	38.58 ± 0.44 (38.28, 39.09)	39.99	3.5	96.5	1.46
Swamp morning glory	*Ipomoea aquatica*	3	0.19 ± 0.16 (0.03, 0.36)	69.05 ± 36.27 (31.58, 103.99)	69.24	0.3	99.7	3.05
Wild betel	*Piper sarmentosum*	6	11.67 ± 4.60 (6.10, 17.23)	99.65 ± 28.26 (61.33, 140.38)	111.32	10.5	89.5	3.30
Yanang	*Tiliacora triandra*		3.64 ± 1.69	130.01 ± 24.05	133.65	2.7	97.3	4.68
Fruits/pod vegetables								
Corn	*Zea mays*	2	2.78 (2.68, 2.88)	3.15 (2.87, 3.42)	5.93	46.9	53.1	0.45
Eggplant/brinjal	*Solanum melongena* var. *esculentum*	3	0.38 ± 0.19 (0.18, 0.56)	18.49 ± 3.84 (14.14, 21.41)	18.87	2.0	98.0	1.22
Hummingbird flower	*Sesbania grandiflora*	3	0.20 ± 0.07 (0.14, 0.28)	13.57 ± 1.51 (11.85, 14.67)	13.77	1.5	98.5	0.56
Jackfruit, green	*Artocarpus heterophyllus*	3	0.26 ± 0.11 (0.18, 0.94)	18.08 ± 2.05 15.81, 19.80)	18.35	1.4	98.5	2.91
Long eggplant	*Solanum melongena* var. *serpentium*	3	0.27 ± 0.06 (0.22, 0.33)	10.15 ± 1.42 (8.62, 11.42)	10.42	2.6	97.4	0.66
Long yard bean	*Vigna unguiculata*	3	0.31 ± 0.12 (0.24, 0.45)	21.88 ± 2.80 (18.78, 24.24)	22.19	1.4	98.6	1.38
Pea eggplant	*Solanum torvum*	4	3.35 ± 1.01 (1.99, 4.18)	85.75 ± 20.42 (74.11, 116.33)	89.10	3.8	96.2	3.51
Petai bean	*Parkia speciosa*	5	0.35 ± 0.19 (0.20, 0.64)	20.93 ± 7.33 (15.23, 31.72)	21.27	1.6	98.4	0.85
Pumpkin	*Cucurbita moschata* Decne.	2	1.10 (1.07, 1.13)	3.61 (3.51, 3.70)	4.71	23.4	76.6	0.35
Sponge gourd	*Luffa cylindrica*	2	0.19 (0.12, 0.27)	2.87 (0.00, 5.74)	3.06	6.2	93.8	0.46
Wild tomato	*Lycopersicon esculentum*	3	0.17 ± 0.06 (0.13, 0.24)	7.26 ± 2.19 (5.98, 9.79)	7.43	2.3	97.7	0.49
Wing bean	*Psophocarpus tetragonolobus*	3	0.21 ± 0.05 (0.17, 0.26)	13.62 ± 0.31 (13.29, 13.92)	13.83	1.5	98.5	0.53
Culinary herbs/spices								
Bird chili	*Capsicum frutescens*	3	17.37 ± 1.39 (15.97, 18.75)	54.27 ± 6.88 (47.10, 60.82)	71.64	24.2	75.8	2.08
Chili pepper, green	*Capsicum annuum* var. *acuminatum*	3	2.38 ± 0.76 (1.82, 3.24)	16.90 ± 2.12 (15.23, 19.29)	19.28	12.3	87.7	0.93
Chili pepper, red	*Capsicum annuum* var. *acuminatum*	3	1.47 ± 0.68 (0.81, 2.17)	12.20 ± 0.57 (11.56, 12.67)	13.67	10.8	89.2	1.31
Cilantro root	*Coriandrum sativum*	1	0.21	5.96	6.17	3.4	96.6	0.29
Coriander seed	*Coriandrum sativum*	2	25.82 (25.12, 26.51)	37.05 (32.83, 41.27)	62.87	41.1	58.9	2.02
Cumin, dried	*Cuminum cyminum*	2	34.15 (29.42, 38.87)	308.12 (293.99, 322.25)	342.27	10.0	90.0	8.09
Dill	*Anethum graveolens*	5	0.92 ± 0.61 (0.46, 1.90)	62.00 ± 13.41 (40.72, 77.59)	62.92	1.5	98.5	2.82
Fingerroot	*Boesenbergia pandurata*	3	48.81 ± 2.20 (46.94, 51.23)	9.29 ± 0.85 (8.38, 10.05)	58.10	84.0	16.0	0.61
Galangal	*Alpinia galanga*	3	1.04 ± 0.14 (0.89, 1.17)	13.05 ± 1.05 (12.00, 14.10)	14.09	7.4	92.6	1.23

Common name or Thai name	Scientific name	n	L-ORAC [b] (µmol TE.g^{-1} FW) (min, max)	H-ORAC [b] (µmol TE.g^{-1} FW) (min, max)	TAC [c] (µmol TE.g^{-1} FW)	L-ORAC / TAC (%)	H-ORAC / TAC (%)	TPC [d] (mg GAE.g^{-1} FW)
Garlic	*Allium sativum*	4	0.41 ± 0.20 (0.19, 0.64)	22.12 ± 0.51 (21.64, 22.78)	22.53	1.8	98.2	0.89
Hairy basil	*Ocimum americanum*	4	8.44 ± 6.12 (0.91, 15.73)	72.27 ± 48.15 (39.42, 142.67)	80.71	10.5	89.5	2.63
Holy basil	*Ocimum tenuiflorum*	4	2.39 ± 0.52 (2.02, 3.16)	97.83 ± 28.42 (77.41, 137.81)	100.22	2.4	97.6	3.16
Kaffir lime leaf	*Citrus hystrix*	3	13.89 ± 1.57 (12.90, 15.71)	179.39 ± 38.78 (149.42, 223.18)	193.28	7.2	92.8	5.07
Kaffir lime peel	*Citrus hystrix*	3	36.72 ± 3.93 (32.19, 39.09)	103.25 ± 11.40 (90.10, 110.44)	139.97	26.2	73.8	5.08
Ka yaeng	*Limnophila aromatica*	2	35.78 (31.43, 40.13)	89.91 (74.30, 105.52)	125.69	28.5	71.5	3.68
Kitchen mint	*Mentha cordifolia*	4	2.93 ± 0.85 (1.52, 3.73)	162.06 ± 75.15 (100.05, 266.98)	165.02	1.8	98.2	6.48
Lemongrass	*Cymbopogon citratus*	3	10.21 ± 2.11 (8.68, 12.62)	36.06 ± 8.87 (27.79, 45.43)	46.26	22.1	78.0	1.52
Peppercorn, young	*Piper nigrum*	3	84.94 ± 13.08 (72.06, 98.21)	186.14 ± 15.30 (170.49, 201.07)	271.07	31.3	68.7	8.38
Phak chi farang	*Eryngium foetidum*	4	0.32 ± 0.19 (0.07, 0.53)	19.46 ± 8.63 (12.32, 31.83)	19.75	1.6	98.5	0.79
Shallot	*Allium ascalonicum*	3	0.33 ± 0.31 (0.13, 0.69)	15.52 ± 3.22 (12.21, 18.64)	15.85	2.1	97.9	0.74
Spring onion	*Allium fistulosum*	3	0.40 ± 0.14 (0.29, 0.56)	10.28 ± 0.62 (9.72, 10.94)	10.68	3.7	96.3	0.45
Turmeric	*Curcuma longa*	4	262.02 ± 82.29 (166.37, 364.16)	607.17 ± 240.61 (360.91, 184.33)	869.18	30.1	69.9	10.03

n = Sample number.
[a] Data presented as mean ± SD for sample numbers greater than 2. [b] L-ORAC and H-ORAC data expressed as micromoles of Trolox equivalents per gram (µmol of TE.g^{-1} FW). [c] TAC = L-ORAC + H-ORAC. [d] Total phenolic content data expressed as milligrams of gallic acid equivalents per gram (mg GAE.g^{-1} FW).

higher than for the other plants except for corn and pumpkin. Fingerroot provided the highest percentage of the L-ORAC to the TAC.

It was found that the TAC of bird chili was four to five times higher than that of red/green chili pepper. Red chili is widely used as a hot spice in Asian foods and contains a high amount of capsaicin. Capsaicin provides notable antioxidative properties and is most abundant in red and green chili. Isabelle *et al*. (2010) found that red chili contained higher levels of capsaicin (26.79 µg.g^{-1} fresh weight) than green chili (18.98 µg.g^{-1} fresh weight).

In the current study, the H-ORAC results were compared with the values of similar vegetables commonly available in Singapore, obtained by Isabelle *et al.* (2010). Thai vegetables such as pumpkin, red/green chili, garlic and spring onion had comparable H-ORAC levels with the same vegetables in Singapore. However, eggplant and flowering cabbage grown in Thailand were found to have H-ORAC levels 31% and 26% higher than in Singapore, respectively. On the other hand, corn in Singapore contained a H-ORAC level 70% higher than that found in corn in Thailand. This may likely have been due to different cultivars and growing conditions.

Total phenolic contents of vegetables

The TPC values of 42 plants were analyzed using Folin–Ciocalteu reagent in the same AWA extracts used to analyze H-ORAC. Phenolic compounds were attributed to the antioxidant activity of plants. The results of all samples are presented in Table 2. Most of the plants contained TPC levels within the range 0.29–10.03 mg GAE.g^{-1} FW. Turmeric, young pepper, cumin, kitchen mint and *cha om* had high phenolic contents ranging from 6.13 to 10.03 mg GAE.g^{-1} FW followed by *chiang da*, *yanang*, kaffir lime leaf and kaffir lime peel with a range of 5.07 to 4.68 mg GAE.g^{-1} FW. The remaining samples (33) recorded

TPC levels ranging from 0.29 to 3.68 mg GAE.g^{-1} FW. It should be noted that the vegetables having TPC levels of less than 1 mg GAE.g^{-1} FW, such as flowering cabbage, long eggplant, long yard bean, petai bean, pumpkin, sponge gourd and wing bean, are typically consumed in high amounts due to their relatively plain taste and/or mild aroma.

Relationship between hydrophilic oxygen radical absorbance capacity and total phenolic content

This study demonstrated a positive linear correlation between the TPC and H-ORAC of the hydrophilic extract, as shown in Figure 1. The H-ORAC of 42 vegetable extracts was correlated with the TPC (R^2 = 0.7472). The correlation increased to 0.8259 when the turmeric data were excluded. The good correlation of the two values illustrated that phenolic compounds are responsible for the peroxyl radical scavenging activity of the plants. The ORAC values in the lipophilic portion of the vegetable extracts generally were not significant as reported by Wu *et al.*, (2004). However, in the current study, 10 out of 42 vegetables displayed high L-ORAC values which accounted for more than 20% of the TAC (Table 2). Corn, pumpkin, brid chili, coriander seed, fingerroot, hairy basil, kaffir lime peel, *Ka yaeng*, lemongrass young peppercorn and turmeric, contained high levels of lipophilic antioxidant.

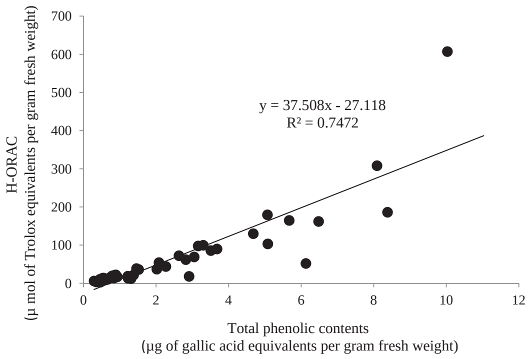

Figure 1 Relationship between total phenolic contents and hydrophilic oxygen radical absorbance capacity (H-ORAC) of 42 vegetables.

Total antioxidant capacity and total phenolic content of the 18 selected foods

The 18 selected foods contained moisture contents ranging from 46 to 91.1% (Table 3). Most soup-style dishes, which had a relatively high moisture content, fell in the range 74.5 to 91.1%. The salad-style dishes such as SuMaK, YumTua and YuMK also had quite high moisture contents, ranging from 72.4 to 88.6%. The other foods, which were stir-fried or deep-fried, had moisture contents from 46 to 80.2%.

The TAC of these 18 tested foods ranged from 11.13 to 45.96 µmol TE.g^{-1} FW (Table 3). PChD exhibited the highest value due to the high total antioxidant capacity of *phak chiang da*, which was the major ingredient of this dish (24.4%; Table 1). Four kinds of foods—KuaKG, KTaePo, KPaG and KBaiCP—showed antioxidant capacities ranging from 30.66 to 42.21 µmol TE.g^{-1} FW. KuaKG and KPaG were mixed-vegetable style dishes containing 39.8% and 37.1% of mixed plants, respectively (Table 1). Thus, the TAC of these two dishes evidently is derived from various plant sources. Swamp morning glory and wild betel contained TAC levels of 69.24 and 111.32 µmol TE.g^{-1} FW, respectively (Table 2) and hence these plants are probably the major antioxidant sources in KTaePo and KBaiCP.

The other four foods—SuMaK, PSTor, KTai and PWan—contained antioxidant capacities ranging from 20.32 to 25.07 µmol TE.g^{-1} FW. Half of the studied dishes had antioxidant capacities less than 20 µmol TE.g^{-1} FW. These tested foods possessed antioxidant capacities close to those of USA breakfast cereals, including corn flakes, granola, toasted oatmeal, and oat bran, whose TAC range was found to be 13.03–23.59 µmol TE.g^{-1} FW (Wu *et al.*, 2004). The TPC levels of all tested foods varied widely, ranging from 0.56 to 2.22 mg GAE.g^{-1} FW. PChD provided the highest TPC, followed by KuaKG, KTaePo, SuMaK, KPaG, KBaiCP, YumTua, KTai, PWan and KKnoon, respectively. These 10 foods contained phenolic contents equal to or more than 1 mg GAEg^{-1} FW. The other 8 foods provided less than 1 mg GAE.g^{-1} FW. SuMaK, which contained 37.4% brinjal eggplant as its primary plant ingredient (Table 1), showed a relatively high phenolic content (155 mg GAE per 100 grams fresh weight), a finding which is in agreement with a previous study (Tangkanakul *et al.*, 2006). Chlorogenic acid was the dominant phenolic compound in purple eggplant, which is known to exhibit antioxidant activity (Whitaker and Stommel, 2003).

It should be noted that foods prepared at home cooking temperatures possessed antioxidant activity. This result was similar to a study which

Table 3 Hydrophilic (H-ORAC), lipophilic (L-ORAC), total antioxidant capacity (TAC) and total phenolic content (TPC) of 18 studied foods [a].

Foods (abbreviation)	% moisture	L-ORAC [b] (µmol TE.g^{-1} FW)	H-ORAC (µmol TE.g^{-1} FW)	TAC [c] (µmol TE.g^{-1} FW)	TPC [d] (mg GAE.g^{-1} FW)	L-ORAC (µmol TE per serving)	H-ORAC (µmol TE per serving)	TAC (µmol TE per serving)	TPC (mg GAE per serving)	Serving (g)
Northern dishes										
Kaeng kanoon on (KKnoon)	87.3	0.41 ± 0.03	19.57 ± 1.77	19.98 ± 1.79	1.00 ± 0.10	96	4,599	4,696	235	235
Kaeng phak gad jaw (KPJaw)	81.6	0.78 ± 0.05	13.73 ± 1.89	14.51 ± 1.95	0.68 ± 0.08	172	3,021	3,192	150	220
Kua kae gai (KuaKG)	75.7	1.56 ± 0.39	40.65 ± 3.51	42.21 ± 3.51	1.93 ± 0.07	203	5,285	5,487	251	130
Pad phak chiang da (PChD)	64.3	1.59 ± 0.25	44.37 ± 2.44	45.96 ± 2.19	2.22 ± 0.33	111	3,106	3,217	155	70
Northeastern dishes										
Kaeng naw mai bai ya nang (KNMai)	91.1	0.61 ± 0.04	10.53 ±0.50	11.13 ± 0.47	0.56 ± 0.02	122	2,106	2,226	112	200
Om kai (OmK)	87.5	0.53 ± 0.12	15.07 ± 0.50	15.60 ± 0.58	0.74 ± 0.04	106	3,014	3,121	148	200
Lap pla duk (LPD)	78.3	1.44 ± 0.16	9.82 ± 0.28	11.26 ± 0.26	0.65 ± 0.05	115	786	901	52	80
Sup ma khua por (SuMaK)	88.6	0.48 ± 0.09	22.51 ± 5.51	22.98 ± 5.48	1.55 ± 0.40	62	2,926	2,988	201	130
Southern dishes										
Kaeng nhua bai cha plu (KBaiCP)	74.5	2.21 ± 0.48	28.4 ± 1.56	30.66 ± 2.03	1.29 ± 0.06	376	4,828	5,211	219	170
Pad sat or (PSTor)	70.7	1.70 ± 0.27	23.37 ± 1.95	25.07 ± 1.73	0.82 ± 0.05	145	1,986	2,131	70	85
Kaeng tai pla (KTai)	83.0	4.58 ± 0.95	20.04 ± 0.92	24.62 ± 1.43	1.14 ± 0.18	916	4,008	4,924	228	200
Pla tod kha min (PlaTod)	57.4	4.85 ± 1.84	13.34 ± 2.12	18.20 ± 3.77	0.81 ± 0.05	291	800	1,092	49	60
Central dishes										
Kaeng pa gai (KPaG)	82.5	3.81 ± 0.12	31.49 ± 2.02	35.30 ± 2.12	1.31 ± 0.03	762	6,298	7,059	262	200
Kaeng mhoo tae po (KTaePo)	75.7	0.66 ± 0.11	35.53 ± 9.11	36.18 ± 9.18	1.63 ± 0.37	132	7,106	7,237	326	200
Pha naeng nhua, (PNN)	46.0	1.66 ± 0.19	17.44 ± 0.08	19.10 ± 0.26	0.94 ± 0.02	141	1,482	1,623	80	85
Pad phak wan ban (PWan)	80.2	1.25 ± 0.58	19.07 ± 1.23	20.32 ± 0.79	1.04 ± 0.05	125	1,907	2,032	104	100
Yum tua poo (YumTua)	72.4	0.71 ± 0.47	15.75 ± 2.63	16.47 ± 2.86	1.22 ± 0.12	57	1,260	1,317	98	80
Yum ma khuea yao (YuMK)	78.9	0.51 ± 0.08	14.64 ± 1.63	15.16 ± 1.70	0.80 ± 0.06	82	2,342	2,425	128	160

[a] Data presented as mean ± SD. [b] L-ORAC and H-ORAC data expressed as micromoles of Trolox equivalents per gram (µmol of TE.g^{-1} FW). [c] TAC = L-ORAC + H-ORAC. [d] Total phenolic content data expressed as milligrams of gallic acid equivalents per gram (mg GAEg^{-1} FW).

reported that natural antioxidants retained their activity after thermal processing (Tangkanakul *et al.*, 2009).

Hydrophilic and lipophilic oxygen radical absorbance capacity per serving in foods

To make an overall evaluation of the total antioxidant capacity of a given dish, serving sizes must be considered. The values of H-ORAC per serving of all dishes were in a very wide range, from 786 to 7,106 µmol TE (Table 3). KTaePo had the highest value, followed by KPaG and KuaKG which provided 6,298 and 5,285 µmol TE, respectively. Eight foods had H-ORAC levels ranging from 2,106 to 4,828 µmol TE. The other seven foods contained H-ORAC levels of less than 2,000 µmol TE.

Because the H-ORAC makes up the majority of the TAC, KTaePo, KPaG and KuaKG could thus be regarded as good sources of antioxidants. Their TAC levels ranged from 5,487 to 7,237 µmol TE, which is comparable to common fruits in the USA such as blackberry, raspberry, strawberry and apple, whose total antioxidant capacity was found to be in the range 5,381–7,701 µmol TE per serving (Wu *et al*., 2004).

The levels of L-ORAC per serving of tested foods were in the range 57–916 µmol TE. KTai exhibited the highest values, followed by KPaG and KBaiCP with 762 and 376 µmol TE, respectively. Eleven dishes had L-ORAC levels ranging from 106 to 291 µmol TE per serving and the remainder contained 57–96 µmol TE per serving. It was found that lipophilic antioxidant was a comparatively minor component in most of these dishes (78%), with L-ORAC providing only 2–9% of TAC.

Total phenolic content per serving in foods

The TPC of all studied foods varied from 49 to 326 mg GAE per serving (Table 3). The dishes with the highest TPC were KTaePo followed by KPaG, KuaKG, KKnoon, KTai, KBaiCP and SuMaK, respectively, which exhibited TPC levels in the range 201–262 mg GAE per serving. It was found that six other tested foods—KPJaw, PChD, KNMai, OmK, PWan and YuMK—provided phenolic content in the range 104–155 mg GAE per serving. The five remaining foods—LPD, PSTor, PlaTod, PNN and YumTua—had phenolic contents ranging from 49 to 98 mg GAE per serving.

Set menu of selected foods

The present results demonstrated that nine (50%) of the selected dishes provided a TAC value per serving of more than 3,000 µmol TE; these were *kaeng kanoon on*, *kaeng phak gad jaw*, *kua kae gai*, *pad phak chiang da*, *om kai*, *kaeng nhua bai cha plu*, *kaeng tai pla*, *kaeng pa gai* and *kaeng mhoo tae po*. This means that a single serving of one of these dishes could provide the recommended daily allowance (RDA) of antioxidants (3,000–5,000 µmol TE) according to United States Department of Agriculture (2010). However, the traditional Thai eating pattern typically includes at least two dishes with rice. Nonetheless, even if a large part of the average Thai diet is composed of foods such as rice, which contain a low ORAC value, it is still easily possible to meet the RDA simply by eating traditional Thai cuisine, with its high content of vegetables, herbs and spices. For example, a set menu of Northern style KuaKG and KKnoon will provide a high level of antioxidant activity (10,183 µmol TE per serving). Similarly, when selecting LPD, which contained the lowest TAC (901 µmol TE per serving) in combination with KNMai (2,226 µmol TE per serving), this combination could increase the ORAC value to 3,127 µmol TE per serving.

CONCLUSION

This paper contributed to the body of knowledge regarding the functional properties of certain Thai foods, the details of which have been only partially documented to date. The present investigation showed that the selected Thai foods possess substantial antioxidant capacity. This antioxidative activity is derived from total phenolics, which are mainly found in the various vegetables, herbs and spices that are commonly used as ingredients in the foods studied. The results illustrated that the health benefits from these plant sources are retained in the foods after cooking. It was demonstrated that just one serving among a variety of Thai dishes provides an adequate amount of antioxidants to meet a person's recommended daily requirement, according to United States Department of Agriculture (2010). This study also provided valuable information to Thais in all parts of the country, and should encourage their consumption of a wide variety of local plant foods, many of which are often incorporated into traditional rice dishes, in order to promote improved public health.

ACKNOWLEDGEMENT

The authors are grateful to the National Research Council of Thailand for financial support.

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