Antioxidant Capacities of Plant-Derived Foods Commonly Consumed in Japan

Jun TAKEAYASHI1, Tomoyuki Oki2, Megumi TSUBOTA-UTSIGI3, Takayoshi OHKUBO4 and Jun WATANABE5,∗

1National Institute of Health and Nutrition, National Institutes of Biomedical Innovation and Health and Nutrition, Tokyo 162–8636, Japan
2Graduate School of Nutritional Sciences, Nakamura Gakuen University, Fukuoka 814–0198, Japan
3Department of Hygiene and Preventive Medicine, Iwate Medical University School of Medicine, Iwate 028–3694, Japan
4Department of Hygiene and Public Health, Teikyo University School of Medicine, Tokyo 173–8605, Japan
5Food Research Institute, National Agriculture and Food Research Organization, Ibaraki 305–8642, Japan

(Received April 11, 2019)

Summary To provide reliable data for high quality epidemiological studies examining the relationship between health and antioxidant intake from daily foods, 107 plant-derived food items (12 rice, bread and noodles, 5 potatoes and starches, 9 pulses, 6 nuts/seeds, 29 vegetables, 22 fruits, 5 mushrooms, 7 algae, and 12 beverages) were selected as commonly consumed foods in Japan based on dietary records, and their antioxidant capacities were evaluated by validated hydrophilic- and lipophilic-oxygen radical absorbance capacity (H-ORAC and L-ORAC) methods. The food items covered more than 60% of total food intake for each category on a weight basis. The H-ORAC and L-ORAC values were widely distributed at 0–210 and 0–30 μmol-Trolox equivalent/g, respectively. The foods possessing potent antioxidant capacities were found in vegetables and fruits as well as other plant-derived foods. In most foods measured, the H-ORAC values were much larger than the L-ORAC values, except for certain kinds of pulses, nuts/seeds, mushrooms, and algae. The ORAC data shown here is sufficient to accurately estimate the antioxidant intake from plant-derived foods in Japan, and should be useful in future epidemiological studies aiming to clarify the biological significance of ORAC values.

Key Words antioxidant capacity, plant-derived food, oxygen radical absorbance capacity, typical Japanese food, multi-days dietary record, food composition table, food category, antioxidant intake, antioxidant database

Numerous epidemiological studies have suggested that the intake of fruits and vegetables is negatively correlated with risk of coronary heart disease (1), stroke (2), and other diseases including cancer (3). Antioxidant compounds, such as vitamin C, vitamin E, carotenoids, and polyphenols, are thought to be promising contributors to risk reduction (4). However, recent researches suggest that antioxidant supplements fail to prevent chronic diseases (5). It is likely that antioxidants as chemical compounds and antioxidant-rich foods may have different effects on human health. Therefore, several epidemiological approaches have attempted to clarify the interaction between dietary intakes of antioxidants and health (6–8). For these epidemiological studies, reliable data on the antioxidant capacities of various foods is necessary to precisely estimate dietary intakes of antioxidants.

To date, many methods for evaluating antioxidant capacities of foods were developed. Apak et al. (9) reviewed more than 200 literature on in vitro antioxidant assays and concluded that ideal analytical method should be selective, robust, and reproducible, use conventionally available reagents and instruments, and measure a wide variety of antioxidant types including both lipophilic and hydrophilic antioxidants. The oxygen radical absorbance capacity (ORAC) method is one of the most widely used methodologies, and its main principle is the inhibition of a peroxyl radical-induced degradation of a fluorescent dye by antioxidants contained in food extracts (10). Two variations of the ORAC method have been developed to reflect the solubility of the measured antioxidants: a hydrophilic-ORAC (H-ORAC) method for water-soluble antioxidants such as vitamin C and a large part of polyphenols, and a lipophilic-ORAC (L-ORAC) method for lipid-soluble antioxidants such as vitamin E and esters of polyphenols. We have recently developed and validated reliable analytical methods for H-ORAC and L-ORAC measurements (11–13). Thus, our validated ORAC methods enable us to accumulate reliable data on antioxidant capacities of both hydrophilic- and lipophilic-antioxidants in foods.

Using the validated H-ORAC method, we reported H-ORAC values of 23 vegetables and 13 fruits (14); however, the corresponding L-ORAC values have not yet been clarified. Therefore, in this paper, we report

∗To whom correspondence should be addressed.
E-mail: nabej@affrc.go.jp
a data set of H-ORAC and L-ORAC values of selected foods measured using these reliable methods. Several studies (8, 15) indicated that vegetables and fruits as well as other plant-derived foods, such as grain products and beverages, were good sources of antioxidants. Thus, we selected 107 plant-derived foods as commonly consumed foods in Japan based on dietary records, and evaluated their antioxidant capacities, aiming to provide reliable data for high quality epidemiological studies examining the relationship between health and antioxidant intake from daily foods.

MATERIALS AND METHODS

Selection of food items. To select appropriate plant-derived foods that adequately reflect modern Japanese eating habits, previously reported multi-days dietary records data for 59 males and 60 females conducted over 1 year in Miyagi (northeastern part of Japan) were used (16, 17). For each food group, a list of foods commonly consumed in Japan was made in order of the weight-based intake, and food items were selected from the top of the list with the aim to cover more than 60% of the total food intake of each group. Some of the H-ORAC data were from our previous reports (14, 18, 19), while the remaining were newly measured.

Food sample preparation. All foodstuffs were commercially purchased from local grocery stores in Ibaraki (eastern part of Japan), Tokyo (eastern part of Japan), Kumamoto (southwestern part of Japan), or Aichi (central part of Japan). At least 2 samples were obtained in the different regions. Samples of each fresh food were purchased in each season. Detailed information regarding individual food samples, namely when and where it was obtained, is shown in Table S1 (Supplemental Online Material).

Foods other than dry foods (<ca. 5% moisture) and liquid/semi-liquid foods were promptly freeze-dried after removing inedible portions. The freeze-dried samples and naturally dried foods were pulverized using a bench blender, such as GM-200 (Retsch, Haan, Germany) and naturally dried foods were pulverized using a top blender, such as GM-200 (Retsch, Haan, Germany), and stored below 20°C until used. Liquid/semi-liquid foods were directly used as samples.

Chemicals. Sodium fluorescein and 2,2′-azobis(2-methylpropionamide) dihydrochloride (AAPH) were purchased from FUJIFILM Wako Pure Chemical Corporation (Osaka, Japan), and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was obtained from Sigma-Aldrich Japan K.K. (Tokyo, Japan). Ferulic acid was from Tokyo Chemical Industry Co., Ltd. (Tokyo, Japan). All other reagents were of analytical grade.

Food extract preparation. The pulverized food samples (ca. 1 g each) were extracted with n-hexane/dichloromethane (Hex/Dc: 1 : 1) followed by extraction with methanol/water/acetic acid (90 : 9.5 : 0.5; MWA) using a pressurized solvent extraction apparatus (Dionex ASE-350; Thermo Fisher Scientific K.K., Tokyo, Japan) according to a procedure validated in a single-laboratory (12). Liquid/semi-liquid foods, such as green tea and fruit/vegetable juices, are rich in water, and most of the chemicals in these foods are hydrophilic. Thus, each sample was extracted with MWA as described by Wu et al. (20) with slight modifications. A 50 mL screw-cap tube containing the sample (ca. 1 mL) and MWA (10 mL) was vortexed for 30 s, and sonicated for 5 min with occasionally shaking. The tube was left at rest for 5 min, and vortexed for 30 s, and left at rest for 5 min again. Then, the tube was centrifuged at 1,580 × g for 10 min, and the supernatant was collected. The pellet was further extracted with 10 mL of MWA in the same manner, and the pooled supernatant was filled up to 25 mL with MWA.

ORAC assay. The total sum of antioxidant capacities of antioxidants contained in the food extracts was evaluated by comparing the antioxidant capacity of the extracts to that of a standard antioxidant, Trolox. The results of the ORAC assay are expressed as Trolox equivalent (TE), that is, the amount of Trolox necessary to obtain the same antioxidant capacity of the sample (μmol-TE/g edible portion).

H-ORAC values, which reflect the total sum of hydrophilic antioxidants in the foods, were obtained by evaluating the antioxidant activity of the MWA extract by the previously described method ("method B" shown in the literature (13)). When H-ORAC values of the MWA extracts were less than 0.625 μmol-TE/L (lower limit of the calibration range), the results were expressed as NQ (not quantitated). An MWA solution of ferulic acid (1 mg/mL) was used as a quality control, and the H-ORAC value of this solution was confirmed each time to be 17.552 ± 1.864 μmol-TE/L (mean ± 2SE (reproducibility standard deviation) in the multi-laboratory validation study (13)).

L-ORAC values, which reflect the total sum of lipophilic antioxidants in the foods, were obtained by evaluating the antioxidant activity of the Hex/Dc extract by the previously described method ("method B" shown in the literature (11)). The Hex/Dc extract was dried under nitrogen gas flow at 30°C, and then re-dissolved in 5 mL dimethylsulfoxide (DMSO) for L-ORAC measurement. When L-ORAC values of these DMSO solutions were less than 2 μmol-TE/L (lower limit of the calibration range), the results were expressed as NQ. On the other hand, ND (not determined) was used in the case of liquid/semi-liquid foods, since Hex/Dc extracts of these foods were not prepared. A DMSO solution of Trolox (800 mg/L) was used as a positive control, and DMSO without antioxidant was used as a negative control in order to ensure the reliability of each measurement (11). In the calculation of average values of H-ORAC and L-ORAC, NQ was treated as zero.

RESULTS AND DISCUSSION

Selection of food items

We selected 107 commonly consumed plant-derived foods in Japan based on dietary surveys (12 rice, bread and noodles, 5 potatoes and starches, 9 pulses, 6 nuts and seeds, 29 vegetables, 22 fruits, 5 mushrooms, 7 algae, and 12 beverages). These foods covered 64.1–
96.5% of total food intakes of each group on a weight basis. The differences in the coverages depended on diversity of eating habits. For instance, the selected 6 nuts and seeds covered 96.5%; on the other hand, the selected 29 vegetables covered 64.1%. These data indicated that Japanese people consumed limited kinds of nuts and seeds but wide varieties of vegetables.

H-ORAC and L-ORAC values of plant-derived foods commonly consumed in Japan

All raw data on the ORAC measurements are shown in Table S1 (Supplemental Online Material). The H-ORAC and L-ORAC values are expressed as μmol-TE per gram fresh weight (μmol-TE/g) of the edible portion. Rice, bread and noodles showed the H-ORAC and L-ORAC values ranged from 1.95 to 14.55 and 0 (NQ) to 6.11 μmol-TE/g, respectively (Table S2, Supplemental Online Material). Among food items in this group, wheat flour (14.55 (10.50–18.61)) and buckwheat noodle (12.78 (11.65–13.90)) possessed potent H-ORAC values, and those possessing potent L-ORAC values were wheat flour (6.11 (3.96–8.25)) and cooked brown rice (3.14 (2.03–4.25)). Ferulic acid and its derivatives were the predominant antioxidants found in whole wheat (21), but their contribution to the antioxidant activity of wheat flour may be limited (22). Rutin is a well-known antioxidant in buckwheat, but its contribution to the antioxidant activity of common buckwheat may not be high (23). Cooked rice is a staple of the Japanese diet, with white rice (polished rice) preferred over brown rice (unpolished rice). Both the H-ORAC and L-ORAC values for brown rice were superior to those of white rice. Rice contains several phenolic antioxidants including ferulic acid (24, 25), with a portion of ferulic acid found as a lipophilic ester linked to sterol (γ-oryzanol) in rice bran (25). Rice bran is removed during the milling process, and this may be one reason for the difference in the ORAC values between white rice and brown rice.

The potatoes/starches showed the H-ORAC and L-ORAC values ranged from 0.23 to 10.10 and 0 (NQ) to 1.15 μmol-TE/g, respectively (Table S3, Supplemental Online Material). The potatoes/starches possessing potent H-ORAC values were taro (satoimo, 10.10 (7.15–14.83)) and potato (6.61 (5.53–7.72)), and those possessing potent L-ORAC values were sweet potato (1.15 (0.69–1.57)) and potato (0.86 (0.56–1.08)). Potato (26) and sweet potato (27) contain several phenolic antioxidants, predominantly chlorogenic acid. Anthocyanins are found in red or purple colored potatoes as potent antioxidants (28); however, all samples used here were white or yellow potatoes, which are common in Japan. On the other hand, taro was reported to contain no chlorogenic acid, but a variety of flavonols (29).

The pulses showed the H-ORAC and L-ORAC values ranged from 5.31 to 50.84 and 0 (NQ) to 9.68 μmol-TE/g, respectively (Table S4, Supplemental Online Material). The pulses possessing potent H-ORAC values were natto (fermented soybean, 50.84 (38.19–63.49)) and boiled soybean (16.23 (12.30–20.16)), and those possessing potent L-ORAC values were abura-age (deep-fried tofu, 9.68 (3.72–15.64)) and natto (5.08 (4.61–5.54)). Isoflavones, such as daidzein and genistein, are well-known antioxidants in soybean (30). In addition, several polyphenols, such as gallic acid, chlorogenic acid, and trans-cinnamic acid, were reported to be contained in considerable amounts (31). The H-ORAC value of natto (fermented soybean) was about 3 fold greater than that of boiled soybean, despite the fact that the isoflavone contents of natto and boiled soybean were nearly the same (32). Thus, some antioxidants may be generated during the fermentation process of natto. Abura-age (deep-fried tofu) showed the highest L-ORAC value in the tested pulses. The L-ORAC values of tofu were not high, suggesting that antioxidants contained in frying oil may contribute to the L-ORAC activity.

The nuts and seeds showed the H-ORAC and L-ORAC values ranged from 13.17 to 65.82 and 2.55 to 23.68 μmol-TE/g, respectively (Table S5, Supplemental Online Material). Nuts and seeds showed relatively high H- and L-ORAC values as compared to all of the foods investigated. It should be noted, however, that all of the nuts and seeds investigated were dry foods, and thus all components including antioxidants should be condensed as compared to raw foods. The nuts/seeds possessing potent H-ORAC value was walnut (65.82 (63.82–67.81)), and those possessing potent L-ORAC value was sesame seed (23.68 (12.42–34.94)). Walnut contains a high level of phenolic compounds including hydrolysable tannins such as pedunculagin (33). Sesame contains a high amount of lignans, such as sesamin, sesamolin, and sesamol (34, 35). Among them, sesamol, which is a thermal degradation product of sesamin, is reported to be a lipophilic antioxidant (35), and thus may be a potent contributor to the L-ORAC activity.

The vegetables showed the H-ORAC and L-ORAC values ranged from 1.66 to 66.07 and 0.17 to 7.92 μmol-TE/g, respectively (Table S6, Supplemental Online Material). The raw vegetables possessing potent H-ORAC values were edible burdock (66.07 (52.17–77.19)), garland chrysanthemum (46.44 (17.80–96.03)), flower of turnip rape (44.48), eggplant (27.65 (15.55–38.79)), and East Indian lotus root (22.78 (19.57–27.18)), and those possessing potent L-ORAC values were spinach (7.92 (5.45–13.87)), flower of turnip rape (7.82), bracken (7.07 (5.36–8.77)), garland chrysanthemum (6.78 (4.43–9.83)), and Chinese chive (4.52 (3.59–5.45)). Edible burdock is reportedly rich in caffeoylquinic acids and their derivatives and lignans, which are main contributors to its high H-ORAC value (36). Anthocyanins and catechins are major hydrophilic antioxidants in eggplant and East Indian lotus root, respectively (36, 37). Lutein may contribute to the high L-ORAC value of spinach, since it has been reported that lutein was a major contributor to the L-ORAC value of Japanese parsley and that its content was positively correlated with the L-ORAC value (38).

The fruits showed the H-ORAC and L-ORAC values ranged from 1.59 to 30.72 and 0 (NQ) to 1.84 μmol-TE/g, respectively (Table S7, Supplemental Online Material). The raw fruits possessing potent H-ORAC values...
were strawberry (30.72 (22.45–36.30)), peach (23.28 (17.96–28.59)), Valencia orange (20.13 (18.92–21.21)), grapefruit (18.13 (15.89–21.28)), and apple (18.02 (16.89–19.14)), and these possessing potent L-ORAC values were strawberry (1.84 (1.21–2.47)), banana (1.14 (1.08–1.19)), and peach (0.71 (0.68–0.73)). Anthocyanins were potent H-ORAC contributors in strawberry, but other higher polar antioxidants including vitamin C also made significant contributions (39). Procyanidins were predominant phenolic compounds found in peach (40), and glucosides of flavonones, such as hesperetin and naringenin, were abundant in orange and grapefruit (41). Grape contains much higher phenolic compounds in the seed and skin than in the pulp (42), and this may be the reason why the H-ORAC value for raw grape, measured after removing the skin and seed as non-edible portions, was lower than that for grape juice, which was made from the
whole fruit including the skin and seed.

The mushrooms showed the H-ORAC and L-ORAC values ranged from 2.86 to 24.99 and 1.28 to 15.17 μmol-TE/g, respectively (Table S8, Supplemental Online Material). The H- and L-ORAC values of raw mushrooms were not high as compared to all other foods investigated. The relatively high ORAC value of dried shiitake mushrooms (H-ORAC: 24.99 (24.68–25.29), L-ORAC: 15.17 (9.68–20.66)) could be explained by the concentration of antioxidants as a result of moisture evaporation. Ergothioneine is a specific hydrophilic antioxidant found in various genera of mushrooms; however, it may not be a major contributor to H-ORAC values (43). There were no flavonoids, but several phenolic acid derivatives in Portuguese wild mushroom species, and p-hydroxybenzoic acid was reported to be a major compound in most cases (43).

The algae showed the H-ORAC and L-ORAC values ranged from 0.56 to 209.79 and 0.66 to 29.88 μmol-TE/g, respectively (Table S9, Supplemental Online Material). The H-ORAC value of toasted purple laver (yaki-nori) was very high (209.79 (161.19–258.38)) as compared to all other foods investigated. It should be noted that all of the investigated algae were dry foods, and thus all components including antioxidants should be condensed as compared to raw foods. It was reported that heat treatment of purple laver extract resulted in the production of a dehydrated porphyra-334, which showed potent antioxidant activity (44). Phlorotannins, major antioxidants specific to brown algae including kombu, exist in a variety of structures according to the degree of polymerization of phloroglucinol units (45). Phlorotannins having a high polymerization degree seem to be lipophilic, whereas those having a low polymerization degree seem to be hydrophilic. This might be the reason why, in the case of ma-kombu, the H-ORAC value was higher than the L-ORAC value, and conversely, in the case of Mitsubishi-kombu, the L-ORAC value was higher than the H-ORAC value.

The beverages showed the H-ORAC values ranged from 0 (NQ) to 36.57 (Table S10, Supplemental Online Material). Their L-ORAC values were not determined because Hex/Dec extracts for the L-ORAC measurements were not prepared. The beverages possessing potent H-ORAC values were coffee (coffee, infusion: 35.80 (33.47–38.12)), wine (29.21 (25.27–33.15)), and tea (ban-cha: 15.04 (8.22–21.85), sen-cha: 9.60 (8.96–10.23)). Coffee contains hydroxycinnamic acids including chlorogenic acid (46). Anthocyanins are well known as antioxidants in red wine; however, other phenolics, such as phenolic acids and catechins, are also found in red wine (47). Catechins are major antioxidants contained in teas, and the amount and proportion of catechins depend on various conditions, such as the type of tea, cultivar, agronomic conditions, leaf age, and degree of fermentation (48, 49).

Overview of the antioxidant capacities of plant-derived foods commonly consumed in Japan

In this study, we measured the H-ORAC and L-ORAC values of 107 plant-derived foods commonly consumed in Japan. Figure 1 shows box-plots for the ORAC values of the food groups. The H-ORAC and L-ORAC values were widely distributed from 0–210 and 0–30 μmol-TE/g, respectively. The foods possessing potent antioxidant capacities were found in vegetables and fruits as well as in other plant-derived foods. In the majority of foods measured, the H-ORAC values were much larger than the L-ORAC values, except for certain kinds of pulses (abura-age), nuts/seeds (cashew nut and sesame seed), mushrooms (bunashimeji), and algae (Mitsubishi-kombu, hijiki, and wakame). Relatively high H-ORAC and L-ORAC values were observed in nuts/seeds and algae. One possible reason for this was that a large number of the samples of those food groups were dry foods, whereas a large number of the samples of the other food groups were raw foods. Thus, if the ORAC values were compared on a dry mass basis, the rank order of food groups would change. However, the purpose of our study was not to identify plant-derived foods rich in antioxidants, but to provide reliable data for high quality epidemiological studies concerning the relationship between health and antioxidant intake from daily foods. Therefore, the selection of raw foods versus dry foods was dependent on their frequency in the diet records of epidemiological studies. In any event, it should be noted that the biological significance of the ORAC values presented here is unknown, and future epidemiological studies are needed to demonstrate the benefits.

Issues and perspectives of this study

The human body is exposed to a variety of oxidative stresses (50); thus an “effective antioxidant” may depend on the situation and nature of the stress (51). There are several analytical methods used to measure the antioxidant capacities of foods (9). These methods evaluate only one aspect of the antioxidant potential of foods, and thus have both advantages and disadvantages. Therefore, it is an important but difficult issue to select an optimal analytical method. At present, no definitive answer to this question is available from the viewpoint of biological significance. However, from the viewpoint of the reliability of the analytical method, we selected the validated H-ORAC and L-ORAC methods.

Our final goal is to provide reliable data for high quality epidemiological studies. In this research, all foodstuffs were purchased in more than 2 different regions in Japan, and fresh foods were obtained in several seasons. We previously reported that antioxidant capacities of commonly consumed 23 vegetables and 13 fruits measured by validated H-ORAC method were roughly consistent with values on an antioxidant database in the public domain (14). Thus, we believe that antioxidant capacities in this report possess enough reliable for the future epidemiological studies. We measured 107 commonly consumed plant-derived foods, which covered 64.1–96.5% of total food intake of each group on a weight basis. These coverages are strictly valid only in the case of the supposed population in Miyagi. Notably, a future epidemiological study possibly includes additional food items according to dietary habits of the research population to adequately estimate antioxidant
intakes. In this case, reliable ORAC data can be added to our data without compromising total reliability by using the same validated ORAC methods (11, 13).

The major limitation of this study was the lack of information regarding the contributors to antioxidant capacity, in other words, which specific compounds were the main contributors. However, this is a very general issue in studies focusing on food antioxidant activities. Many studies have compared in vitro antioxidant activities to total polyphenol contents measured by the Folin-Ciocalteu method; however, few studies have determined the degree of contribution of specific antioxidants to in vitro antioxidant capacities. On the other hand, several studies have reported specific antioxidants contained in individual foods. However, in those cases, only antioxidants of interest were measured, and thus, it is unclear if other potent antioxidants were contained. Therefore, the determination of specific antioxidants and their contributions to net antioxidant activity should be studied in individual food extracts in future work.

Disclosure of state of COI
There are no conflicts of interest to be declared.

Acknowledgments
This study was supported by a Grant-in-Aid ‘A Scheme to Revitalize Agriculture and Fisheries in Disaster Area through Deploying Highly Advanced Technology’ from the Ministry of Agriculture, Forestry and Fisheries of Japan, and JSPS KAKENHI (Grants-in-Aid for Scientific Research; Grant Number 26282200 and 23700947) from the Ministry of Education, Culture, Science, and Technology, Japan.

Supporting information
Supplemental Online Material is available on J-STAGE.

REFERENCES
1) Dauchet L, Amouyel P, Hercberg S, Dallongeville J. 2006. Fruit and vegetable consumption and risk of coronary heart disease: a meta-analysis of cohort studies. J Nutr 136: 2588–2593.
2) He FJ, Nowson CA, MacGregor GA. 2006. Fruit and vegetable consumption and stroke: Meta-analysis of cohort studies. Lancet 367: 320–326.
3) Wang X, Ouyang Y, Liu J, Zhu M, Zhao G, Bao W, Hu FB. 2014. Fruit and vegetable consumption and mortality from all causes, cardiovascular disease, and cancer: systematic review and dose-response meta-analysis of prospective cohort studies. Br Med J 349: g4490.
4) Fang Y-Z, Yang S, Wu G. 2002. Free radicals, antioxidants, and nutrition. Nutrition 18: 872–879.
5) Bjelakovic G, Nikolova D, Gluud C. 2014. Antioxidant supplements and mortality. Curr Opin Clin Nutr 17: 40–44.
6) Kobayashi S, Murakami K, Sasaki S, Uemishi K, Yamasaki M, Hayabuchi H, Goda T, Oka J, Bubu K, Ohki K, Watanabe R, Sugiyama Y. 2012. Dietary total antioxidant capacity from different assays in relation to serum C-reactive protein among young Japanese women. Nutr J 11: 91.
7) Stedile N, Canuto R, Col CD De, Sene JS De, Stolfo A, Wisintainer GNDS, Henriques JAP, Salvador M. 2016. Dietary total antioxidant capacity is associated with plasmatic antioxidant capacity, nutrient intake and lipid and DNA damage in healthy women. Int J Food Sci Nutr 67: 479–488.
8) Valtueña S, Pellegrini N, Franzini L, Bianchi MA, Ardigò D, Río D Del, Piatti P, Scanzina E, Zavaroni I, Brighenti F. 2008. Food selection based on total antioxidant capacity can modify antioxidant intake, systemic inflammation, and liver function without altering markers of oxidative stress. Am J Clin Nutr 87: 1290–1297.
9) Apak R, Özürek M, Gürüli K, Çağanoğlu E. 2016. Antioxidant activity/capacity measurement. 1. Classification, physicochemical principles, mechanisms, and electron transfer (ET)-based assays. J Agric Food Chem 64: 997–1027.
10) Prior RL, Wu X, Schaich K. 2005. Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. J Agric Food Chem 53: 4290–4302.
11) Watanabe J, Oki T, Takebayashi J, Yada H, Wagaki M, Takano-Ishikawa Y, Yasui A. 2016. Improvement and interlaboratory validation of the lipophilic oxygen radical absorbance capacity: Determination of antioxidant capacities of lipophilic antioxidant solutions and food extracts. Anal Sci 32: 171–175.
12) Watanabe J, Oki T, Takebayashi J, Takano-Ishikawa Y. 2014. Extraction efficiency of hydrophilic and lipophilic antioxidants from lyophilized foods using pressurized liquid extraction and manual extraction. J Food Sci 79: C1665–C1671.
13) Watanabe J, Oki T, Takebayashi J. Yamasaki K, Takano-Ishikawa Y, Hino A, Yasui A. 2012. Method validation by interlaboratory studies of improved hydrophilic oxygen radical absorbance capacity methods for the determination of antioxidant capacities of antioxidant solutions and food extracts. J Agric Food Chem 60: 159–165.
14) Takebayashi J, Oki T, Watanabe J, Yamasaki K, Chen J, Sato-Furukawa M, Tsubota-Utsugi M, Taku K, Goto K, Matsumoto T, Ishimi Y. 2013. Hydrophilic antioxidant capacities of vegetables and fruits commonly consumed in Japan and estimated average daily intake of hydrophilic antioxidants from these foods. J Food Comp Anal 29: 25–31.
15) Rautiainen S, Serafini M, Morgenstern R, Prior RL, Wolk A. 2008. The validity and reproducibility of food frequency questionnaire-based total antioxidant capacity estimates in Swedish women. Am J Clin Nutr 87: 1247–1253.
16) Ogawa K, Tsubono Y, Nishino Y, Watanabe Y, Ohkubo T, Watanabe T, Nakatsuka H, Takahashi N, Kawamura M, Tsuji I, Hisamichi S. 2003. Validation of a food-frequency questionnaire for cohort studies in rural Japan. Public Health Nutr 6: 147–157.
17) Tsubono Y, Ogawa K, Watanabe Y, Nishino Y, Tsuji I, Watanabe T, Nakatsuka H, Takahashi N, Kawamura M, Hisamichi S. 2001. Food frequency questionnaire as a screening test. Nutr Cancer 39: 78–84.
18) Takebayashi J, Oki T, Chen J, Sato M, Matsumoto T, Taku K, Tsubota-Utsugi M, Watanabe J, Ishimi Y. 2010. Estimated average daily intake of antioxidants from typical vegetables consumed in Japan: A preliminary study. Biosci Biotechnol Biochem 74: 2137–2140.
19) Wukagi M, Watanabe J, Takano-Ishikawa Y. 2014. Effects of producing area and harvest season on anti-
oxidant capacities of spinach, komatsuna, tomato, and cucumber. Rep Natl Food Res Inst 78: 65–71.

20) Wu X, Beecher GR, Holden JM, Haytowitz DB, Gebhardt SE, Prior RL. 2004. Lipophilic and hydrophilic antioxidant capacities of common foods in the United States. J Agric Food Chem 52: 4026–4037.

21) Okarter N, Liu CS, Sorrells ME, Liu RH. 2010. Phytochemical content and antioxidant activity of six diverse varieties of whole wheat. Food Chem 119: 249–257.

22) Anson NM, Berg R Van Den, Havenaar R, Bast A, Hae- nen GRMM. 2008. Ferulic acid from aleurone determines the antioxidant potency of wheat grain (Triticum aestivum L.). J Agric Food Chem 56: 5589–5594.

23) Morishita T, Yamaguchi H, Degi K. 2007. The Contribution of polyphenols to antioxidative activity in common buckwheat and tartary buckwheat grain. Plant Prod Sci 10: 99–104.

24) Tian S, Nakamura K, Kayahara H. 2004. Analysis of phenolic compounds in white rice, brown rice, and germinated brown rice. J Agric Food Chem 52: 4808–4813.

25) Xu Z, Godber JS. 1999. Purification and Identification of components of γ-oryzanol in rice bran oil. J Agric Food Chem 47: 2724–2728.

26) Evers D, Deußer H. 2012. Potato antioxidant compounds: Impact of cultivation methods and relevance for diet and health. In: Nutrition, Well-Being and Health (Bouayed J, Bohn T, eds), p 95–118. InTech, London.

27) Teow CC, Truong V D, McFeeters RF, Thompson RL, Pecota KV, Yencho GC. 2007. Antioxidant activities, phenolic and β-carotene contents of sweet potato genotypes with varying flesh colours. Food Chem 103: 829–838.

28) Oki T, Masuda M, Furuta S, Nishiba Y, Terahara N, Suda I. 2002. Involvement of anthocyanins and other phenolic compounds in radical-scavenging activity of purple-fleshed sweet potato cultivars. J Food Sci 67: 1752–1756.

29) Champagne A, Hilbert G, Legendre L, Lebot V. 2011. Diversity of anthocyanins and other phenolic compounds among tropical root crops from Vanuatu, South Pacific. J Food Comp Anal 24: 315–325.

30) Wang H, Murphy PA. 1994. Isolavone content in commercial soybean foods. J Agric Food Chem 42: 1666–1673.

31) Xu B, Chang SKC. 2008. Total phenolics, phenolic acids, isoflavones, and anthocyanins and antioxidant properties of yellow and black soybeans as affected by thermal processing. J Agric Food Chem 56: 7165–7175.

32) Toda T, Sakamoto A, Takayama ME, Liu RH. 2010. Changes in isolavone compositions of soybean foods during cooking process. Food Sci Technol Res 6: 314–319.

33) Shimoda H, Tanaka J, Kikuchi M, Fukuda T, Ita H, Hatano T, Yoshida T. 2008. Walnut polyphenols prevent liver damage induced by carbon tetrachloride and D-galactosamine: Hepatoprotective hydroxyzable tannins in the kernel pellicles of walnut. J Agric Food Chem 56: 4444–4449.

34) Dar AA, Arumugan N. 2013. Lignans of sesame: Purification methods, biological activities and biosynthesis—A review. Bioorg Chem 50: 1–10.

35) Mahendra Kumar C, Singh SA. 2015. Bioactive lignans from sesame (Sesamum indicum L.): evaluation of their antioxidant and antibacterial effects for their applications. J Food Sci Technol 52: 2934–2941.

36) Liu J, Cai YZ, Wong RNS, Lee CKF, Tang SCW, Sze SCW, Tong Y, Zhang Y. 2012. Comparative analysis of cafeoylquinic acids and lignans in roots and seeds among various burdock (Arctium lappa) genotypes with high antioxidant activity. J Agric Food Chem 60: 4067–4075.

37) Jing P, Qian B, Zhao S, Qi X, Ye L, Mónica GM, Wang X. 2015. Effect of glycosylation patterns of Chinese egg-plant anthocyanins and other derivatives on antioxidant effectiveness in human colon cell lines. Food Chem 172: 183–189.

38) Ogita T, Manaoris RV, Wakagi M, Oki T, Takano Ishikawa Y, Watanabe J. 2016. Identification and evaluation of antioxidants in Japanese parsley. Int J Food Sci Nutr 67: 431–440.

39) Tulipani S, Mezzetti B, Capocasa F, Bombadre S, Beckwilder J, Ves CHR De, Capanoghlu E, Boyc A, Battino M. 2008. Antioxidants, phenolic compounds, and nutritional quality of different strawberry genotypes. J Agric Food Chem 56: 696–704.

40) Tomás-Barberán FA, Gil MI, Cremin P, Waterhouse AL, Hess-Pierce B, Kader AA. 2001. HPLC-DAD-ESIMS analysis of phenolic compounds in nectarines, peaches, and plums. J Agric Food Chem 49: 4748–4760.

41) Kawai S, Tomono Y, Kate E, Ogawa K, Yano M. 1999. Quantification of flavonoid constituents in citrus fruits. J Agric Food Chem 47: 3565–3571.

42) Sandhu AK, Gu L. 2010. Antioxidant capacity, phenolic content, and profiling of phenolic compounds in the seeds, skin, and pulp of vitis rotundifolia (Muscadine grapes) as determined by HPLC-DAD-ESI-MSn. J Agric Food Chem 58: 4681–4692.

43) Dubost NJ, Ou B, Beelman RB. 2007. Quantification of polyphenols and ergothioneine in cultivated mushrooms and correlation to total antioxidant capacity. Food Chem 105: 727–735.

44) Yoshiki M, Tsuge K, Tsuruya T, Kogane-maru K, Sumi T, Matsui T, Matsumoto K. 2009. Production of new antioxidant compound from mycosporine-like amino acid, porphyra-334 by heat treatment. Food Chem 113: 1127–1132.

45) Tierney MS, Croft AK, Hayes M. 2010. A review of anti-hypertensive and antioxidant activities in macroalgae. Bot Mar 53: 387–408.

46) Moreira DP, Monteiro MC, Ribeiro-Alves M, Donangelo CM, Trugo LC. 2005. Contribution of chlorogenic acids to the iron-reducing activity of coffee beverages. J Agric Food Chem 53: 1399–1402.

47) Ghiselli A, Nardini M, Baldi A, Scaccini C. 1998. Anti-oxidant activity of different phenolic fractions separated from an Italian red wine. J Agric Food Chem 46: 361–367.

48) Carloni P, Tiano L, Padella L, Bacchetti T, Customo C, Kay A, Damiani E. 2013. Antioxidant activity of white, green and black tea obtained from the same tea cultivar. Food Res Int 53: 900–908.

49) Khokhar S, Magnusdottir SGM. 2002. Total phenol, catechin, and caffeine contents of teas commonly consumed in the United Kingdom. J Agric Food Chem 50: 565–570.

50) Selfrid HE, Anderson DE, Fisher EI, Milner JA. 2007. A review of the interaction among dietary antioxidants and reactive oxygen species. J Nutr Biochem 18: 567–579.

51) Niki E. 2010. Assessment of antioxidant capacity in vitro and in vivo. Free Radic Bio Med 49: 503–515.