

Primary Screening of Antioxidant Activity, Total Polyphenol Content, Carotenoid Content, and Nutritional Composition of 13 Edible Flowers from Japan

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ABSTRACT: Thirteen edible flowers, which are used as food ingredients in Japan, were evaluated as possible sources of antioxidants and biological compounds. The nutritional composition, total polyphenol content (TPC), carotenoid content, and antioxidant activity of the edible flowers were determined based on the oxygen radical absorbance capacity (ORAC). Water was the main constituent of edible flowers, and carbohydrates were the primary macronutrients. The TPC of the edible flowers varied from 1.47 to 13.08 mg gallic acid equivalent/g fresh weight (FW). Carotenoids, including β -carotene and β -cryptoxanthin, were detected mainly in the edible flowers with petal colors ranging from yellow to orange, but especially in primula and cosmos yellow flowers, which have yellow petals. The ORAC value of the hydrophilic extract (HORAC) of edible flowers was higher than the ORAC value of the lipophilic extract (LORAC). The total antioxidant capacity (TAC) ranged from 33.03 to 320.36 μ M Trolox equivalent/g FW. The highest TPC and TAC were observed in cosmos yellow flowers. On the basis of Pearson's correlation coefficient, the HORAC value and the TPC of the analyzed edible flowers were highly correlated ($r=0.736$). This preliminary study indicates that edible flowers are a potential source of antioxidants, and the addition of edible flowers to the human diet may be associated with health benefits.

Keywords: edible flower, ORAC, polyphenols, β -carotene, β -cryptoxanthin

INTRODUCTION

Edible flowers have a long history in many regions (e.g., China, other parts of Asia, and Europe) of use as food ingredients and in traditional medicines (Mlcek and Rop, 2011). In ancient Rome, *Calendula officinalis* was used as a soup ingredient, as seasoning for salads and meat dishes, and as a coloring agent in butter. In Asia, roses have been used in wine and as an ingredient in Chinese barbecues and sauces (Kirker and Newman, 2016). More recently, there has been increasing interest in edible flowers among consumers and chefs because of their use as a food ingredient that enhances the nutrition, appearance, taste, and texture of dishes (Kelley et al., 2001; Fernandes et al., 2017). Edible flowers contain diverse secondary metabolites such as polyphenols, anthocyanins, flavonoids, carotenoids, and vitamin E (Kaisoon et al., 2011; Lee et al., 2011; Zhang et al., 2011; Pires et al., 2017). The bioactive compounds of edible flowers exhibit various activities, including anti-allergic and anti-inflamma-

tory activities as well as anti-proliferative effects against cancer cells (Lee et al., 2011; Kaisoon et al., 2012; Arya et al., 2014). Moreover, the compounds within edible flowers may also function as antioxidants (Kaisoon et al., 2011; Lee et al., 2011; Yin et al., 2015). The importance of including antioxidants in the human diet has been investigated in many epidemiological studies, which indicate antioxidants can counteract the effects of reactive oxygen species (ROS) and free radicals (Arts and Hollman, 2005). Excessive amounts of ROS and free radicals, which are by-products of normal metabolism, can damage DNA, proteins, lipids, and other biological molecules, thereby contributing to the pathogenesis of many diseases (e.g., ischemic heart disease, stroke, cancers, diabetes mellitus, Alzheimer's disease, and neurodegenerative diseases) (Aruoma, 1998; Pham-Huy et al., 2008; Pisoschi and Pop, 2015). Plant polyphenols, which are natural antioxidants, are considered to have protective effects against diseases such as cardiovascular diseases, cancers, and diabetes mellitus (Arts and Hollman, 2005; Scalbert et al., 2005).

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In addition to polyphenols, carotenoids are also potential antioxidants because of their ability to quench singlet oxygen (Stahl and Sies, 2003; Mehta and Gowder, 2015). Moreover, an added benefit of some carotenoids, including β -carotene and β -cryptoxanthin, is that they can be converted to vitamin A. The consumption of foods containing β -carotene is reportedly inversely related to the risk of cardiovascular diseases and certain cancers (Rao and Rao, 2007). Furthermore, β -cryptoxanthin influences bone formation and prevents bone loss under *in vitro* conditions as well as in ovariectomized mice (Yamaguchi, 2012; Ozaki et al., 2015).

The objective of this study was to confirm that edible flowers are a source of biological compounds with antioxidant effects that may be beneficial for human health. Various cultivated edible flowers, which have recently been widely used as food ingredients in Japan, were used as the study materials. The nutritional composition, total polyphenol content (TPC), carotenoid content, and antioxidant activity were determined. Although several studies have demonstrated the antioxidant activity of edible flowers, diverse methods were used, with each reflecting different antioxidant properties. In this study, we used the oxygen radical absorbance capacity (ORAC), which is relevant to the human biological system (Prior, 2015), for estimating antioxidant activities.

MATERIALS AND METHODS

Reagents

The following reagents were purchased from Wako Pure Chemical Industries, Ltd. (Osaka, Japan): 2,2'-azobis(2-amidinopropane) dihydrochloride (AAPH), acetonitrile, methanol, methyl *tert*-butyl ether (MTBE), methyl- β -cyclodextrin, β -carotene, trifluoroacetic acid (TFA), and pyrogallol. Fluorescein and Folin-Ciocalteu reagent were purchased from Nacalai Tesque, Inc. (Kyoto, Japan). Ad-

ditionally, 6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox) was purchased from Sigma-Aldrich Co. (St. Louis, MO, USA), and β -cryptoxanthin was purchased from Funakoshi Co., Ltd. (Tokyo, Japan).

Materials

The edible parts of 13 types of edible flowers were analyzed. The botanical information is presented in Table 1. Rose 'Purple Fragrance' and rose 'Yves Piaget' flowers were collected in July 2015 by Bellebara Engei, Aichi, Japan. The cosmos yellow, Diana elegance pink, Diana pink, torenia blue, and torenia violet flowers were collected in August 2016, whereas begonia, nasturtium, pentas, petunia, primula, and snapdragon flowers were collected in November 2016 by Toyohashi Onshitsu Engei JA, Aichi, Japan. All materials were frozen in liquid nitrogen and kept at -80°C until analysis.

Proximate analysis

The crude protein content was determined according to the Kjeldahl method, with a conversion factor of 6.25 (digestion unit: K-435; distillation unit: K-315; Büchi, Flawil, Switzerland). The crude fat content was determined by extracting a specific amount of edible flower with diethyl ether for 8 h by the Soxhlet apparatus. The ash content was determined by incineration at 550°C (ROP-001; AS ONE Corporation, Osaka, Japan). The moisture content was analyzed with an FD-600 moisture determination balance (Kett, Tokyo, Japan). The carbohydrate content was calculated by subtracting the crude protein, crude fat, ash, and moisture contents from one hundred. The results were expressed as g/100 g fresh weight (FW).

Extraction of hydrophilic compounds

Hydrophilic compounds were extracted according to a modified version of a method described by Kaisoon et al. (2012). Approximately 1 g sample was treated with a 20-fold volume of a solution comprising ethanol : MilliQ wa-

Table 1. Botanical information of analyzed edible flowers

Scientific name	Common name	Colors
<i>Begonia</i> × <i>semperflorens-cultorum</i> hort.	Begonia	Pink
<i>Cosmos sulphureus</i> cav.	Cosmos yellow	Yellow
<i>Lathyrus odoratus</i>	Diana elegance pink	Pink
	Diana pink	Pink
<i>Tropaeolum majus</i>	Nasturtium	Orange
<i>Pentas lanceolata</i>	Pentas	Red
<i>Petunia</i> × <i>hybrida</i>	Petunia	Pink
<i>Primula</i> × <i>polyantha</i>	Primula	Yellow
<i>Rosa</i> 'Purple Fragrance'	Rose 'Purple Fragrance'	Pink
<i>Rosa</i> 'Yves Piaget'	Rose 'Yves Piaget'	Pink
<i>Antirrhinum majus</i>	Snapdragon	Mixed color of yellow, white, pink, and purple
<i>Torenia fournieri</i>	Torenia blue	Blue
	Torenia violet	Violet

ter : 0.1% TFA (80:19:1; v/v/v). The resulting mixture was shaken for 2 h at room temperature (25°C), after which it was centrifuged at 1,000 g for 10 min, and the supernatant was collected. The extraction was repeated twice. The combined supernatant was evaporated under reduced pressure at 40°C (NVC-1100; EYELA, Tokyo, Japan). The concentrated extract was freeze-dried to obtain a lyophilized powder (VA-500F; TAITEC, Saitama, Japan).

Extraction of lipophilic compounds

Lipophilic compounds were extracted according to a modified version of a method described by Prior et al. (2003). The freeze-dried edible flower (0.1 g) was treated twice with 10 mL hexane. The resulting extract was dried in a nitrogen atmosphere.

TPC

The TPC of the hydrophilic extract was determined with the Folin-Ciocalteu assay. A 200- μ L aliquot of the hydrophilic extract solution, re-dissolved in MilliQ water, was mixed with 1 mL 10% Folin-Ciocalteu reagent prepared in MilliQ water. The mixture was vortexed and incubated at room temperature for 4 min, after which 800 μ L 7.5% Na₂CO₃ was added. Following a 60-min incubation, the absorbance of the mixture (at 765 nm) was measured with a spectrophotometer (UV-1800; Shimadzu, Kyoto, Japan). The results were expressed as gallic acid equivalent (GAE)/g FW.

Carotenoid content

Carotenoids, including β -carotene and β -cryptoxanthin, were extracted from the edible flowers by saponification and were quantified by high-performance liquid chromatography (HPLC). Pyrogallol (0.6 g) and 15 mL ethanol were added to 0.5 g sample, which was then homogenized for 30 s. Next, the sample was saponified by adding 2.5 mL 60% KOH, and the mixture was shaken (120 rpm) for 30 min at 56°C. The saponified sample was subsequently cooled in water for 5 min, and then 10 mL of each 1% NaCl and hexane were added. The mixture was vortexed for 1 min, centrifuged at 1,000 g for 10 min, and the supernatant was collected. The hexane extraction was completed four times. The combined hexane extract was evaporated under reduced pressure at 40°C. The resulting fraction was re-dissolved in MTBE containing 1% butylated hydroxytoluene and 0.1% ammonium acetate. Carotenoids were quantified using the HPLC system (Shimadzu) coupled with the YMC carotenoid-S3 column (4.6 mm \times 100 mm, YMC Co., Ltd., Kyoto, Japan) and an UV-Vis detector at 450 nm. The column temperature was 40°C. The mobile phases were A (methanol : acetonitrile : water, 7:1:2; v/v/v) and B (MTBE : methanol, 9:1; v/v). The gradient elution was completed as follows: at 0.1

min, B=22.5%; at 19.9 min, B=80%; and at 20 min, B=22.5%. The flow rate was 1.0 mL/min. The carotenoid content of the edible flowers was calculated by comparing the retention times and peak areas between the samples and the carotenoid standard.

ORAC of the hydrophilic extract (HORAC)

The protocol for the ORAC assay was kindly provided by the Food Research Institute, National Agriculture and Food Research Organization, Ibaraki, Japan. Briefly, the hydrophilic extract and Trolox were prepared in a solution comprising of 90 mL of 75 mM phosphate buffer (pH 7.4) and 10 mL of a solution comprising methanol : MilliQ water : acetic acid (90:9:1; v/v/v). Fluorescein and AAPH solutions were prepared in phosphate buffer. A 35- μ L aliquot of the hydrophilic extract solution, Trolox, or a blank solution was added to individual wells of a 96-well black microplate. Next, 115 μ L fluorescein solution (110.7 nM) was added to each well, and the microplate was incubated at 37°C for 10 min. After adding 50 μ L AAPH solution (31.7 mM), the fluorescence was recorded every 2 min for 90 min using a microplate reader (MTP-800 AFC; Corona Electric Co., Ltd., Ibaraki, Japan) at excitation and emission wavelengths of 490 nm and 530 nm, respectively. The ORAC value was calculated using the following equation:

Area under curve (AUC) =

$$\frac{(0.5 \times f_{8 \text{ min}} + f_{10 \text{ min}} + f_{12 \text{ min}} + f_{14 \text{ min}} + \dots + f_{88 \text{ min}}) + (0.5 \times f_{90 \text{ min}})}{f_{0 \text{ min}} \times 2}$$

net AUC = AUC_{Trolox or sample} - AUC_{blank}

where $f_{8 \text{ min}}$ is fluorescence intensity at 8 min, $f_{10 \text{ min}} + f_{12 \text{ min}} + f_{14 \text{ min}} + \dots + f_{88 \text{ min}}$ is sum of the fluorescence intensities from 10 min to 88 min, $f_{90 \text{ min}}$ is fluorescence intensity at 90 min, and $f_{0 \text{ min}}$ is fluorescence intensity after adding the fluorescein solution.

The ORAC value was calculated based on the calibration curve for the net AUC of Trolox at different concentrations. The results were expressed as μ M Trolox equivalent (TE)/g FW.

ORAC of the lipophilic extract (LORAC)

The lipophilic extract was re-suspended in 250 μ L acetone, and the LORAC assay was carried out as described by Batista et al. (2016). The samples and a Trolox standard were diluted with 7% methyl- β -cyclodextrin in 50% acetone. The fluorescein and AAPH solutions were dissolved in 75 mM phosphate buffer (pH 7.4). After adding 120 μ L fluorescein (96 nM) to wells containing 20 μ L diluted sample or Trolox, the microplate was incubated at 37°C for 10 min. Following the addition of 120 μ L AAPH

solution (31.7 mM), fluorescence was recorded as described for the HORAC analysis. Trolox was used as the reference standard. The results were expressed as $\mu\text{M TE/g FW}$. The experiment was repeated three times for begonia, primula, petunia, and nasturtium, but two times for the other edible flowers. The total antioxidant capacity (TAC) was calculated by addition of HORAC and LORAC value.

Statistical analysis

Data were analyzed using IBM SPSS Statistics (version 25; IBM Corp., Armonk, NY, USA). The correlation between the HORAC value and the TPC was determined based on Pearson's correlation coefficient.

RESULTS AND DISCUSSION

Hydrophilic extraction yield of thirteen edible flowers

The hydrophilic extraction yield of thirteen edible flowers is presented in Table 2. The percentage yield ranged from 1.70 to 12.87, with the highest yield observed for Diana pink flowers followed by Diana elegance pink and snapdragon flowers (10.65 and 10.10%, respectively).

Nutritional composition of edible flowers

The nutritional composition of edible flowers (i.e., crude protein, crude fat, ash, moisture, and carbohydrates) is presented in Table 3. The most abundant constituent of edible flowers was water. The moisture content ranged from 75.7 g/100 g FW (Diana pink) to 96.2 g/100 g FW (begonia). The highest carbohydrate, crude protein, and ash contents (18.9, 3.5, and 1.4 g/100 g FW, respectively) were observed in Diana pink. The crude fat content of all tested edible flowers was less than 1 g/100 g FW. The

Table 2. Hydrophilic extraction yield of 13 edible flowers (unit: %)

Edible flower	Yield
Begonia	1.70
Cosmos yellow	7.02
Diana elegance pink	10.65
Diana pink	12.87
Nasturtium	6.20
Pentas	9.09
Petunia	5.80
Primula	6.82
Rose 'Purple Fragrance'	8.25
Rose 'Yves Piaget'	6.80
Snapdragon	10.10
Torenia blue	5.74
Torenia violet	4.66

proximate composition of the 13 edible flowers was consistent with that of a previous study by Pires et al. (2017) in which carbohydrates were the main macronutrients in dried edible petals. Moreover, the nutrient profile of the edible flowers was similar to that of vegetables (Belitz et al., 2009).

TPC of edible flowers

There were considerable differences in the TPCs of the 13 analyzed edible flowers (Table 4). The highest TPC was observed in cosmos yellow flowers, followed by rose 'Purple Fragrance' and rose 'Yves Piaget' flowers (i.e., 13.08, 12.36, and 9.99 mg GAE/g FW, respectively). The lowest TPC was observed in petunia flowers (1.47 mg GAE/g FW). Edible flowers are a potential source of polyphenols, which are phytochemicals with multiple functions, including antioxidant activity (Kähkönen et al., 1999; Scalbert et al., 2005). A large variety of polyphenols were

Table 3. Nutritional composition of edible flowers

(unit: g/100 g fresh weight)

Edible flowers	Proximate composition				
	Crude protein	Crude fat	Ash	Moisture	Carbohydrates
Begonia ¹⁾	0.6	0.4	0.3	96.2	2.5
Cosmos yellow ²⁾	1.6	0.8	0.4	86.4	10.8
Diana elegance pink ²⁾	2.4	0.5	0.6	83.6	12.9
Diana pink ²⁾	3.5	0.5	1.4	75.7	18.9
Nasturtium ¹⁾	2.1	0.4	0.8	90.6	6.1
Pentas ²⁾	0.9	0.5	0.7	87.7	10.2
Petunia ¹⁾	1.1	0.4	1.0	89.8	7.7
Primula ¹⁾	1.3	0.6	1.0	87.5	9.6
Rose 'Purple Fragrance'	1.4	0.8	0.6	86.2	11.0
Rose 'Yves Piaget'	1.3	0.6	0.5	88.0	9.6
Snapdragon ²⁾	0.9	0.5	0.5	86.7	11.4
Torenia blue	0.3	0.5	0.6	91.5	7.1
Torenia violet	0.5	0.6	0.7	88.9	9.3

¹⁾Mean content (n=3). ²⁾Mean of crude protein content (n=2). Remaining data are from a single experiment (n=1).

Table 4. Oxygen radical absorbance capacity (ORAC) and total polyphenol content (TPC) of edible flowers

Edible flower	Antioxidant capacity ($\mu\text{M TE/g FW}$)			TPC (GAE/g FW)
	HORAC	LORAC	TAC	
Begonia	44.07	1.01	45.08	2.04
Cosmos yellow	317.91	2.45 ¹⁾	320.36	13.08
Diana elegance pink	124.85	0.56 ¹⁾	125.41	3.43
Diana pink	78.11	0.35 ¹⁾	78.46	3.02
Nasturtium	51.45	0.72	52.17	2.39
Pentas	130.43	0.35 ¹⁾	130.78	6.52
Petunia	31.82	1.21	33.03	1.47
Primula	108.02	1.02	109.04	7.32
Rose 'Purple Fragrance'	128.13	1.40 ¹⁾	129.53	12.36
Rose 'Yves Piaget'	105.49	1.40 ¹⁾	106.89	9.99
Snapdragon	114.55	0.38 ¹⁾	114.93	3.02
Torenia blue	94.23	0.27 ¹⁾	94.50	2.37
Torenia violet	109.15	0.42 ¹⁾	109.57	4.85

Data are presented as the mean (n=3).

¹⁾Data are presented as the mean of a duplicate assay.

identified in edible flowers. An earlier study by Kaisoon et al. (2012) revealed 10 phenolic acids in edible flowers from Thailand. Chlorogenic acid and gallic acid are reportedly the most abundant phenolic compounds in common edible flowers from China (Xiong et al., 2014). Moreover, gallic acid, protocatechuic acid, (+)-catechin, caffeic acid, syringic acid, epicatechin, *p*-coumaric acid, ferulic acid, chlorogenic acid, rutin, isoquercitrin, quercitrin, and quercetin have been previously detected in 30 analyzed flowers (Chen et al., 2018).

Carotenoids in edible flowers

The β -carotene and β -cryptoxanthin contents of edible flowers are presented in Table 5. All analyzed edible flowers contained β -carotene, except for rose 'Yves Piaget' and torenia blue. In contrast, β -cryptoxanthin was detected in only 4 of the 13 edible flowers. The highest β -carotene content (23 $\mu\text{g/g FW}$) was observed in the primula flower, which has yellow petals, whereas the highest β -cryptoxanthin content (28 $\mu\text{g/g FW}$) was detected in the cosmos yellow flower. A previous study by Yamamizo et al. (2011) revealed that in addition to β -carotene and β -cryptoxanthin, the yellow primula flower contains (9Z)-violaxanthin, (all-E)-violaxanthin, lutein, and antheraxanthin. The nasturtium (*Tropaeolum majus* L.) flower contains large amounts of lutein, but β -carotene and β -cryptoxanthin are also present in trace amounts (Niizu and Rodriguez-Amaya, 2007). In varieties of roses, anthocyanins are the primary phytochemicals; however, carotenoids are also present in rose flowers ranging from pink to red (de Vries, 1974). Our results indicated that trace amounts of β -carotene are detectable in the rose 'Purple Fragrance', which has pink petals. Green and yellow-orange vegetables and fruits typically contain β -carotene,

Table 5. Carotenoid content of edible flowers (unit: $\mu\text{g/g}$ fresh weight)

Edible flower	β -Carotene	β -Cryptoxanthin
Begonia	1 ¹⁾	ND
Cosmos yellow	10	28
Diana elegance pink	8	ND
Diana pink	9	ND
Nasturtium	6 ¹⁾	5 ¹⁾
Pentas	9	ND
Petunia	3 ¹⁾	ND
Primula	23 ¹⁾	20 ¹⁾
Rose 'Purple Fragrance'	1	ND
Rose 'Yves Piaget'	ND	ND
Snapdragon	8	ND
Torenia blue	ND	ND
Torenia violet	1	1

¹⁾Data are presented as the mean (n=3).

Remaining data are presented as the mean of a duplicate assay.

ND, not detected.

whereas orange, citrus, papaya, and tangerine represent the major sources of β -cryptoxanthin (Fernández-García et al., 2012; Burri, 2015). Additionally, β -carotene was detected in edible flowers of various colors, whereas β -cryptoxanthin was mainly only present in yellow and orange edible flowers, especially primula, cosmos yellow, and nasturtium flowers. Since carotenoids are antioxidants (Fiedor and Burda, 2014), the correlation between LORAC and carotenoids was investigated. In this study, the Pearson's correlation coefficient between LORAC and β -cryptoxanthin showed a moderate correlation ($r=0.664$), whereas no correlation was found between LORAC and β -carotene ($r=0.051$). The antioxidant activities of carotenoids in biological systems depend on their structure and localized membrane. β -cryptoxanthin exhibits protective effects against peroxy radicals in the liposomal membranes (Jomova and Valko, 2013), while β -carotene is a singlet oxygen quencher (Stahl and Sies, 2003).

Antioxidant capacity of edible flowers

The ORAC values indicated that the TAC of edible flowers varies considerably (Table 4). Moreover, the HORAC values were obviously higher than the LORAC values. The highest HORAC value was observed in cosmos yellow (317.91 $\mu\text{M TE/g FW}$), followed by pentas (130.43 $\mu\text{M TE/g FW}$) and rose 'Purple Fragrance' (128.13 $\mu\text{M TE/g FW}$), whereas the lowest TAC value was observed in the petunia flower (31.82 $\mu\text{M TE/g FW}$). ORAC values represent the chain-breaking antioxidant capacity in the presence of peroxy radicals generated by AAPH (Prior, 2015). The antioxidant activity of edible flowers is consequently due to bioactive compounds. Zeng et al. (2014) and Huang et al. (2017) reported that the 2,2-diphenyl-

1-picrylhydrazyl (DPPH), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), hydroxyl radical-scavenging activity, and ferric-reducing antioxidant capacity of edible flowers were related to the TPC. In this study, we showed that cosmos yellow, which contains a wide range of phenolic compounds, e.g., ferulic acid, caffeic acid, chlorogenic acid, gallic acid, and myricetin (Kaisoon et al., 2012; Saleem et al., 2017), exhibited the highest HORAC value. These phenolic compounds may correspond to the high HORAC value of cosmos yellow. Additionally, other biological compounds [e.g., vitamins, nitrogenous substances (peptides, amino acids, amines, and alkaloids), and other metabolites] are correlated with the antioxidant activities of edible flowers (Arrom and Munné-Bosch, 2010; González-Barrio et al., 2018).

The United States Department of Agriculture (USDA) removed the USDA ORAC Database for Selected Foods from the NDL website because of mounting evidence that values corresponding to the antioxidant capacity are unrelated to the effects of specific bioactive compounds, including polyphenols, on human health (USDA, 2010). Nevertheless, Kobayashi et al. (2012) conducted an investigation involving 443 young Japanese women to determine that the dietary antioxidant capacity (i.e., ORAC) is inversely associated with the abundance of serum C-reactive protein, which is a non-specific marker of inflammation influencing cardiovascular diseases, type 2 diabetes mellitus, and cancers. Furthermore, a population-based case-control study in New Jersey, USA by Gifkins et al. (2012) also suggested that total phenolic consumption may decrease the risk of endometrial cancer. Therefore, our ORAC results may be a useful indicator that edible flowers are a source of antioxidants that can scavenge the peroxy radical, which is the most prevalent radical in the human biological system, under *in vitro* conditions (Prior, 2015). However, there are many types of ROS and free radicals in the human biological system. Consequently, further research regarding additional ROS and radicals is necessary to confirm the full antioxidant activities of edible flowers.

Correlation between the HORAC value and TPC

Many studies have confirmed a strong correlation between the TPC and the antioxidant activities of edible flowers based on the DPPH, ABTS radical scavenging activities, and ferric-reducing activities (Zheng et al., 2014; Yin et al., 2015; Huang et al., 2017). The correlation between the HORAC value and TPC is presented in Fig. 1. In this study, the antioxidant activity expressed as a HORAC value of 13 edible flowers was highly correlated with the TPC [Pearson correlation coefficient, $r=0.736$, 95% confidence interval (CI) (0.548, 0.853)]. However, the results differed between the cosmos yellow flower

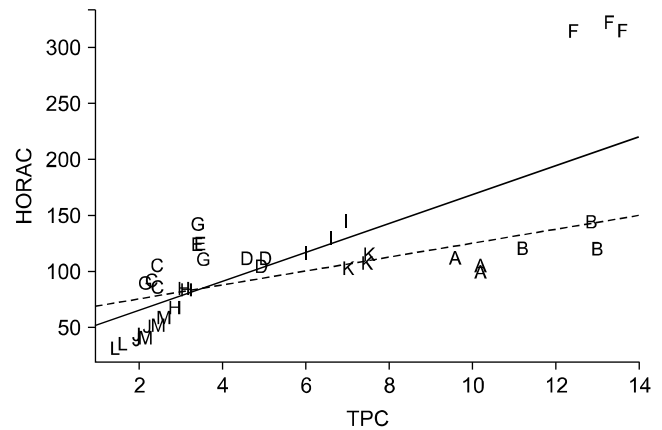


Fig. 1. Correlation between the oxygen radical absorbance capacity (ORAC) value of the hydrophilic extract (HORAC) value [μM Trolox equivalent/g fresh weight (FW)] and the total polyphenol content (TPC) (mg gallic acid equivalent/g FW) of edible flowers. The solid line represents the correlation between the HORAC value and the TPC of 13 edible flowers, whereas the dashed line represents the correlation between the HORAC value and the TPC of 12 edible flowers (excluding cosmos yellow). A, rose 'Yves Piaget'; B, rose 'Purple Fragrance'; C, torenia blue; D, torenia violet; E, diana elegance pink; F, cosmos yellow; G, snapdragon; H, diana pink; I, pentas; J, begonia; K, primula; L, petunia; M, nasturtium.

and the other edible flowers. The cosmos yellow flower had a HORAC value that was approximately 2.4-times higher than that of rose 'Purple Fragrance', despite a comparable TPC (Table 2). In this case, the cosmos yellow flower may represent an outlier. Therefore, if the cosmos yellow data are excluded, the correlation between the HORAC value and the TPC of 12 edible flowers is moderate [$r=0.613$, 95% CI (0.357, 0.784)]. The antioxidant activities of plant extracts are generally largely contributed by polyphenols, with the number and arrangement of hydroxyl groups in each polyphenol correlated with its antioxidant activity (Shahidi and Ambigaipalan, 2015).

In summary, edible flowers from Japan have a nutritional composition profile that is similar to that of vegetables. The data presented herein indicate that the 13 analyzed edible flowers are a promising source of polyphenols and antioxidant compounds. Among these edible flowers, cosmos yellow is the best source of polyphenols and antioxidants. Moreover, some of the selected edible flowers also contain a provitamin A precursor, β -carotene and β -cryptoxanthin, which may enhance human health. This preliminary study suggests that edible flowers are a potential beneficial food source for improving human health.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

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