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Original article

Polyphenol content of various vegetables: Relationship to antiglycation activity

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Abstract

Purpose**:** Using various commercial vegetables in dried, powdered form, we investigated polyphenol content comparatively and in relation to antiglycation activity as reported previously.

Method**:** Using the same 187 commercial vegetables studied in a previous report, we produced dried, powdered samples and measured their polyphenol content by the Folin-Ciocalteu (FC) method. The results were calculated as catechin equivalents (mg catechin Eq) using (+)-catechin as a standard substance. The relationship of the results to inhibition of fluorescent advanced glycation end product (AGE) formation (as reported previously) was then analyzed in an *in vitro* glucose/human serum albumin (HSA) glycation model.

Results**:** In decreasing order, polyphenol content in the 187 vegetable samples (units: mg catechin Eq/mg solid content) was highest in the following samples: Chestnut, soft layer (*Castanea crenata*) 0.509; chestnut, outer skin (*Castanea crenata*) 0.444; water chestnut, seed coat (*Trapa japonica*) 0.274; lemon balm (*Melissa officinalis*) 0.125; spearmint (*Mentha spicata*) 0.124; rosemary (*Rosmarinus officinalis*) 0.115; bay leaves (*Laurus nobilis*) 0.096; lady's thumb (*Polygonum hydropiper*) 0.890; thyme (*Thymus*) 0.080; and mugwort, powder (*Artemisia indica* var. *maximowiczii*) 0.077. By vegetable type, polyphenol content (units: mg catechin Eq/mg solid content) was as follows: Nuts (0.105), herbs (0.063), leaf vegetables (0.032), stem vegetables (0.025), fruit vegetables (0.025), beans (0.024), grains (0.019), mushrooms (0.018), and root vegetables (0.017). By plant taxonomic family, polyphenol content was highest in samples of Fagaceae, Lamiaceae, Polygonaceae, Asteraceae, and Convolvulaceae in that order. No significant correlations were observed between polyphenol content and antiglycation activity (50% inhibitory concentration [IC_{50}] values) in the vegetable samples.

Conclusion**:** Though various vegetables have substantial polyphenol content, various polyphenol-based or non-polyphenol-based components may contribute to antiglycation effect in different vegetable species.

KEY WORDS**:** glycation stress, advanced glycation end products (AGEs), vegetables, polyphenols

Introduction

Glucose and other reducing sugars are an essential nutrient for sustenance of life. However, fructose, glucose, and other sugars bind to proteins non-enzymatically *in vivo* and alter the structure and function of proteins. This phenomenon is known as a glycation reaction and leads to formation and accumulation of advanced glycation end products (AGEs). In turn, binding of AGEs to receptors (receptors for AGEs, "RAGE") causes degradation of functional proteins and damage to tissues. Accumulation of AGEs also contributes to the onset and progression of diabetic complications, osteoporosis, and lifestyle diseases such as arteriosclerosis. *In vivo* glycation represents a risk factor for accelerated aging and is known as glycation stress, a topic of recent interest [1]. Mitigation of glycation stress to inhibit accumulation of AGEs is believed to play a role in prevention of lifestyle and other such diseases.

Familiar vegetables are rich in components such as vitamins and polyphenols [2]. "Polyphenol" is a general term for substances found in molecules which have large multiples of phenolic hydroxy groups. More than 5000 types exist, such as catechin, contained in tea; rutin, contained in soba; and tannin, an astringent component of tea [3]. Polyphenols are a component of bitter flavors and, for example, pigments which are biosynthesized to protect the body from active oxygen, which proliferates under ultraviolet light when plants are

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exposed to light and grow. The antioxidation effect [4-7] and antiglycation effect [8-10] of polyphenols have attracted recent attention, and polyphenols have been shown to be an effective factor [11-17] in prevention of lifestyle diseases. Previous research has also been pursued among plants to determine whether vegetables which may be consumed in the form of familiar foods have previously unknown functional characteristics. Using an *in vitro*, glucose/human serum albumin (HSA) model [2] to measure inhibitory effect on glycation reactions, such research has shown that many vegetables contain components with antiglycation activity [18]. In our research, we measured the polyphenol content of such vegetables to investigate its relationship to antiglycation activity.

Method

Sample preparation

The samples used were the same 187 varieties of commercial vegetables as in a previous report [18]. As reported previously [18], dried powders were prepared by drying vegetables for 20 hours, slicing into 5 mm thicknesses, pulverizing, and sieving (approximately 120-mesh) the material.

Measurement of polyphenols

The polyphenol content in vegetable extract solutions was measured using the Folin-Ciocalteu (FC) method in conjunction with the "Commercial Product Test Results for Polyphenol-Containing Foods" produced by the National Consumer Affairs Center of Japan (NCAC) [19, 20]. Specifically, 100 μL of various dried vegetable powder solutions was added to 50 μL of a 2-fold dilution of FC reagent (Wako Pure Chemical Industries; Chuo-ku, Osaka) and 500 μL of 0.4 M aqueous Na_2CO_3 to make up a total volume of 650 μL, the material was left to stand at ambient temperature for 30 minutes, and absorbency at 660 nm was then measured. A (+)-catechin solution (Wako Pure Chemical Industries) was used as a standard. Multiple (+)-catechin solutions were prepared in 11 steps as 1.0, 0.5, 0.25, 0.1, 0.05, 0.025, 0.0125, 0.01, 0.00625, 0.001, and 0 mg/mL concentrations; 100 μL of each concentration of (+)-catechin solution was added to 50 μL of the 2-fold diluted FC reagent and 500 μL of 0.4 M aqueous Na_2CO_3 to make up a total volume of 650 μL, the material was left to stand at ambient temperature for 30 minutes, and absorbency at 660 nm was then measured. Using the (+)-catechin calibration curve prepared, total polyphenol content per solid unit of each vegetable extract solution was calculated as a catechin equivalent (mg catechin Eq/mg solid content). Measurement was repeated three times for each sample.

Results

Table 1 presents the results for measurement of polyphenol content (catechin equivalents) for the 187 vegetable samples. In decreasing order, polyphenol content was highest in chestnut, soft layer (*Castanea crenata*) 0.509; chestnut, outer skin (*Castanea crenata*) 0.444; water chestnut, seed coat (*Trapa japonica*) 0.274; lemon balm (*Melissa officinalis*) 0.125; spearmint (*Mentha spicata*) 0.124; rosemary (*Rosmarinus officinalis*) 0.115; bay leaves (*Laurus nobilis*) 0.096; lady's thumb (*Polygonum hydropiper*) 0.890; thyme (*Thymus*) 0.080; and mugwort, powder (*Artemisia indica* var. *maximowiczii*) 0.077 (***Fig. 1***).

Comparison of polyphenol content by vegetable category showed that polyphenol content (units: mg catechin Eq/mg solid content) was highest in nuts (0.105), herbs (0.063 ± 0.038), leaf vegetables (0.032 ± 0.017), stem vegetables (0.025 ± 0.018), fruit vegetables (0.025 ± 0.013), beans (0.024 ± 0.006), grains (0.019 ± 0.009), mushrooms (0.018 ± 0.004), and root vegetables 0.017 ± 0.011 in that order (***Fig. 2***). Polyphenol content was significantly higher in nuts than in all categories other than herbs ($p < 0.05$).

Fig. 3 presents polyphenol content (units: mg catechin Eq/mg solid content) by taxonomic family for vegetable samples classified by plant taxonomy. Polyphenol content was highest in species of the Fagaceae (0.321 ± 0.271), Lamiaceae (0.074 ± 0.040), Polygonaceae (0.046 ± 0.033), Asteraceae (0.036 ± 0.023), and Convolvulaceae (0.033 ± 0.002) families in that order. In decreasing order, polyphenol content was lowest in species of the Cucurbitaceae (0.019 ± 0.009), Amaryllidaceae (0.017 ± 0.008), Poaceae (Gramineae (0.017 ± 0.008)), Alliaceae (0.012 ± 0.005), and Araceae (0.010 ± 0.005) families. Polyphenol content was also significantly higher in Fagaceae than in the other 17 families and significantly higher in Lamiaceae than in Poaceae (Gramineae) ($p < 0.05$).

Fig. 4 presents the relationship between polyphenol content and antiglycation activity in vegetable samples. The results showed that there were no significant correlations between polyphenol content and antiglycation activity. In the following 12 species, antiglycation activity was potent (50% inhibitory concentration [IC_{50}] < 0.15 mg/mL), but polyphenol content was low: Nalta jute (*Corchorus olitorius*); new ginger (*Zingiber officinale*); red leaf lettuce (*Lactuca sativa*); scallion (*Allium fistulosum*); spinach (*Spinacia oleracea*); rice eggplant, no peel (*Solanum melongena*); Boston lettuce (*Lactuca sativa*); green perilla, leaf (*Perilla frutescens*); edible chrysanthemum, petal (*Chrysanthemum morifolium*); ashitaba (*Angelica keiskei*); bell pepper (*Capsicum annuum*); and green leaf lettuce (*Lactuca sativa*). In the following 7 species, polyphenol content was high (≥ 0.05 mg/mL), but antiglycation activity was weak (IC_{50} ≥ 0.15 mg/mL): Walnut (Juglans), ostrich fern (*Matteuccia struthiopteris*), thyme (*Thymus*), sweet leaf (*Stevia rebaudiana*), peppermint (*Mentha x piperita*), radish sprouts (*Raphanus sativus*), and pistachio (*Pistacia vera*).

Table 1. Polyphenol content in 187 vegetable samples.

ID	Common Name	Japanese name	Scientific Name	Vesicaria	Family	Polyphenol (mg catechin/mL)
1	Green spring onion	Ao-negi	*Allium fistulosum*	Leaf vegetable	Alliaceae	0.015
2	Avocado	Abogado	*Persea americana*	Fruit vegetable	Lauraceae	0.018
3	Amanaga Chili pepper	Amanaga-tougarashi	*Amanaga capsicum*	Fruit vegetable	Solanaceae	0.032
4	Edamame	Eda-mame	*Clycine max*	Bean	Fabaceae	0.020
5	Pumpkin	Kabocha	*Cucurbita*	Fruit vegetable	Cucurbitaceae	0.040
6	Sweet potato	Satsuma-imo	*Lpomoea batatas*	Root vegetables	Convolvulaceae	0.035
7	Eddoe	Sato-imo	*Colocasia esculenta*	Root vegetables	Araceae	0.015
8	Kidney bean	Saya-ingen	*Phaseolus vulgaris*	Fruit vegetable	Fabaceae	0.014
9	Potato	Jaga-imo	*Solanum tuberosum*	Root vegetables	Solanaceae	0.023
10	Jumbo kidney bean	Jumbo-ingen	*Phaseolus vulgaris*	Fruit vegetable	Fabaceae	0.012
11	Ginger	Shouga	*Zingiber officinale*	Root vegetables	Zingiberaceae	0.032
12	Welsh onion	Shiro-negi	*Allium fistulosum*	Leaf vegetable	Alliaceae	0.014
13	Zucchini	Zucchini	*Cucurbita pepo*	Fruit vegetable	Cucurbitaceae	0.017
14	Broad bean	Sora-mame	*Vicia faba*	Bean	Fabaceae	0.026
15	Daikon (Japanese radish)	Daikon	*Raphanus sativus*	Root vegetables	Vesicaria	0.010
16	Onion	Tama-negi	*Allium cepa*	Root vegetables	Amaryllidaceae	0.010
17	Winter melon	Tougan	*Benincasa hispida*	Fruit vegetable	Cucurbitaceae	0.011
18	Corn	Toumorokoshi	*Zea mays*	Grain	Poaceae (Gramineae)	0.010
19	Chinese yam	Naga-imo	*Dioscorea batatas*	Root vegetables	Dioscoreaceae	0.010
20	Chinese chive	Nira	*Allium tuberosum*	Leaf vegetable	Amaryllidaceae	0.026
21	Garlic	Ninniku	*Allium sativum*	Root vegetables	Amaryllidaceae	0.007
22	Broccoli (Stem)	Broccoli	*Brassica oleracea*	Fruit vegetable	Vesicaria	0.014
23	Broccoli (Flower bud)	Broccoli	*Brassica oleracea*	Fruit vegetable	Vesicaria	0.027
24	Lotus roots	Renkon	*Nelumbo nucifera*	Root vegetables	Nelumbonaceae	0.021
25	Okra	Okura	*Abelmoschus esculentus*	Fruit vegetable	Malvaceae	0.035
26	Carrot	Ninjin	*Daucus carota*	Root vegetables	Apiaceae	0.010
27	Cherry tomato	Mini-tomato	*Lycopersicon esculentum Mill*	Fruit vegetable	Solanaceae	0.019
28	Tomato	Tomato	*Solanum lycopersicum*	Fruit vegetable	Solanaceae	0.017
29	Red onion	Red onion	*Allium cepa*	Root vegetables	Amaryllidaceae	0.015
30	Eggplant	Nasu	*Solanaceae*	Fruit vegetable	Solanaceae	0.024
31	Great burdock	Gobou	*Arctium lappa*	Root vegetables	Asteraceae	0.012
32	Cucumber	Kyuri	*Cucumis sativus*	Fruit vegetable	Cucurbitaceae	0.018
33	Bitter melon	Gouya	*Momordica charantia*	Fruit vegetable	Cucurbitaceae	0.021
34	Celery (Stem)	Serori	*Apium graveolens*	Stem vegetables	Apiaceae	0.018
35	Celery (Leaf)	Serori	*Apium graveolens*	Stem vegetables	Apiaceae	0.056
36	Cabbage	Kyabetsu	*Brassica oleracea*	Leaf vegetable	Vesicaria	0.016
37	Lily bulb	Yurine	*Lilium*	Root vegetables	Liliaceae	0.004
38	Shiitake mushroom (Pileus)	Shii-take	*Lentinula edodes*	Mushroom	Tricholomataceae	0.020
39	Shiitake mushroom (The foundation)	Shii-take	*Lentinula edodes*	Mushroom	Tricholomataceae	0.021
40	Hen of the woods	Mai-take	*Grifola frondosa*	Mushroom	Meripilaceae	0.026
41	King oyster	Eringi	*Pleurotus eryngii*	Mushroom	Pleurotaceae	0.016
42	Buna-shimeji	Buna-shimeji	*Hypsizygus marmoreus*	Mushroom	Lyophyllaceae	0.015
43	Pea	Kinusaya	*Pisum sativum*	Fruit vegetable	Fabaceae	0.025
44	Enoki mushroom	Enoki-dake	*Flammulina velutipes*	Mushroom	Tricholomataceae	0.019
45	Bean sprout	Midorimame-moyashi	*Vigna radiate*	Leaf vegetable	Fabaceae	0.032
46	Garlic shoots	Ninniku-no-me	*Allium sativum*	Stem vegetables	Amaryllidaceae	0.017
47	Bell pepper	Piman	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.027
48	Pak choy	Chingen-sai	*Brassica rapa*	Leaf vegetable	Vesicaria	0.026
49	Mioga ginger	Myouga	*Zingiber mioga*	Fruit vegetable	Zingiberaceae	0.015
50	Asparagus	Asuparagasu	*Asparagus officinalis*	Stem vegetables	Liliaceae	0.024
51	Broccoli sprouts	Hatsuga-broccoli	*Brassica oleracea*	Leaf vegetable	Vesicaria	0.052
52	Broccoli super sprouts	Super-Hatsuga-broccoli	*Brassica oleracea*	Leaf vegetable	Vesicaria	0.051
53	Radish sprouts	Kaiware	*Raphanus sativus*	Leaf vegetable	Vesicaria	0.065

Polyphenol content of various vegetables

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54	Water morning glory (Sprout)	Kushin-sai	*Ipomoea aquatic*	Leaf vegetable	Convolvulaceae	0.032
55	Lettuce	Retasu	*Lactuca sativa*	Leaf vegetable	Asteraceae	0.011
56	Red leaf lettuce	Sunny-retasu	*Lactuca sativa*	Leaf vegetable	Asteraceae	0.047
57	Leaf lettuce	Green leaf	*Lactuca sativa*	Leaf vegetable	Asteraceae	0.025
58	Napa cabbage	Haku-sai	*Brassica rapa*	Leaf vegetable	Vesicaria	0.014
59	Paprika (Red color)	Papurika	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.015
60	Paprika (Yellow color)	Papurika	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.017
61	Paprika (Orange color)	Papurika	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.017
62	Chicory	Chikori	*Cichorium intybus*	Leaf vegetable	Asteraceae	0.024
63	Crown daisy	Kiku-na	*Glebionis coronaria*	Leaf vegetable	Asteraceae	0.013
64	Radish	Radish	*Raphanus sativus*	Root vegetables	Vesicaria	0.038
65	Scallion	Wakegi	*Allium fistulosum*	Leaf vegetable	Amaryllidaceae	0.024
66	Parsley	Paseri	*Petroselinum crispum*	Herb	Apiaceae	0.030
67	Spinach	Horenso	*Spinacia oleracea*	Leaf vegetable	Chenopodiaceae	0.024
68	Nalta jute	Moroheiya	*Corchorus olitorius*	Leaf vegetable	Tiliaceae Juss.	0.046
69	Mizuna (Potherb mustard)	Mizu-na	*Brassica rapa*	Leaf vegetable	Vesicaria	0.024
70	Mibuna	Mibu-na	*Brassica rapa*	Leaf vegetable	Vesicaria	0.031
71	Komatsuna (Japanese mustard spinach)	Komatsu-na	*Brassica rapa*	Leaf vegetable	Vesicaria	0.021
72	Red cabbage	Aka-kyabetu	*Brassica oleracea*	Leaf vegetable	Vesicaria	0.037
73	Carrot greens (Leaf)	Ninjin-sai	*Daucus carota*	Leaf vegetable	Apiaceae	0.022
74	Japanese honeywort	Mitsuba	*Cryptotaenia canadensis*	Leaf vegetable	Apiaceae	0.018
75	Green perilla (Leaf)	Oba	*Perilla frutescens*	Leaf vegetable	Lamiaceae	0.037
76	Japanese parsley	Seri	*Oenanthe javanica*	Leaf vegetable	Apiaceae	0.030
77	Boston lettuce	Sarada-na	*Lactuca sativab*	Leaf vegetable	Asteraceae	0.027
78	Japanese horseradish	Wasabi	*Wasabia japonica*	Root vegetables	Vesicaria	0.005
79	White mushroom	White mushroom	*Agaricus bisporus*	Mushroom	Pleurotaceae	0.017
80	Green pepper	Shishitou	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.026
81	Malabar spinach	Tsurumurasaki	*Basella alba*	Leaf vegetable	Basellaceae	0.026
82	Malabar spinach (Leaf)	Tsurumurasaki	*Basella alba*	Leaf vegetable	Basellaceae	0.042
83	Malabar spinach (Stem)	Tsurumurasaki	*Basella alba*	Leaf vegetable	Basellaceae	0.018
84	Shirona Chinese cabbage	Shiro-na	*Brassica rapa*	Leaf vegetable	Vesicaria	0.024
85	Garden pea sprouts (Sprout)	Mame-nae	*Pisum sativm*	Leaf vegetable	Fabaceae	0.030
86	Water morning glory	En-sai (Enkushin)	*Ipomoea aquatic*	Leaf vegetable	Convolvulaceae	0.032
87	Red giant elephant ear (Petiole)	Beni-zuiki	*Colocasia gigantean*	Stem vegetables	Araceae	0.008
88	Ginkgo	Ginnan	*Ginkgo biloba*	Nut	Ginkgoaceae	0.029
89	Chrysanthemum (Petal)	Shokuyo-kiku	*Chrysanthemum morifolium*	Fruit vegetable	Asteraceae	0.067
90	Jew's ear fungs	Kikurage	*Auricularia auricular*	Mushroom	Auricularaceae	0.014
91	Chinese yam	Yamato-imo	*Dioscorea batatas*	Root vegetables	Dioscoreaceae	0.007
92	Horseradish	Seiyou-wasabi	*Armoracia rusticana*	Root vegetables	Vesicaria	0.011
93	New ginger	Shin-shouga	*Zingiber officinale*	Root vegetables	Zingiberaceae	0.019
94	Saltwort	Wakame-okahijiki	*Salsola komarovii*	Leaf vegetable	Chenopodiaceae	0.022
95	Common ice plant	Barafu	*Mesembryanthemum crystallinum*	Leaf vegetable	Aizoaceae	0.013
96	Wasabi leaves	Wasabi-na	*Brassica juncea*	Leaf vegetable	Vesicaria	0.027
97	Perilla (Shiso)	Hojiso	*Perilla frutescens*	Fruit vegetable	Lamiaceae	0.068
98	Giant elephant ear	Hasu-imo	*Colocasia gigantea*	Stem vegetables	Araceae	0.007
99	Red rhubarbe	Aka-rubabu	*Rheum rhabarbatum*	Stem vegetables	Polygonaceae	0.026
100	Red rhubarbe (None peel)	Aka-rubabu	*Rheum rhabarbatum*	Stem vegetables	Polygonaceae	0.015
101	Red rhubarbe (Peel)	Red-rubaubu	*Rheum rhabarbatum*	Stem vegetables	Polygonaceae	0.053
102	Shallot	Esharotto	*Allium oschaninii*	Root vegetables	Alliaceae	0.005
103	Cauliflower (Flower bud)	Karihurawa	*Brassica oleracea*	Fruit vegetable	Vesicaria	0.019
104	Cauliflower (Stem)	Karifurawa	*Brassica oleracea*	Fruit vegetable	Vesicaria	0.020

ID	Common Name	Japanese name	Scientific Name	Vesicaria	Family	Polyphenol (mg catechin/mL)
105	Cauliflower (Leaf)	Karifurawa	*Brassica oleracea*	Fruit vegetable	Vesicaria	0.025
106	Turnip (Root)	Ko-kabura	*Brassica rapa*	Root vegetables	Vesicaria	0.017
107	Turnip	Ko-kabura	*Brassica rapa*	Root vegetables	Vesicaria	0.020
108	Green cucumber	Ao-uri	*Cucumis sativus*	Fruit vegetable	Cucurbitaceae	0.011
109	Kagahuto cucumber	Kagahuto-kyuri	*Cucumis sativus*	Fruit vegetable	Cucurbitaceae	0.013
110	Rice eggplant (None peel)	Bei-nasu	*Solanum melongena*	Fruit vegetable	Solanaceae	0.023
111	Rice eggplant (Peel)	Bei-nasu	*Solanum melongena*	Fruit vegetable	Solanaceae	0.066
112	Kintoki carrot* (Root)	Kintoki-ninjin	*Daucus carota*	Root vegetables	Apiaceae	0.008
113	Kintoki carrot* (Leaf)	Kintoki-ninjin	*Daucus carota*	Root vegetables	Apiaceae	0.023
114	Red bell pepper	Aka-piman	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.020
115	Leaf ginger (Root)	Ha-shouga	*Zingiber officinale*	Root vegetables	Zingiberaceae	0.023
116	Leaf ginger (Leaf)	Ha-shouga	*Zingiber officinale*	Root vegetables	Zingiberaceae	0.017
117	Mugwort (Powder)	Yomogi	*Artemisia indica*	Leaf vegetable	Asteraceae	0.077
118	Azuki bean	Azuki	*Vigna angularis*	Bean	Fabaceae	0.027
119	Red kidney beans	Kintoki-mame	*Phaseolus vulgaris*	Bean	Fabaceae	0.026
120	Black-eyed pea	Sasage	*Vigna unguiculata*	Bean	Fabaceae	0.029
121	Black soybeen	Kuro-mame	*Glycine max*	Bean	Fabaceae	0.023
122	Soybeen	Daizu	*Glycine max*	Bean	Fabaceae	0.019
123	Black sesame	Kuro-goma	*Sesamun indicum*	Nut	Pedaliaceae	0.033
124	White sesame	Shiro-goma	*Sesamun indicum*	Nut	Pedaliaceae	0.017
125	White opium poppy seeds (Seed)	Shirokeshi-no-mi	*Papaver somniferum*	Nut	Papaveraceae	0.012
126	Almond	Almond	*Amygdalus communis*	Nut	Rosaceae	0.009
127	Cahew nuts	Kashu-nattsu	*Anacardium occidele*	Nut	Anacardiaceae	0.021
128	Walnut	Kurumi	*Juglans*	Nut	Juglandaceae	0.059
129	Pumpkin seeds (Seed)	Kawanashi-kabocha-no-tane	*Cucurbita sp.*	Nut	Cucurbitaceae	0.019
130	Peanut	Rakkasei	*Arachis hypogaea*	Nut	Fabaceae	0.036
131	Polished rice A	Haku-mai A	*Oryza sativa*	Grain	Poaceae (Gramineae)	0.016
132	Red-kerneled rice	Aka-mai	*Oryza sativa*	Grain	Poaceae (Gramineae)	0.024
133	Reddish black rice	Kuro-mai	*Oryza sativa*	Grain	Poaceae (Gramineae)	0.017
134	Rolled barley	Oshi-mugi	*Hordeum vulgare*	Grain	Poaceae (Gramineae)	0.011
135	Pearl barley	Hato-mugi	*Coix lacryma-jobi*	Grain	Poaceae (Gramineae)	0.010
136	Pistachio	Pisutachio	*Pistacia vera*	Nut	Anacardiaceae	0.058
137	Foxtail millet	Awa	*Setaria italic*	Grain	Poaceae (Gramineae)	0.010
138	Japanese millet	Hie	*Echinochloa esculenta*	Grain	Poaceae (Gramineae)	0.033
139	Proso millet	Kibi	*Panicum miliaceum*	Grain	Poaceae (Gramineae)	0.008
140	Amaranth	Amaransasu	*Amaranthus*	Grain	Amaranthaceae	0.030
141	Quínua	Kinusu	*Chenopodium quinoa*	Grain	Chenopodiaceae	0.032
142	Pecan nuts	Pecan	*Carya illinoinensis*	Nut	Juglandaceae	0.059
143	Lady's thumb	Tade	*Polygonum hydropiper*	Leaf vegetable	Polygonaceae	0.089
144	Polished rice B	Haku-mai B	*Oryza sativa*	Grain	Poaceae (Gramineae)	0.010
145	Unpolished rice B	Gen-mai	*Oryza sativa*	Grain	Poaceae (Gramineae)	0.012
146	Rice B bran	Nuka	*Oryza sativa*	Grain	Poaceae (Gramineae)	0.029
147	Garbanzo	Garbanzo	*Cicer arietinum*	Bean	Fabaceae	0.015
148	Lentil	Renzu-mame	*Lens culinaris*	Bean	Fabaceae	0.027
149	Bay leaves	Bay leaf	*Laurus nobilis*	Herb	Lauraceae	0.096
150	Water caltrop (Seed)	Hishi	*Trapa japonica*	Nut	Trapaceae	0.014
151	Water caltrop (Seed coat)	Hishi	*Trapa japonica*	Nut	Trapaceae	0.274
152	Butterscotch mushroom	Nameko	*Pholiota microspore*	Mushroom	Strophariaceae	0.012
153	Chestnut (Seed)	Kuri	*Castanea crenata*	Nut	Fagaceae	0.011
154	Chestnut (Outer skin)	Kuri	*Castanea crenata*	Nut	Fagaceae	0.444
155	Chestnut (Soft layer)	Kuri	*Castanea crenata*	Nut	Fagaceae	0.509
156	Chrysanthemum (Receptacle)	Shokuyo-kiku	*Chrysanthemum morifolium*	Fruit vegetable	Asteraceae	0.024

ID	Common Name	Japanese name	Scientific Name	Vesicaria	Family	Polyphenol (mg catechin/mL)
157	Pea (Pod)	Endou-mame	*Pisum sativum*	Bean	Fabaceae	0.020
158	Pea (Bean)	Endou-mame	*Pisum sativum*	Bean	Fabaceae	0.022
159	Turnip rape	Nanohana	*Brassica rapa*	Fruit vegetable	Vesicaria	0.033
160	Horikawa gobo*	Horikawa-gobou	*Arctium lappa*	Root vegetables	Asteraceae	0.049
161	Shogoin turnip*	Seigoin-kabura	*Brassica rapa*	Root vegetables	Vesicaria	0.007
162	Ashitaba	Ashitaba	*Angelica keiskei*	Leaf vegetable	Apiaceae	0.041
163	Kyoto eggplant*	Nasubi "Kyo-shizuku"	*Solanum melongena*	Fruit vegetable	Solanaceae	0.030
164	Ostrich fern	Kogomi	*Matteuccia struthiopteris*	Leaf vegetable	Athyriaceae	0.060
165	Kamo eggplant*	Kamo-nasu	*Solanum melongena*	Fruit vegetable	Solanaceae	0.019
166	Manganzi Chile pepper* (Red)	Mannganji-tougarashi	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.024
167	Manganzi Chile pepper* (Green)	Manganji-tougarashi	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.025
168	Manganzi Chile pepper* (Mix)	Manganji-tougarashi Mix	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.040
169	Takagamine Chile pepper*	Takagamine-tougarashi	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.024
170	Husimiamanaga Chile pepper* (Red)	Fushimi-amanaga-tougarashi	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.028
171	Husimiamanaga Chile pepper* (Green)	Fushimi-amanaga-tougarashi	*Capsicum annuum*	Fruit vegetable	Solanaceae	0.029
172	Super Yuga tomato*	Super Yuga tomato	*Solanum lycopersicum*	Fruit vegetable	Solanaceae	0.020
173	Renaissance tomato*	Runessansu tomato	*Solanum lycopersicum*	Fruit vegetable	Solanaceae	0.013
174	Kyo-akane tomato*	Kyo-akane tomato	*Solanum lycopersicum*	Fruit vegetable	Solanaceae	0.019
175	Kyo-temari tomato*	Kyo-temari tomato	*Solanum lycopersicum*	Fruit vegetable	Solanaceae	0.019
176	Rucola	Rukkora	*Eruca vesicaria*	Herb	Vesicaria	0.017
177	Sweet basil	Sweet bajiru	*Ocimum basilicum*	Herb	Lamiaceae	0.037
178	Common sage	Seiji	*Salvia officinalis*	Herb	Lamiaceae	0.026
179	Dill	Diru	*Anethum graveolens*	Herb	Apiaceae	0.048
180	Italian parsley	Italian-pasure	*Petroselinum neapolitanum*	Herb	Apiaceae	0.024
181	Chervil	Chabiru	*Anthriscus cerefolium*	Herb	Apiaceae	0.045
182	Thyme	Taimu	*Thymus sp.*	Herb	Lamiaceae	0.059
183	Sweet leaf	Sutebia	*Stevia rebaudiana*	Herb	Asteraceae	0.080
184	Lemon balm	Lemon baumu	*Melissa officinalis*	Herb	Lamiaceae	0.125
185	Peppermint	Peppermint	*Mentha x piperita*	Herb	Lamiaceae	0.051
186	Spearmint	Spearmint	*Mentha spicata*	Herb	Lamiaceae	0.124
187	Rosemary	Rosemary	*Rosmarinus officinalis*	Herb	Lamiaceae	0.115

IC_{50}: 50% inhibitory concentration. Polyphenol content shown as catechin equivalents. Mean of three measurements for each sample shown.
*Kyoto regional vegetable

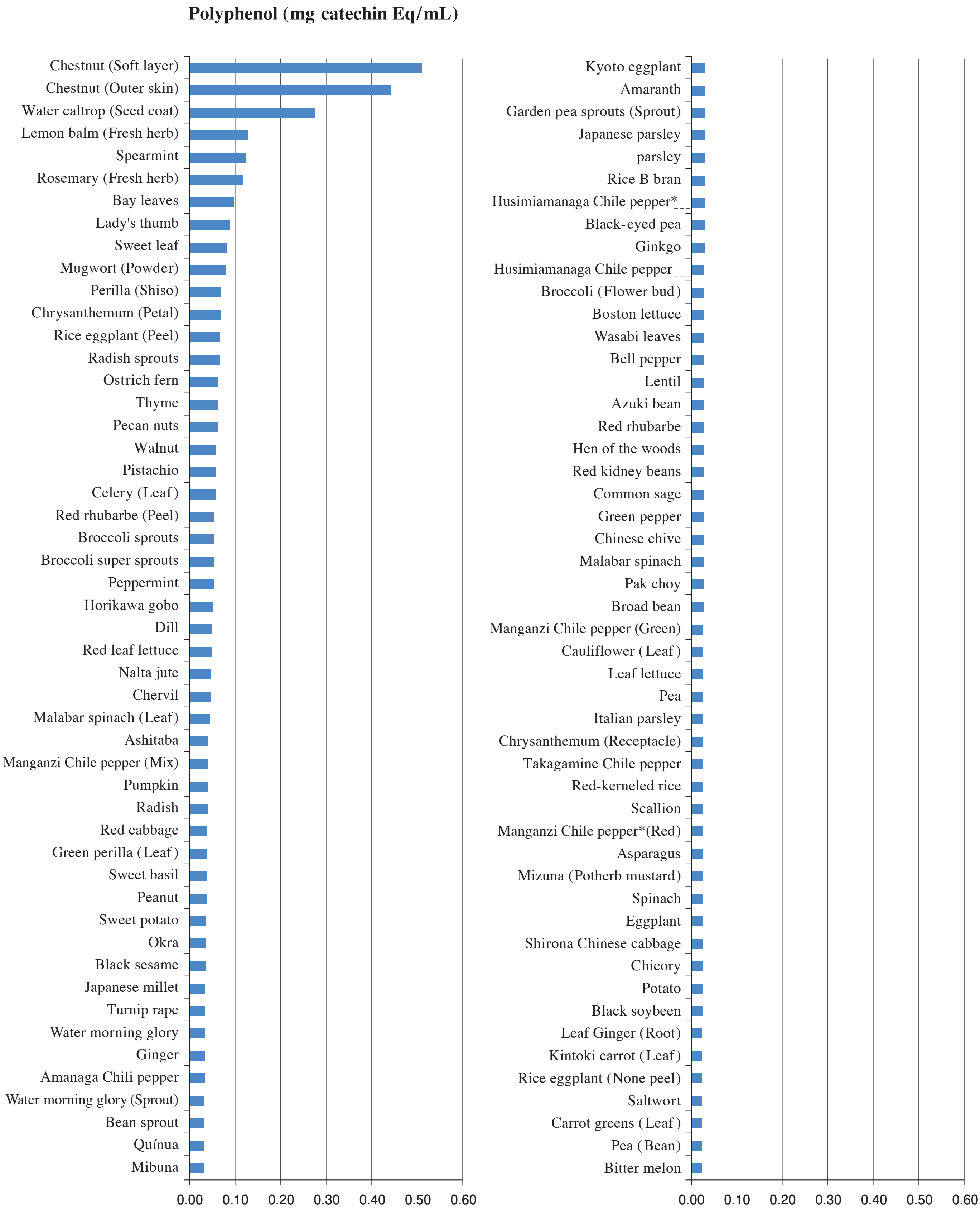

Fig 1. **Polyphenol content ranking of 187 vegetable samples (catechin equivalents, top 100)**

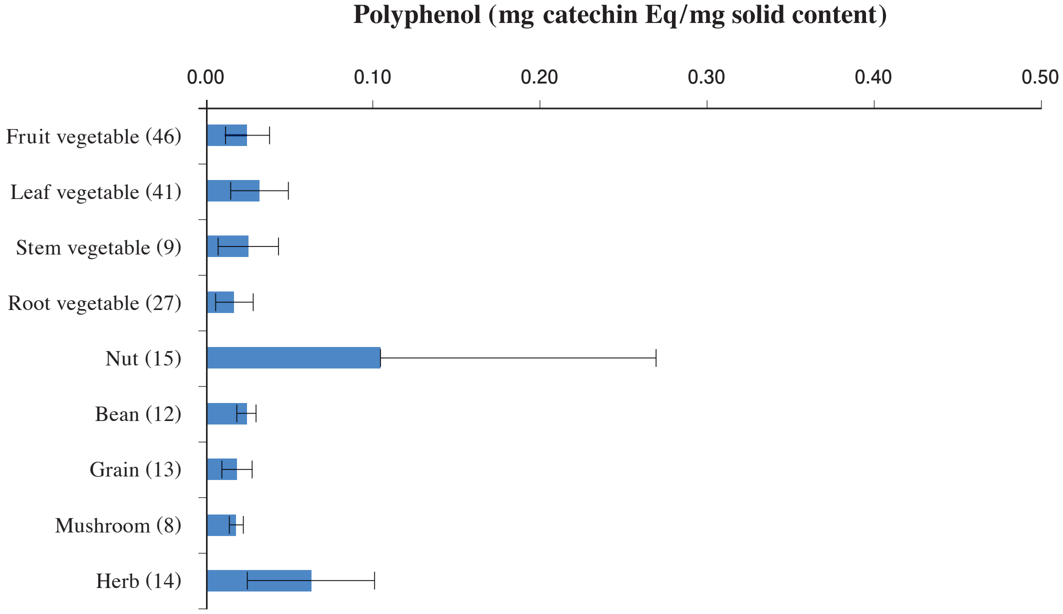

Fig 2. **Polyphenol content by vegetable category**

Polyphenol content shown as catechin equivalents. Parentheses indicate number of samples included in vegetable category. Bars indicate standard deviation. No. of sample measurements n=3.

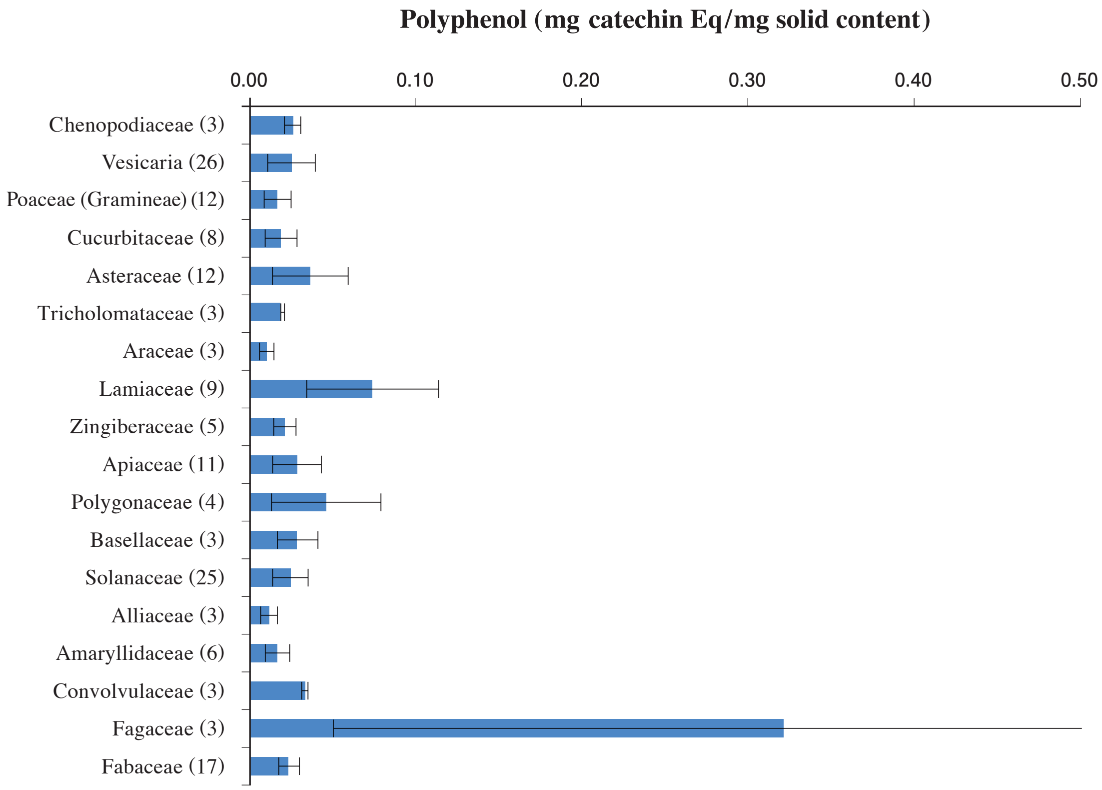

Fig 3. **Polyphenol content by vegetable sample taxonomic family**

Polyphenol content shown as catechin equivalents. Parentheses indicate number of samples included in vegetable family. Bars indicate standard deviation. No. of sample measurements n=3.

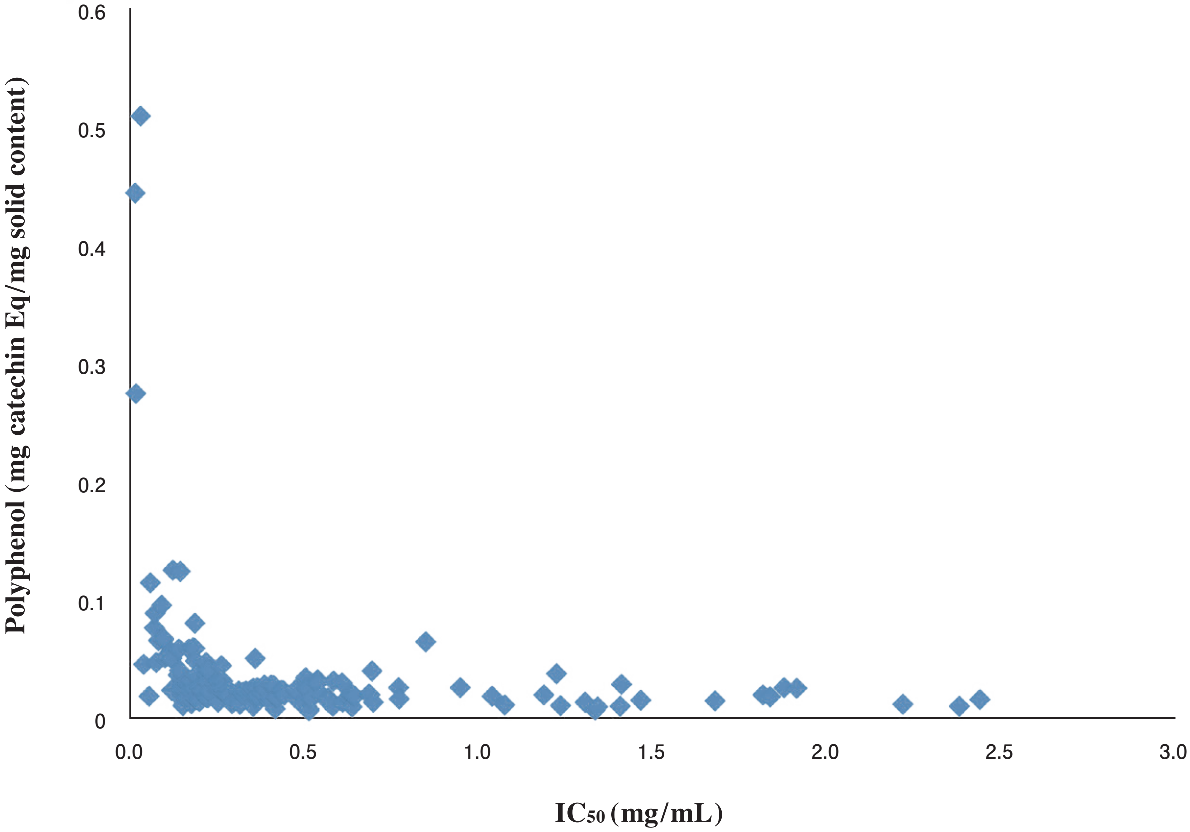

Fig 4. **Relationship between polyphenol quantity and antiglycation activity in vegetable samples**

Antiglycation activity represents inhibitory activity for fluorescent AGE formation (IC_{50}) in dried vegetable powder samples in a previously reported [18] *in vitro* glucose/HSA reaction model. Polyphenol content shown as catechin equivalents. Regression function: $y = -3E\text{-}13x + 0.0338$, $R^2 = 0.0004$, $p > 0.05$. HSA, human serum albumin; AGEs, advanced glycation end-products; IC_{50}, 50% inhibitory concentration.

Discussion

Many reports state that tea leaves [9,21], herbs and spices [22-24] herbal remedies [25], and other natural, plant-based materials contain substantial quantities of polyphenols and have an antiglycation effect *in vitro* or in animal experiments. Our results for measurement of polyphenol content in 187 vegetables showed that polyphenol content was highest in nuts, herbs, leaf vegetables, stem vegetables, fruit vegetables, and beans in that order. By plant taxonomic family, polyphenol content was highest in samples of Fagaceae, Lamiaceae, Polygonaceae, Asteraceae, and Convolvulaceae in that order. However, in a previous report [18], results for measurement of inhibitory activity for fluorescent AGE formation in an *in vitro* glucose/HSA model found high antiglycation activity among herbs, leaf vegetables, and stem vegetables in that order. By taxonomic family, high antiglycation activity was observed in species of the Asteraceae, Lamiaceae, Basellaceae, and Polygonaceae families. In all vegetable samples generally, no significant correlations were observed between polyphenol content and antiglycation activity, but in terms of vegetable type, a high association between polyphenol content and antiglycation activity was anticipated for herbs, leaf vegetables, and stem vegetables. Likewise, by taxonomic family, a high association was anticipated for species of the Asteraceae, Lamiaceae, and Polygonaceae families. The Asteraceae family contains high levels of the polyphenols luteolin and anthrocyanidin [8]. Lamiaceae species contain copious rosmarinic acid [26,27], and Polygonaceae species contain copious quercetin [28] and kaempferol [29].

By individual vegetable, antiglycation activity was potent ($IC_{50} < 0.15$ mg/mL) but polyphenol content low (< 0.05 mg catechin Eq/mg solid content) in 12 vegetables: Nalta jute, new ginger, red leaf lettuce, scallion, spinach, rice eggplant (no peel), Boston lettuce, green perilla, edible chrysanthemum (petal), ashitaba, bell pepper, and green leaf lettuce. Polyphenol content was also extremely low (< 0.0125 mg catechin Eq/mg solid content) but antiglycation activity slightly weaker (0.15 mg/mL $\leq IC_{50} < 0.5$ mg/mL) than that of aminoguanidine in four vegetables: Green cucumber (*Cucumis sativus*), great burdock (*Arctium lappa*), lettuce (*Lactuca sativa*), and red giant elephant ear (petiole, *Colocasia gigantea*). In these 16 vegetables, components other than polyphenols are believed to contribute to antiglycation effect. Polyphenol content was high (≥ 0.05 mg catechin Eq/mg solid content) but antiglycation activity weak (IC_{50} ≥ 0.15 mg/mL) in seven vegetables: Walnut, ostrich fern, thyme, sweetleaf, peppermint, radish sprouts, and pistachio. Polyphenols in these samples may contain components which inhibit antiglycation activity.

There are numerous reports on research concerning vegetables. Results for measurement of hydroxyl radical antioxidant capacity (H-ORAC) in 23 different Japanese vegetables showed a mean estimated H-ORAC value of 594.3 μmol trolox-equivalent (TE/100 g)[30]. Consumption of 350 g of these vegetables per day would result in consumption of 2,080 μmol TE/day of hydrophilic antioxidants.

Results for measurement of polyphenol content, low-density lipoprotein (LDL) oxidation and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical reduction in 30 different Vietnamese vegetables by FC method showed that antioxidant activity was high in vegetables with high polyphenol content[31]. The mean daily intake of polyphenols by Vietnamese individuals was found to be 595 mg catechin Eq, with the highest contribution, 45%, from water spinach (*Ipomoea aquatica*), green vegetable.

Research measuring polyphenol content, α-glucosidase inhibitory activity and antioxidant activity by FC method in extracts from 28 different Vietnamese vegetables showed a positive correlation between this activity and polyphenol content[32]. In particular, four species possessed α-glucosidase inhibitory activity and antioxidant activity equivalent to or better than that of guava leaf extract: *Syzygium zeylanicum*, *Cleistocalyx operculatus*, *Horsfieldia amygdalina*, and *Careya aroborea*.

Our research and these reports[31,32] show that the FC method used for polyphenol measurement produces a high correlation (r = 0.96) with total phenolic OH number and is an analytical method allowing evaluation of the total phenolic OH number in various polyphenol compounds[33]. Measurement sensitivity is comparatively higher than in other measurement methods. Though reactivity to compounds with differing chemical structures differs to some extent, the FC method tends to produce high values in compounds with an odiphenol structure.

On this basis, we believe that a commitment to consuming a target amount of 350 g/day of various vegetables, regarded as a preferable figure for required daily vegetable intake, may provide substantial antioxidant effect[30] and antiglycation activity[18] and may also go beyond inhibition of aging to play a role in preventing the onset and progression of lifestyle-related diseases.

Conclusion

Though vegetables contain substantial quantities of polyphenols, it may be the case that various components, polyphenolic or non-polyphenolic, contribute to antiglycation effect in different vegetable species. By vegetable type, we found a high association between polyphenol quantity and antiglycation activity in herbs, leaf vegetables, and stem vegetables. By taxonomic family, we found a similar association in species of the Asteraceae, Lamiaceae, and Polygonaceae families. A contribution by non-polyphenolic substances was suggested in nalta jute, new ginger, red leaf lettuce, scallion, spinach, rice eggplant (no peel), Boston lettuce, green perilla, edible chrysanthemum (petal), ashitaba, bell pepper, green leaf lettuce, green cucumber, great burdock, lettuce, and red giant elephant ear (petiole). We believe that this information is useful for creating dietary regimens to counter glycation stress.

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Conflict of Interest Statement

The authors state that performance of this study entailed no issues representing a conflict of interest.

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