Original Article

Content and distribution of flavonoids among 91 edible plant species

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Flavonoid contents as aglycones (for quercetin, kaempherol, isorhamnetin, luteolin and apigenin) were reported for 115 edible plants (91 species). Plant materials mostly originated in tropical zones were grown and harvested from AVRDC, Taiwan. Acid extraction and HPLC were used as analytical methods. Total flavonoid contents ranged from 0 to 254 mg/100g fresh weight. About 75% of samples were found to contain flavonoids > 0.5 mg/100g with the group mean 33 ± 48 mg/100g. Data for only 30 samples (20 species) in this study are also available (measured as raw vegetables) in the USDA flavonoid database. This study can expand the flavonoid database and contribute to measurement of flavonoid intake, especially for populations consuming tropical and underutilized vegetables.

Key Words: flavonoid, underutilised vegetables, tropical plants

INTRODUCTION

Flavonoids are present in most plant tissues and often in vacuoles.[1] The basic structures of flavonoid molecules are composed of three rings with various substitutions, including glycosylation, hydrogenation, hydroxylaltion, malonylation, methylation and sulfation.[2, 3] Flavonoids are divided into classes according to their substitutes and oxidation level on the middle ring. The main subclasses and their respective food sources are anthocyanidins (red, purple and blue berries), flavanols (teas, red grapes and red wines), flavones (green leafy species), flavonols (ubiquitous in foods), flavanones (citrus), and isoflavones (soybeans).[4] In nature, they are present principally as glycosylated, esterified, and polymerized derivatives. Sugar moieties attached to flavonoids increases polarity of the molecules for their storage in plant cell vacuoles.[2,3]

Flavonoids in plants can function as color definitions and attractants to pollinators and seed dispersers, as antioxidants to protect plants against UV-radiation, as insect feeding attractants in host-species recognition, as signal molecules to facilitate nitrogen fixation, in inducible defense against bacteria and fungal attack; and as bitter or astringent taste attributes to repel birds and other animals.[1, 5−7] For humans, several health beneficial properties of dietary flavonoids are recognized for their antioxidant and antiproliferative effects which may protect the body from various diseases, such as cancers, cardiovascular disease and inflammatory.[8, 9]

To better understand the association of flavonoid intake and health outcomes, analyses of flavonoids in plant foods, an intense area of research, clinical and epidemiological studies are required.[10,11] Although data such as the USDA database for flavonoids enables and facilitates investigations,[1,12,13] dietary flavonoid intake of was estimated based on US adult population according to food types and social factors such as gender, income and age.[10] However, types and intake amounts of dietary flavonoids vary among populations because different populations consume different kinds and quantities of plant foods.[14−16]

Over 100 plant species are consumed worldwide as vegetables, but of these, only about 20 species are grown globally and account for most of the vegetables produced and consumed.[17] Flavonoids of popular vegetables have been intensively studied, but little is known about the flavonoid content of under-utilized vegetable species, many of which are partially domesticated, or wild. This study investigated 5 types of flavonoids in 90 edible plants species which mostly originate in tropical or subtropical zones.

MATERIALS AND METHODS

Materials

Chemicals and solvents were analytical grade or chromatography grade. Commercial standard compounds were used including quercetin (Sigma-Aldrich), kaempherol, isorhamnetin and lueolin (Fluka, Germany), apigenin, myricetin, hesperetin, nargigenin, and eriodictyol (Extrasynthese, France).

A total of 115 samples representing 91 species (Table 1), including popular and lesser-known plants consumed as vegetables and spices in tropical and sub-tropical areas of Asia were analyzed. Plants were grown during 2003−2006 from fields of the AVRDC − The World Vegetable Center, southern Taiwan. Their antioxidant capacities have been

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Table 1. Flavonoid[1] contents (mg/ 100g fw) and dry matter (%) of 115 edible plants (91 species).

Common name	Scientific name	Part	DM	Que	Kae	Isor	Lut	Api	TF
Ailanthus prickly ash	*Zanthoxylum ailanthoides*	shoot	27.7	4.8	0.0	0.0	0.0	0.0	4.8
Amaranth	*Amaranthus mangostanus*	shoot	15.3	18.4	0.0	1.9	0.0	0.0	20.3
Amaranth, Joseph's coat	*Amaranthus tricolor*	shoot	12.0	0.0	0.0	0.0	0.0	0.0	0.0
Amaranth, livid	*Amaranthus lividus*	shoot	13.5	4.4	1.8	0.0	0.0	0.0	6.2
Amaranth, purple	*Amaranthus cruentus*	shoot	10.2	0.0	0.0	0.0	0.0	0.0	0.0
Amaranth, redroot	*Amaranthus retroflexus*	shoot	12.2	9.3	0.4	0.0	0.0	0.0	9.7
Amaranth, spleen	*Amaranthus dubius*	shoot	11.1	1.3	0.0	0.0	0.0	0.0	1.3
Aromatic turmeric	*Curcuma aromatica*	stem	31.0	0.0	0.0	0.0	0.0	0.0	0.0
Ashitaba	*Angelica keiskei*	shoot	20.9	121.7	1.7	0.0	95.0	0.0	219
Bamboo shoot	*Dendrocalamus latifloxus*	root	7.8	0.0	0.0	0.0	0.0	0.0	0.0
Baobab tree	*Adansonia digitata*	shoot	22.6	38.2	4.5	0.0	1.6	0.0	44.3
Basil	*Ocimum basilicum*	shoot	11.9	0.0	0.0	0.0	0.0	0.0	0.0
Beach naupaka	*Scaevola sericea*	shoot	10.9	0.0	0.0	0.0	7.3	2.7	9.9
Beet	*Beta vulgaris*	root	8.4	0.0	0.0	0.0	0.0	0.0	0.0
Big-leaved marshweed	*Limnophila rugosa*	shoot	12.8	0.0	0.0	0.0	0.0	0.0	0.0
Cabbage, white	*Brassica oleracea*	leaf	6.4	0.0	0.0	0.0	0.0	0.0	0.0
Celery	*Apium graveolens*	stem	5.0	0.0	0.0	0.0	1.0	2.5	3.4
Chard, dark green	*Beta vulgaris*	shoot	5.8	0.0	0.0	0.0	0.0	0.0	0.0
Chard, light green	*Beta vulgaris*	shoot	4.8	0.0	0.0	0.0	0.0	0.0	0.0
Chard, red	*Beta vulgaris*	shoot	6.5	0.0	0.0	0.0	0.0	0.0	0.0
Chard, Swiss	*Beta vulgaris*	shoot	6.3	0.0	0.0	0.8	0.0	0.0	0.8
Chard, yellow	*Beta vulgaris*	shoot	5.5	0.0	0.0	0.0	0.0	0.0	0.0
Cheese weed	*Malva parviflora*	shoot	19.6	0.0	1.7	0.0	0.0	0.0	1.7
Chili pepper	*Capsicum annuum*	shoot	12.5	0.0	0.0	0.0	53.0	2.2	55.2
Chinese boxthorn	*Lycium chinense*	shoot	13.8	5.5	44.6	0.0	0.0	0.0	50.1
Chinese cabbage	*Brassica rapa*	leaf	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Chinese cedar	*Toona sinensis*	leaf	29.9	94.5	60.4	0.0	0.0	0.0	155
Chinese foldwing	*Dicliptera chinensis*	shoot	15.7	16.5	10.3	0.0	0.0	0.0	26.8
Chinese violet	*Asystasia gangetica*	shoot	12.9	0.0	0.0	0.0	27.7	12.7	40.4
Chinese wedelia	*Wedelia chinensis*	shoot	17.1	0.0	0.0	0.0	12.8	0.0	12.8
Cluster bean, Guar	*Cyamopsis tetragonoloba*	pod	12.6	10.4	24.3	0.0	0.0	0.0	34.7
Cluster mallow	*Malva verticillata*	shoot	11.5	0.0	0.0	0.3	0.0	0.0	0.3
Comfrey	*Symphytum officinale*	shoot	8.7	1.1	1.7	0.0	0.0	0.0	2.8
Coriander	*Coriandrum sativum*	shoot	8.7	8.0	0.0	0.0	0.0	0.0	8.0
Cowpea	*Vigna unguiculata*	leaf	15.0	105	11.4	8.9	0.0	0.0	125
Cucumber, spiny bitter	*Momordica cochinchinensis*	shoot	20.0	78.0	32.0	0.0	0.0	0.0	110
Cucumber, spiny bitter	*Momordica cochinchinensis*	fruit	14.3	0.0	0.0	0.0	0.0	0.0	0.0
Dandelion	*Taraxacum officinale*	shoot	13.7	0.0	0.0	0.0	6.2	0.0	6.2
Drumstick	*Moringa oleifera*	leaf	25.5	89.8	36.3	2.9	0.0	0.0	129
Duck's tongue grass	*Monochoria vaginalis*	stem	8.8	0.3	0.0	0.0	0.0	0.0	0.3
Duck's tongue grass	*Monochoria vaginalis*	leaf	16.3	3.1	0.0	0.0	0.0	0.0	3.1
Eggplant, African	*Solanum aethiopicum*	fruit	9.7	0.3	0.3	0.0	0.0	0.0	0.6
Eggplant, nakati	*Solanum zuccagnianum*	leaf	15.7	6.1	29.8	0.0	0.0	0.0	35.8
Eggplant, nakati	*Solanum zuccagnianum*	fruit	19.9	2.3	1.8	0.0	0.0	0.0	4.1
Eggplant, nakati	*Solanum zuccagnianum*	imm fruit	14.6	0.0	0.0	0.0	0.0	0.0	0.0
Endive	*Cichorium endivia*	shoot	5.2	0.0	7.6	0.0	0.0	0.0	7.6
Feather cockscomb	*Celosia argentea*	shoot	11.0	3.8	0.5	0.3	0.0	0.0	4.6
Fishwort	*Houttuynia cordata*	shoot	18.6	61.2	3.0	0.0	0.0	0.0	64.2
Frog fruit	*Phyla nodiflora*	shoot	12.9	0.0	0.0	0.0	39.0	0.0	39.0
Garden chrysanthemum	*Chrysanthemum coronarium*	shoot	9.5	2.9	0.0	0.0	0.0	0.0	2.9
Gynura, white	*Gynura oralis*	shoot	6.0	7.4	0.9	0.0	0.0	0.0	8.3
Hairy beggarticks	*Bidens pilosa*	shoot	11.5	6.3	0.0	0.0	0.0	0.0	6.3
India gourd	*Cucurbita maxima*	shoot	9.1	1.4	2.1	1.1	0.0	0.0	4.6
India gourd	*Cucurbita maxima*	bud	6.4	1.2	6.4	1.0	0.0	0.0	8.6
India gourd	*Cucurbita maxima*	fruit	8.0	0.0	0.0	0.0	0.0	0.0	0.0
India gourd	*Cucurbita maxima*	imm fruit	9.0	0.0	0.0	0.0	0.0	0.0	0.0
Indian cress	*Tropaeolum majus*	flower	7.9	32.8	1.6	0.0	0.0	0.0	34.4
Indian mulberry	*Morinda citrifolia*	shoot	18.3	224	30.1	0.0	0.0	0.0	254
Ivy gourd	*Coccinia grandis*	shoot	10.8	6.9	111	0.0	0.0	0.0	118
Jute	*Corchorus capsularis*	shoot	21.8	4.2	13.8	0.0	0.0	0.0	18.1
Jute mallow	*Corchorus olitorius*	shoot	18.5	59.6	4.3	0.0	0.0	0.0	63.9
Jute, wild	*Corchorus trilocularis*	shoot	13.9	9.8	0.7	0.0	0.0	0.0	10.5
Kangkong, green stem	*Ipomoea aquatica*	shoot	8.7	0.2	0.0	0.0	0.0	0.0	0.2
Kangkong, red stem	*Ipomoea aquatica*	shoot	13.2	7.1	0.0	0.0	0.0	0.0	7.1
Komatsuna	*Brassica campestris*	shoot	6.9	0.4	9.7	1.4	0.0	0.0	11.6

Table 1. Flavonoid[1] contents (mg/ 100g fw) and dry matter (%) of 115 edible plants (91 species). (cont.)

Lablab	*Lablab purpureus*	imm pod	11.6	10.9	0.4	1.8	0.0	0.0	13.2
Lablab	*Lablab purpureus*	pod	14.2	2.1	0.4	0.3	0.0	0.0	2.7
Lettuce	*Lactuca sativa*	leaf	4.3	0.0	0.4	0.0	0.0	0.0	0.4
Madeira vine	*Anredera cordifolia*	shoot	9.5	0.6	0.0	0.0	0.0	0.0	0.6
Malabar spinach, green	*Basella alba*	shoot	7.9	0.0	1.4	0.0	0.0	0.0	1.4
Malabar spinach, red	*Basella rubra*	shoot	7.5	0.0	3.6	0.0	0.0	0.0	3.6
Mizuna	*Brassica campestris*	shoot	6.6	1.0	8.7	1.9	0.0	0.0	11.6
Mustard	*Brassica juncea*	shoot	6.9	0.9	14.8	2.7	0.0	0.0	18.4
Mustard, Ethiopian	*Brassica carinata*	shoot	10.7	1.5	53.6	0.6	0.0	0.0	55.7
New Zealand spinach	*Tetragonia tetragonioides*	shoot	15.8	2.0	2.0	0.0	0.0	0.0	4.0
Night fragrant flower	*Telosma cordata*	bud	12.8	0.2	8.7	0.0	0.0	0.0	8.9
Nightshade	*Solanum nigrum*	shoot	7.8	3.7	1.0	0.0	0.0	0.0	4.7
Nightshade, African	*Solanum scabrum*	shoot	11.7	23.2	2.0	0.4	0.0	0.0	25.5
Nightshade, African	*Solanum villosum*	shoot	12.4	18.1	0.9	0.0	0.0	0.0	19.0
Okra	*Abelmoschus esculentus*	fruit	9.0	15.2	0.0	0.0	0.0	0.0	15.2
Orach	*Atriplex hortensis*	shoot	10.0	20.3	46.7	1.5	0.0	0.0	68.5
Pak-choi	*Brassica chinensis*	shoot	4.5	0.5	7.4	1.3	0.0	0.0	9.2
Parsley	*Petroselium crispum*	shoot	10.7	0.0	1.7	0.0	0.0	71.8	73.5
Penghu senna	*Cassia sophora*	shoot	19.4	0.0	0.0	0.0	0.0	0.0	0.0
Pilose beggarticks	*Bidens bipinnata*	shoot	10.8	11.6	0.0	0.0	0.0	0.0	11.6
Princess vine	*Cissus sicyoides*	shoot	29.9	0.0	0.0	0.0	0.0	0.0	0.0
Rocket-salad	*Eruca sativa*	shoot	8.3	8.7	36.5	3.9	0.0	0.0	49.1
Rosemary	*Rosmarinus officinalis*	shoot	30.9	0.0	0.0	0.0	18.4	3.2	21.6
Sawah-flower rush	*Limnocharis flava*	leaf	14.3	0.0	0.0	0.0	0.0	0.0	0.0
Sesame	*Eurca sp.*	shoot	13.2	58.8	2.5	4.8	0.0	0.0	66.1
Sesbania, red	*Sesbania grandiflora*	flower	10.6	10.1	10.3	0.0	0.0	0.0	20.4
Sesbania, white	*Sesbania grandiflora*	flower	10.6	0.0	22.4	0.0	0.0	0.0	22.4
Smooth joyweed	*Alternanthera paronichyoides*	shoot	15.2	0.8	0.9	0.4	0.0	0.0	2.1
Soneysuckle	*Lonicera japonica*	bud	18.4	0.0	1.0	0.7	9.0	0.0	10.7
Sorrel	*Rumex acetosa*	shoot	6.2	5.5	0.0	0.0	0.0	0.0	5.5
Spider plant	*Cleome gynandra*	shoot	10.9	58.9	4.5	1.0	0.0	0.0	64.3
Spinach, green stem	*Spinacia oleracea*	shoot	6.5	0.0	0.0	0.7	0.0	0.0	0.7
Spinach, red stem	*Spinacia oleracea*	shoot	6.7	0.0	0.0	0.8	0.0	0.0	0.8
Staghorn clubmoss	*Lycopodiella cernua*	shoot	7.5	0.4	0.0	0.0	0.0	0.0	0.4
Star gooseberry	*Sauropus androgynus*	shoot	20.4	0.0	58.3	0.0	0.0	0.0	58.3
Sweet bitter leaf	*Vernonia hymenolepis*	shoot	16.3	0.0	0.0	0.0	24.0	0.8	24.7
Sweet potato, green	*Ipomoea batatas*	shoot	14.6	0.0	1.4	0.0	0.0	0.0	1.4
Sweet potato, pink	*Ipomoea batatas*	shoot	11.7	10.1	1.4	0.0	0.0	0.0	11.4
Sweet potato, purple	*Ipomoea batatas*	shoot	14.6	42.3	2.3	0.0	0.0	0.0	44.6
Sweet potato, taro flavor	*Ipomoea batatas*	shoot	11.9	0.0	0.0	0.0	0.0	0.0	0.0
Tomato	*Solanum esculentum*	fruit	5.2	0.4	0.0	0.0	0.0	0.0	0.4
Tomato, cherry	*Solanum esculentum*	fruit	6.8	0.0	0.0	0.0	0.0	0.0	0.0
Vegetable soybean, green	*Glycine max*	seed	28.1	0.0	0.7	0.0	0.0	0.0	0.7
Verticillata pennywort	*Hydrocotyle verticillata*	shoot	11.8	95.5	11.4	0.7	0.0	0.0	108
Vietnamese coriander	*Polygonum odoratum*	shoot	40.6	118	25.5	0.0	0.0	0.0	144
Water cress	*Nasturtium officinale*	shoot	6.5	2.4	35.1	0.0	0.0	0.0	37.5
Water mint	*Mentha aquatica*	shoot	17.5	0.0	0.0	0.0	0.0	0.0	0.0
Wedelia	*Wedelia trilobata*	shoot	15.4	0.5	11.4	0.0	0.0	0.0	11.9
Weed passion flower	*Passiflora foetida*	shoot	13.8	0.0	0.0	0.0	0.5	1.5	2.0
Unknow	*Hydrolea zeylanica*	shoot	18.3	2.2	7.9	0.0	0.0	0.0	10.1

Que: quercetin; Kaem: kaempherol; Isor: isorhamnetin; Api: apigenin; Lut: luteolin; TF: total flavonoids; imm: immature; value of "0.0" :below detection limit (<0.05 mg/100g) .

reported previously.[18] About 2 kg of edible portion of each fresh sample were collected, washed, cut into 5 cm long and well mixed. Exact 100 g of the cut samples were frozen at -20°C for 4 hr, vacuumed dried for < 2 days, ground into fine powder, and stored at -70 °C for subsequent analyses.

Hydrolysis, extraction, and recovery test

Nine flavonoid aglycones were determined in the frozen samples after hydrochloric hydrolysis of the flavonoid derivatives. Briefly, 100 mg sample placed in a 20 mL tube containing 10 mg ascorbic acid dissolved in 5 mL of acidified methanol (1.2 M HCl) was flushed with N_2 air for 30 sec and then refluxed at 80 °C for 2 h. After cooled down to room temperature, the sample was sonicated for 10 min and centrifuged at 4000g for 10 min. Supernatant, approximately 2 mL was taken and filtered through 0.2 μm syringe filter (Millipore, Bedford, MA). The filtrate was kept at 10°C for HPLC analyses within 12 h.

Three vegetables namely white cabbage, parsley, and celery without intrinsic quercetin were used with three replications to determine quercetin recovery rate from the acid extraction. Appropriate amount of rutin equivalent to 25 ppm in extraction solution was also added prior to acid hydrolysis.

HPLC analyses and recovery test

Flavonoid aglycons were separated using the HPLC system equipped with a Waters 2695 separation module and an Agilent Zorbax ODS column (3.5μm, 4.6 x 150 mm) at 35 °C using a gradient from 0 − 15 min, 1 to 25% acetonitrile (ACN) in 1% aqueous formic acid (FA); and 15 − 50 min, 25% − 40% ACN in 1% aqueous FA at a flow rate of 0.7 mL/min. The column elute was monitored using a Waters 2996 photo diode array detector (250 − 700 nm). Identification and quantification of individual flanonoid was carried out using commercial standards.

RESULTS AND DISCUSSION

In this study, contents of flavonoids including 4 flavonols (quercetin, kaempherol, isorhamnetin, myricetin), 2 flavones (apigenin, luteolin) and 3 flavanones (eriodictyol, hesperetin and naringenin) in 115 edible plants (90 species) were determined as aglycons. However, only values for five flavonoids (quercetin, kaempherol, isorhamnetin, apigenin luteolin) are reported in Table 1. Myricetin, eriodictyol and naringenin were not detected in all the plant samples, due to that they were sensitive to acid hydrolysis[14] and rarely occurred in vegetables.[4] Quercetin recovery from extrinsic rutin in selected vegetables after hydrolysis were 81.4 ± 1.7 % in extraction solution, 82.8 ± 8.6 % in celery, 69.5 ± 3.9 % in parsley, and 62.3 ± 3.7 % in cabbage. A higher rate of recovery corresponded to lower soluble solid contents of vegetable extracts measured by refractometer. Values in Table 1 were not adjusted by the recovery rate due to various rate in vegetables were found.

Among the 115 samples, 86 samples contained at least one type of flavonoid (>0.5 mg). Maximums, group means and standard deviations are presented in Table 2. More than 50% of plants contained either or both quercetin and kaempherol.

For most of the plant species analysed in this study, this is the first report of their flavonoid contents. Only 30 samples (20 species) in this study have previously been reported (measured as raw vegetables) in the USDA flavonoid database.[4] In our study, leaves of Indian mulberry (254 mg), ashitaba (218 mg), Chinese cedar (155 mg), Vietnamese coriander (144 mg), moringa (129 mg) (Table 1) have the highest content of for total flavonoids. These plants were rich in quercetin and kaempherol, except for ashitaba, which was high in quercetin and luteolin. The highest values reported in the USDA database for raw vegetables are capers (*Capparis,* 493 mg), parsley (237 mg), lovage leaves (*Levisticum,* 177 mg), dill weed (*Anethum graveolens*, 110 mg), and dock leaves (*Rumer spp*, 102mg). Quercetin was the major type of flavonoid, except for parsley which is rich in apigenin.

Thirteen samples in this study were found to contain flavones as the dominant flavonoid. Among them, parsley (72 mg), chili pepper (55 mg), Chinese violet (41 mg), and frog fruit (39 mg) were the highest (Table 1). The flavonoid contents of parsley and chilli pepper are also reported in USDA database.[4] Similar to our results, apigenin was the dominant type of flavonoid in parsley; however a higher mean value (226 mg) was reported in the database. Values for various pepper varieties are also complied in the database in which quercetin and luteolin values ranged from 0.4 to 31 mg in total. These values are lower than our data.

In several cruciferous vegetables listed in the database except red cabbage, kaempherol and quercetin were the dominant flavonoids, ranging from less than 6 mg in most Brassica samples to 34 mg in Chinese kale.[4] In our study, seven Brasssica species were collected. Our results show that kaempherol was the major flavonoid ranged from 0.0 mg in Chinese cabbage and white cabbage to 56 mg in mustard (Table 1).

In addition to flavonols and flavones, anthocyanins, flavan-3-ols, flavanones, theaflavin and proanthocyanindins are major flavonoids in plant-sourced food. Samples in our study with visible red colour such as red chard, African eggplant, red kangkong, lablab pods, and red sesbania flower will be tested for anthocyanin contents later. Flavan-3-ols and flavanones are known to be sensitive to acids, thus values of their contents in different plant species were not included in our study using an acid extraction method. However, using the non-acid direct extraction method, flavan-3-ols and flavanones were not detected in the selected vegetables, except for tomato that contained narigenin.[19] Theaflavins are flavonoids found mostly in teas. According to USDA database for proanthocyaninds[4], proanthocyanindin concentration was insignificant in the selected vegetables.

Data in this study provide additional information to the flavonoid database and contribute to studies on health benefits from flavonoid intakes, especially for populations consuming tropical and underutilized vegetables.

Table 2. Flavonoid content ranges and group means mg/100g fresh weight)

	Que	Kaem	Isor	Lut	Apig	Total
Content ≥ 0.5 mg/100g						
Max	224	111	9	95	72	254
Mean	27	15	2	23	12	33
SD	42	21	2	27	24	48
n	59	57	20	13	8	86
Content < 0.5 mg/100g						
n	95	58	56	107	102	29

Que: quercetin; Kaem: kaempherol; Isor: isorhamnetin; Api: apigenin; Lut: luteolin

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AUTHOR DISCLOSURES

Ray-Yu Yang, Shou Lin and George Kuo, no conflicts of interest.

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