Review Article

Phytochemical composition of nuts

C-Y Oliver Chen PhD and Jeffrey B Blumberg PhD FACN CNS

Antioxidants Research Lab, Jean Mayer USDA Human Nutrition Research Center on Aging, Tufts University, Boston, MA, USA

Observational studies suggest nut consumption is inversely associated with the incidence of cardiovascular disease and cancer. In addition to being rich in several vitamins and minerals, unsaturated fatty acids, and fiber, tree nuts and peanuts contain numerous phytochemicals that may contribute to promoting health and reducing the risk of chronic disease. While many of these bioactive constituents remain to be fully identified and characterized, broad classes include carotenoids, phenols, and phytosterols. Phytosterols in nuts range from 95-280 mg/100 g. α- and β-Carotene, β-cryptoxanthin, lutein, and zeaxanthin are found in μg/100 g amounts in some nuts but at 1-3 mg/100 g in pistachios and none at all in Brazils, macadamias, and peanuts. Phenols, including phenolic acids, flavonoids, and stilbenes, are present in nuts. Walnuts are particularly rich in total phenols with 1625 mg gallic acid equivalents/100 g. The stilbene resveratrol is found in peanuts and pistachios at 84 and 115 μg/100 g, respectively. The flavonoid content of nuts as provided in USDA Database for the Flavonoid Content of Selected Foods, lists totals in pecans at 34, almonds at 15, and pistachios and hazelnuts at 12 mg/100 g. Proanthocyanidins are found in almonds, cashews, hazelnuts, pecans, pistachios, peanuts, and walnuts, with concentrations varying from 9-494 mg/100 g. Nut phytochemicals have been associated with numerous bioactivities known to affect the initiation and progression of several pathogenic processes. However, as complete phytochemical profiles are lacking for most nuts, information is limited regarding their bioavailability and metabolism, so further research on this topic is warranted.

Key Words: nuts, phytochemicals, chronic disease, nutrition, polyphenols

INTRODUCTION

Consumption of plant foods is inversely associated with the risk of many chronic diseases with studies often attributing this benefit to their content of essential nutrients and/or fiber. During the last decade, research has indicated as well a significant contribution to this outcome from phytochemicals, including carotenoids and phenols (Figure 1). Importantly, while a single nutrient or limited class of nutrients in a plant food have often been postulated as key factor, the bioactivity arising from a more complex and dynamic interaction between an array of essential nutrients and phytochemicals appears a more likely mechanism responsible for its putative health benefits. For example, nut consumption is inversely associated with the incidence of cardiovascular disease, diabetes, and some forms of cancer.[1] This evidence has been sufficiently compelling that nuts have been incorporated into recommended dietary guidelines in the United States, Canada, and Spain and a qualified health claim for reducing the risk of heart disease is provided by the U.S. Food and Drug Administration. This benefit of tree nuts and peanuts has been reasonably attributed to their composition of vitamins and minerals, mono- and polyunsaturated fatty acids, and/or fiber. Carotenoids, phenols (particularly flavonoids), and phyto-sterols have been identified and partly characterized in nuts. We review here the general phytochemical composition of nuts and their potential mechanisms of action that suggest their contribution to health promotion and the prevention of chronic disease.

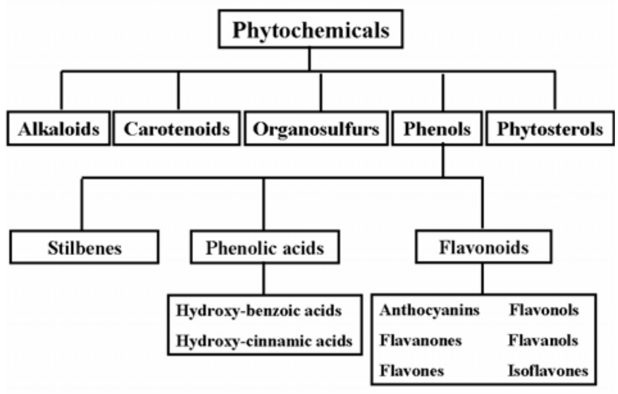

Figure 1. Classification of phytochemicals.

PHYTOSTEROLS

Phytosterols are a group of >200 naturally occurring plant sterols with the capacity to inhibit the absorption of dietary cholesterol and lower serum cholesterol as well as antagonize selected inflammatory pathways.[2,3] Phytosterols, which

Corresponding Author: Dr. C.-Y. Oliver Chen, Antioxidants Research Lab, Jean Mayer USDA Human Nutrition Research Center on Aging, Tufts. University, 711 Washington Street, Boston, MA, 02111 USA
Tel: + 1 617 556 3136; Fax: + 1 617 556 3344
Email: oliver.chen@tufts.edu
Manuscript received 9 September 2007. Accepted 3 December 2007.

are structurally similar to cholesterol, are found in the fatty fraction of nuts. The primary plant sterols in the Western diet are sitosterol (particularly β-sitosterol), stigmasterol, and campesterol, with estimated average intakes at 150-450 mg/d. Efficacious, short-term doses of phytosterols to reduce LDL-cholesterol are formulated into functional foods to achieve intakes of ~2 g/d.[2] However, the impact of more relevant dietary doses over the long durations has yet to be established.

The phytosterol content of nuts (in mg/100 g) is: almonds, 187; Brazil nuts, 95; cashews, 138; hazelnuts, 120; macadamias, 198; pecans, 150; pine nuts, 198; pistachios, 280; walnuts, 113. Interestingly, these concentrations are comparable to those found in chocolate and flaxseed at 168 and 210 mg/100 g.[4]

CAROTENOIDS

Carotenoids, with their polyisoprenoid structure and differing degrees of conjugated double bonds, are abundant in most colorful plant foods. Carotenoid intake has been associated with a reduced risk of cardiovascular disease, age-related cataract and macular degeneration, and some forms of cancer. Although >600 carotenoids have been characterized in nature, those found most concentrated in human blood and tissues are α- and β-carotene, β-cryptoxanthin, lutein, lycopene, and zeaxanthin. Although low concentrations of carotenoids are present in several nuts, they are not a major source of dietary carotenoids; however, β-carotene and lutein are found in pistachios at 0.21 and 2.32 mg/100 g dry weight.[5]

PHENOLS

Plant phenols, including simple phenolic acids, flavonoids, stilbenes, and a variety of other polyphenolic compounds, possess hydroxyl groups conjugated to an aromatic hydrocarbon group. Phenolic compounds are ubiquitous in plant foods with total daily intakes estimated at 500-1000 mg. The reduction in the risk of several chronic diseases associated with the consumption of plant phenols has been attributed to their array of bio-mechanisms, including antioxidation, anti-inflammation, carcinogen detoxification, and cholesterol reduction. The total phenol content among nuts varies widely (Table 1), with pecans, pistachios, and walnuts being the richest sources and Brazil nuts, macadamias, and pine nuts containing the lowest concentrations.[5,6]

RESVERATROL

Resveratrol is a stilbene and, like many other polyphenols acts in the plant as a phytoalexin. In addition to sharing antioxidant and other bioactivities common to polyphenols, resveratrol appears capable of extending the life span of yeast and mice. In addition to the presence of resveratrol in red wine and the skins of red grapes, it has been found in peanuts and pistachios at 84 and 115 µg/100 g.[7] This concentration is in contrast to the 98-1803 µg/100 mL in red wines.[8] Resveratrol has not been found in other nuts.

FLAVONOIDS

Flavonoids are comprised of six principle classes, anthocyanin, flavanone, flavone, flavanol, flavonol, and isoflavone, and are widely distributed throughout the plant kingdom (Figure 1). Flavonoid intake has been associated with a reduced risk of several chronic diseases with their mechanisms of action variously attributed to their capacity for antioxidation, anti-inflammation, anti-proliferation, and modulation of signal transduction pathways. The Flavonoid Content of Selected Foods established by the U.S. Department of Agriculture (USDA) provides the most comprehensive database on these phytochemicals available, though it is important to appreciate that is it far from being either comprehensive or complete.[10] The "total antioxidant capacity" of most nuts have been published (Table 1), although the relevance of values from the Ferric Reducing Antioxidant Power (FRAP), Oxygen Radical Absorbance Capacity (ORAC), and similar in vitro assays to in vivo bioactivity is not clear. Studies in humans are required to directly understand the bioaccessibility, bioavailability, metabolism, and elimination of nut flavonoids. Such clinical studies are required not only because of the differences in specific flavonoid profiles between nut varieties (and other foods) but the impact of the food matrix (and processing thereof) on these factors.

Table 1. Total phenol (TP) content and total antioxidant capacity in tree nuts and peanuts.[1]

Nuts	TP[2]	TP[3]	ORAC[3]	FRAP[4]
	mg GAE/g		µmol TE/g	µmol Fe^{2+}/g
Almonds	2.4 (6)	4.2 (6)	45 (5)	41 (4)
Brazil nuts	1.1 (8)	3.1 (7)	14 (7)	
Cashew	1.4 (7)	2.7 (8)	20 (8)	
Hazelnuts	2.9 (5)	8.4 (4)	97 (3)	42 (3)
Macadamias	0.5 (9)	1.6 (9)	17 (9)	
Peanuts	4.2 (4)	4.0 (5)	32 (6)	16 (5)
Pecans	12.8 (2)	20.2 (1)	179 (1)	
Pine nuts	0.3 (10)	6.8 (10)	7 (10)	13 (6)
Pistachios	8.7 (3)	16.6 (2)	80 (4)	193 (2)
Walnuts	16.3 (1)	15.6 (3)	135 (2)	454 (1)

[1]Numbers in parentheses are rank order among ten nuts; [2-4]Nuts tested were purchased in Austria, USA, and Italy, respectively.[4,5,9] [3,4]FRAP, Ferric Reducing Antioxidant Power; ORAC, Oxygen Radical Absorbance Capacity

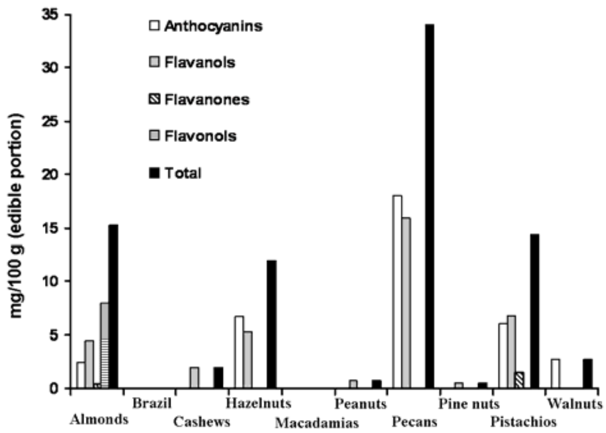

Figure 2. Flavonoid contents in tree nuts and peanuts.

Flavonoids have been identified in most nuts with their aglycone profiles included in the USDA database (Figure 2). The highest total flavonoid concentrations are found in pecans at 34, almonds at 15, and pistachios and hazelnuts at 12 mg/100 g, respectively. No flavonoids have detected in Brazil or macadamia nuts. It is worth noting that some nuts can contribute total flavonoids to the diet in amounts comparable to some fruit and vegetables; e.g., almonds have a similar quantity of total flavonoids as red delicious apples at 15 and apricots at 13 mg/100 g.[10]

PROANTHOCYANIDINS

Proanthocyanidins, flavanol oligomers, are comprised principally of (+)-catechin and (-)-epicatechin linkages with single interflavan bonds between C_4 of the "upper" extension units and C_6 or C_8 of the "lower" unit (C4-C6, C4-C8, B type) or a single C-C bond plus a second ether linkage between C-2 of the upper unit and an A-ring hydroxyl group of the lower unit (A type). Some proanthocyanidins are formed from less common flavanols such as afzelechin, epiafzelechin, gallocatechin, and epigallocatechin. The size of proanthocyanidins varies widely in plant foods and is determined by the degree of polymerization. Daily intake of proanthocyanidins has been roughly estimated to range from ~30 to >300 mg/d. Proanthocyanidins have been found in most but not all nuts with concentrations (mg/100 g) in hazelnuts at 501, pecans at 494, pistachios at 237, almonds at 184, walnuts at 67, peanuts at 16, and cashews at 9.[11] Proanthocyanidins have also been measured in cereals and fruit with sorghum and cocoa containing >1 g/100 g. Some flavanols and proanthocyanidins have been shown to possess chemopreventive activity, promote vascular reactivity, lower platelet aggregation, and reduce urinary tract infections.

BIOLOGICAL ACTIVITIES

As noted, the phytochemicals thus far characterized as rich in nuts, i.e., the polyphenols and phytosterols, possess a variety of bioactions that have been implicated in slowing the pathogenesis of chronic disease, including antioxidant and anti-inflammatory activity as well as the capacity to promote detoxification, reduce cell proliferation, and/or lower serum LDL-cholesterol. Importantly, these compounds may work in synergy with other important nut constituents like vitamins, minerals, mono- and polyunsaturated fatty acids, proteins, and fiber. It is noteworthy that nuts can be particularly rich sources of copper (cashews), linoleic acid (pine nuts), α-linolenic acid (walnuts), manganese (hazelnuts), niacin (peanuts), selenium (Brazil nuts), β-sitosterol (pistachios), α-tocopherol (almonds), and γ-tocopherol (pecans).

Particular attention has been focused on the antioxidant capacity of nuts due to their content of vitamin E, selenium, and phenols. Carotenoids in nuts are found in such low concentrations, they are unlikely to contribute significantly to their antioxidant action. As vitamin E contributes little to the in vitro FRAP and ORAC value of foods, these assessments of total antioxidant capacity appear largely dependent upon the phenolic compounds in nuts. Though the reactions of these two assays are quite different, it is interesting to note that the rank order of values obtained from tests of nuts are quite similar. It is also noteworthy that the ORAC values (in μmol TE/g) found in a serving of many nuts are comparable to those determined in a serving of beans (147-301), broccoli (700), carrots (741), and tomato (415).[6] Importantly, evidence is available from a limited number of studies that the antioxidant capacity of nuts can be demonstrated in vivo as well as in vitro.[12,13] Whether the molecular mechanisms underlying the antioxidant and anti-inflammatory actions of nut phytochemicals are related, it is interesting to note as well the inverse association between nut intake and biomarkers of inflammation in an observational study[14] and clinical trials.[15]

CONCLUSIONS AND PROSPECTS

Together with their presence in cereals, fruits, and vegetables, the content and concentration of phytochemicals in nuts suggest they also contribute to the beneficial role of plant foods in health promotion and disease prevention. However, more compelling evidence for this relationship must be derived directly from additional studies of nuts fully characterizing their content, bioaccessiblity, bioavailability, metabolism, and elimination in humans. Similarly, data remain critically limited regarding the influence on nut phytochemicals of species and variety, cultivation and environmental conditions, and processing and storage, so further research in this area is also warranted.[16]

ACKNOWLEDGEMENTS

Support was provided by the U.S. Department of Agriculture (USDA) Agricultural Research Service under Cooperative Agreement No. 58-1950-7-707.

AUTHOR DISCLOSURES

C-Y Oliver Chen and Jeffrey B Blumberg, no conflicts of interest.

REFERENCES

1. Dreher ML, Maher CV, Kearney P. The traditional and emerging role of nuts in healthful diets. Nutr Rev. 1996; 54:241-245.
2. Piironen V, Lindsay DG, Miettinen TA, Toivo J, Lampi A-M. Plant sterols: Biosynthesis, biological function and their importance to human nutrition. J Sci Food Agric. 2000;80: 939-966.
3. Nashed B, Yeganeh B, HayGlass KT, Moghadasian MH. Antiatherogenic effects of dietary plant sterols are associated with inhibition of proinflammatory cytokine production in Apo E-KO mice. J Nutr. 2005;135:2438-2444.
4. Phillips KM, Ruggio DM, Ashraf-Khorassani M. Phytosterol composition of nuts and seeds commonly consumed in the United States. J Agric Food Chem. 2005;53:9436-9445.
5. Kornsteiner M, Wagner K-H, Elmadfa I. Tocopherols and total phenolics in 10 different nut types. Food Chem. 2006; 98:381-387.
6. Wu X, Beecher GR, Holden JM, Haytowitz DB, Gebhardt SE, Prior RL. Lipophilic and hydrophilic antioxidant capacities of common foods in the United States. J Agric Food Chem. 2004;52:4026-4037.

7. Tokusoglu O, Unal MK, Yemis F. Determination of the phytoalexin resveratrol (3,5,4'-trihydroxystilbene) in peanuts and pistachios by high-performance liquid chromatographic diode array (HPLC-DAD) and gas chromatography-mass spectrometry (GC-MS). J Agric Food Chem. 2005;53:5003-5009.
8. Burns J, Yokota T, Ashihara H, Lean ME, Crozier A. Plant foods and herbal sources of resveratrol. J Agric Food Chem. 2002;50:3337-3340.
9. Pellegrini N, Serafini M, Salvatore S, Del Rio D, Bianchi M, Brighenti F. Total antioxidant capacity of spices, dried fruits, nuts, pulses, cereals and sweets consumed in Italy assessed by three different in vitro assays. Mol Nutr Food Res. 2006;50:1030-1038.
10. USDA Database for the Flavonoid Content of Selected Foods. http://www.ars.usda.gov/Services/docs.htm?docid=6231. Visited on July 13, 2007.
11. Gu L, Kelm MA, Hammerstone JF, Beecher G, Holden J, Haytowitz D, Gebhardt S, Prior RL. Concentrations of proanthocyanidins in common foods and estimations of normal consumption. J Nutr. 2004;134:613-617.
12. Chen CY, Milbury PE, Lapsley K, Blumberg JB. Flavonoids from almond skins are bioavailable and act synergistically with vitamins C and E to enhance hamster and human LDL resistance to oxidation. J Nutr. 2005;135:1366-1373.
13. Anderson KJ, Teuber SS, Gobeille A, Cremin P, Waterhouse AL, Steinberg FM. Walnut polyphenolics inhibit in vitro human plasma and LDL oxidation. J Nutr. 2001;131:2837-2842.
14. Jiang R, Jacobs DR Jr, Mayer-Davis E, Szklo M, Herrington D, Jenny NS, Kronmal R, Barr RG. Nut and seed consumption and inflammatory markers in the multi-ethnic study of atherosclerosis. Am J Epidemiol. 2006;163:222-231.
15. Cortes B, Nunez I, Cofan M, Gilabert R, Perez-Heras A, Casals E, Deulofeu R, Ros E. Acute effects of high-fat meals enriched with walnuts or olive oil on postprandial endothelial function. J Am Coll Cardiol. 2006;48:1666-1671.