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Dietary Phytochemical Delivery: Glucosinolates/Isothiocyanates

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Abstract

Glucosinolates are a class of phytochemicals found in certain dietary vegetables and condiments. They are metabolized in the body to isothiocyanates and are, in part, responsible for the sharp taste of mustard seeds, horseradish, wasabi, and the Brassica vegetables. Certain of these compounds have, in the past two decades, been determined to have many positive health effects, including carcinogen detoxification and antioxidant properties. They are now being explored for their potential as components in a dietary cancer prevention strategy.

Glucosinolates

The first observation on the unique properties of glucosinolates ([beta]-thioglucoside-*N*-hydroxysulfates) (Figure 1) and isothiocyanates or mustard oils, resulted from efforts to understand the sharp taste of mustard seeds in the beginning of the 17th century. Gadamer ¹ proposed a structure for this class of compounds that was then refined by Ettlinger and Lundeen ² and by Marsh and Wasser. ³ Naturally occurring glucosinolates are compounds of some edible plants, and they have been the focus of much research during the past 40 years or so, ⁴⁻⁸ primarily for their role as the precursors of biologically active isothiocyanates. At least 121 different glucosinolates have been identified. They can be grouped into several chemical classes based upon the structural similarities of their side chains (R) (Table 1). These compounds, which convey the distinctive sharp taste to mustard and add to the flavor of Brassica vegetables, are present in a large number of edible species encompassing 16 families of dicotyledonous angiosperms (Table 2).

Class	Description	No. of Compounds
A	Sulfur-containing side chains†	39
B	Aliphatic, straight chain	6
C	Aliphatic, branched-chain	8
D	Olefins: straight, branched, and alcohols	10
E	Aliphatic: straight and branched chain alcohols	12
F	Aliphatic: straight-chain ketones	4
G	Aromatic	17
H	Benzoates	8
I	Heterocyclic (Indole)	6
J	Multiply glycosylated and other	9
	Total	119‡

*Complete structures are provided in Fahey et al⁸ and are the basis of the chemical classification scheme used herein.

†The sulfur-containing side chains consist principally of methylthioalkyl, methylsulfanylalkyl, and methylsulfonylalkyl moieties wherein the alkyl groups have chain lengths ranging from 2 to 11 methylene groups. Some of these compounds have additional side chain oxidations or desaturations.

‡The total of 121 glucosinolates referred to in the text includes 2 glucosinolates of unresolved structure.

Table 1. Structural Classes of Glucosinolates*Complete structures are provided in Fahey et al ⁸ and are the basis of the chemical classification scheme used herein. †The sulfur-containing side chains consist principally of methylthioalkyl, methylsulfanylalkyl, and methylsulfonylalkyl moieties wherein the alkyl groups have chain lengths ranging from 2 to 11 methylene groups. Some of these compounds have additional side chain oxidations or desaturations. ‡The total of 121 glucosinolates referred to in the text includes 2 glucosinolates of unresolved structure.

Family	Chemical Class*
Bataceae	I
Brassicaceae	A-J
Bretschneideraceae	E, G
Capparaceae	A, B, C, D, E, F, G, I
Caricaceae	G
Euphorbiaceae	C, E
Gyrostemonaceae	C
Limnanthaceae	E, G
Moringaceae	C, E, G, J
Pentadiplandraceae	G
Phytolaccaceae	C, E, G
Pittosporaceae	G
Resedaceae	E, G, I, J
Salvadoraceae	C, G
Tovariaceae	C
Tropaeoaceae	B, C, E, G

*Codification of chemical classes refers to Table 1.

Table 2. Structural Classes of Glucosinolates¹ Glucosinolate-containing Angiosperm Families and the General Classes of Glucosinolates That Have Been Described in Those Families¹Codification of chemical classes refers to Table 1.

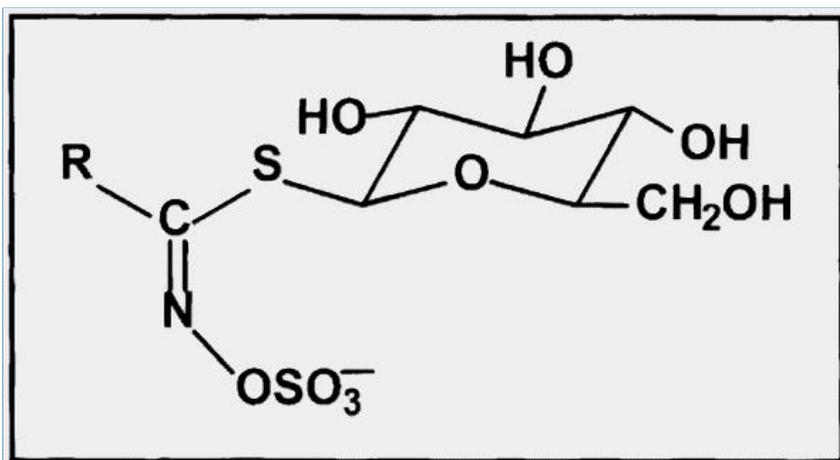


Figure 1. Glucosinolate structure. Side chains (R) are listed in Table 1.

The common feature of glucosinolates is their [beta]-thioglucoside-*N*-hydroxysulfate moiety. They have side chains containing straight or branched carbon chains, aromatic or indole-rings that may be glycosylated, desaturated, or functionalized with hydroxyl groups, carbonyl groups, or sulfur linkages in various oxidation states. The methylthioalkyl- (eg, glucoraphanin, glucoerucin, glucoirebin, blucoalysin), aromatic- (eg, glucotropaeolin, gluconasturtiin), and indole- (eg, glucobrassicin) glucosinolates have been most extensively studied. Fully one third of naturally occurring glucosinolates have a side chain containing a sulfur atom in various states of oxidation (eg, methylthioalkyl, methylsufinylalkyl, or methylsufonylalkyl). These glucosinolates with sulfur-containing side chains are abundant in the Brassicaceae, a plant family containing vegetables such as broccoli, cauliflower, and cabbage. This family contains more than 350 genera and also includes plants such as capers (*Capparis spinosa*), wasabi (*Wasabi japonica*), arugula (*Eruca sativa*), and radish (*Raphanus sativus*) that have been used for food or medicinal purposes by various cultures throughout many centuries. In addition, it contains many plants such as crambe (*Crambe abyssinica*) and rapeseed (*Brassica napus*) that are used for animal fodder and that contain glucosinolates such as progoitrin that have been linked to the development of goiter and other "antinutritional" physiologic effects. The levels of glucosinolates in many of the plants in which they occur can range from 1% of dry weight in vegetative tissues of many Brassica vegetables (also known as crucifers or cole crops) to as much as 10% in the seeds of some plants.

Functional Properties of Glucosinolates

Much previous research focused on the prevalence of certain antinutritional or goitrogenic glucosinolates in the protein-rich meal from widely grown oilseed crops and in some domesticated vegetable crops. There is, however, another positive side of this picture represented by the therapeutic or prophylactic properties of other so-called "functional" glucosinolates with potential dietary or pharmacologic application. Glucosinolates and/or their breakdown products have long been known for their fungicidal, bacteriocidal, nematocidal, allopathic, and insect-feeding attractant and deterrent properties. [6,9](#) Isothiocyanates such as sulforaphane have been shown to be active against numerous human pathogens such as *Escherichia coli*, *Salmonella typhimurium*, and *Candida* sp. [10,11](#) Medicinal properties have been ascribed to such cruciferous vegetables as cabbage and mustard, which have been used as wound poultices and antitumor agents for centuries. [12](#) Viewed in the context of epidemiologic evidence and a growing number of in vitro, animal, and clinical studies, the identification of Phase 2 enzyme elevation by specific phytochemicals, including glucosinolates/isothiocyanates, strongly suggests the involvement of these compounds in cancer chemoprotection. [13-16](#)

Glucosinolates and a Dietary Chemoprevention Strategy

One of the guiding principles in the development of dietary chemoprotective strategies has been the identification of chemical agents that induce a group of proteins, including the Phase 2 detoxification enzymes, in mammalian tissue. [17](#) These proteins reduce the risk of chemical carcinogenesis: (1) by inactivating reactive carcinogens by destruction of their reactive centers (eg, epoxide hydrolase) or by conjugating them with endogenous ligands thereby facilitating their elimination from the body (eg, glutathione *S*-transferase) or (2) by their antioxidant function within the body (eg, heme oxygenase and ferritin). In the cruciferous vegetables (eg, broccoli, *Brassica oleracea* var. *italica*; cabbage, *B. oleracea* var. *capitata*; cauliflower, *B. oleracea* var. *botrytis*; Brussel sprouts, *B. oleracea* var. *gemmifera*; watercress, *Nasturtium officinalis*) this inducer activity is principally due to the highly reactive isothiocyanates (eg, sulforaphane and phenethyl isothiocyanate). [18,19](#)

Glucosinolates and Oxidative Stress

The widespread belief that oxidative damage plays a major role in cancer, aging, and several chronic diseases has focused scientific and public attention on the possibility that antioxidants could prevent or at least retard these processes. Direct antioxidants (eg, glutathione, tocopherols, ascorbic acid, and carotenoids) are substances that can participate in physiological, biochemical, or cellular processes that inactivate free radicals or that prevent free radical-initiated chemical reactions. Direct antioxidants may also exhibit pro-oxidant effects under some experimental conditions, but whether these properties play a significant role in vivo remains unclear. In contrast, indirect antioxidants are not able to participate in radical or redox reactions as such, but they boost the antioxidant capacity of cells by a variety of mechanisms and thereby afford protection against oxidative stress. A largely ignored consequence of Phase 2 enzyme induction is thus their contribution to this cellular antioxidant capacity. [20](#)

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B	Aliphatic, straight chain	6	Brassicaceae	A-J
C	Aliphatic, branched chain	8	Bretschneideraceae	E, G
D	Chiral, straight, topAcid, and olefinic	10	Capparidaceae	A, B, C, D, E, F, G, I
E	Aliphatic, straight and branched chain olefinic	12	Cassicaceae	G
F	Aliphatic, straight chain butenes	4	Euphorbiaceae	C, E
G	Aliphatic	11	Gyrostemonaceae	C
H	Terpenoid	6	Limnathaceae	E, G
I	Terpenoid, bicyclic	6	Moringaceae	C, E, G, J
J	Aliphatic, glycosylated and other	3	Pentadiplandraceae	G
Total		128	Phytolaccaceae	C, E, G
			Pittosporaceae	G
			Rasbadoraceae	E, G, I, J
			Salvadoraceae	C, G
			Toaraceae	C
			Tropaeolaceae	B, C, E, G

†Sulfur-containing side chains in Table 1 of this site are the basis of the original classification under the class name. The sulfur-containing side chains are not always in the same position and are not necessarily the same length. The number of sulfur atoms in the side chain varies from 1 to 10. The number of sulfur atoms in the side chain is indicated in the description. The number of sulfur atoms in the side chain is indicated in the description.

Table 1

Table 2

*Classification of chemical classes refers to Table 1

Figure 1

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