British Journal of Nutrition (2003), **90**, 687–697 DOI: 10.1079/BJN2003917

Development of a food composition database for the estimation of dietary intakes of glucosinolates, the biologically active constituents of cruciferous vegetables

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(Received 19 April 2002 – Revised 21 March 2003 – Accepted 22 April 2003)

Evidence indicates that cruciferous vegetables are protective against a range of cancers with glucosinolates and their breakdown products considered the biologically active constituents. To date, epidemiological studies have not investigated the intakes of these constituents due to a lack of food composition databases. The aim of the present study was to develop a database for the glucosinolate content of cruciferous vegetables that can be used to quantify dietary exposure for use in epidemiological studies of diet–disease relationships. Published food composition data sources for the glucosinolate content of cruciferous vegetables were identified and assessed for data quality using established criteria. Adequate data for the total glucosinolate content were available from eighteen published studies providing 140 estimates for forty-two items. The highest glucosinolate values were for cress (389 mg/100 g) while the lowest values were for Pe-tsai chinese cabbage (20 mg/100 g). There is considerable variation in the values reported for the same vegetable by different studies, with a median difference between the minimum and maximum values of 5·8-fold. Limited analysis of cooked cruciferous vegetables has been conducted; however, the available data show that average losses during cooking are approximately 36 %. This is the first attempt to collate the available literature on the glucosinolate content of cruciferous vegetables. These data will allow quantification of intakes of the glucosinolates, which can be used in epidemiological studies to investigate the role of cruciferous vegetables in cancer aetiology and prevention.

Glucosinolates: Cruciferous vegetables: Food composition database: Dietary intake: Cancer

A high dietary intake of cruciferous vegetables has been consistently associated with protection against a range of cancers (Verhoeven *et al.* 1996). In the most comprehensive review to date of the epidemiological evidence for a link between cruciferous vegetables and cancer, five of the seven cohort studies identified reported an inverse association between the consumption of at least one or more cruciferous vegetables and cancer risk (Verhoeven *et al.* 1996). Of a total of eighty-seven case–control studies, sixty-eight found a lower risk of cancer associated with the consumption of cruciferous vegetables (Verhoeven *et al.* 1996). According to this review, the strongest evidence so far is for an effect in cancers of the digestive and respiratory tracts with less consistent results for the hormone-dependent cancers, although fewer studies have been reported (Verhoeven *et al.* 1996).

The largest and most commonly consumed group of edible plants within the family Cruciferae are the vegetables of the Brassica genus. The Brassica vegetables include cabbage (red, white and savoy), Brussels sprouts, broccoli, cauliflower, turnip, swede (or rutabaga), kohlrabi, kale, collard, Chinese kale, mustard (black, brown and Abyssian) and Chinese cabbage (Nugon-Baudon & Rabot, 1994). Other edible plants of the Cruciferae family include white mustard, sea kale, radish, horseradish, wasabi (Japanese horseradish), salad rocket, garden cress and watercress (Nugon-Baudon & Rabot, 1994).

Cruciferous vegetables contain a range of potentially anti-carcinogenic dietary factors including carotenoids, vitamin C, fibre, flavonoids and glucosinolates (Steinmetz & Potter, 1991). Importantly, glucosinolates are present in almost every member of the Cruciferae family (McGregor *et al.* 1983) and the presence of glucosinolates distinguishes cruciferous vegetables from other vegetables (Van Poppel *et al.* 1999). Tiedink *et al.* (1988) analysed approximately thirty different vegetables including a range of cruciferous vegetables such as cauliflower, Brussels sprouts, savoy cabbage, broccoli, red cabbage, green cabbage, oxheart cabbage, white cabbage, kohlrabi, Chinese cabbage, swede, radish and horseradish. A range of other non-cruciferous vegetables were also investigated including French beans, slicing beans, fava beans, peas, marrowfat peas, endive, chicory, spinach, lettuce, onion, leek, red beet, carrots, green pepper, red pepper, tomato,

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cucumber and mushroom. Only the cruciferous vegetables were shown to contain glucosinolates. However, three non-cruciferous edible plants have also been shown to contain glucosinolates (Nugon-Baudon & Rabot, 1994). These are capers, papaya (pawpaw) and nasturtium (Indian cress). The contribution of these plants to glucosinolate intake will vary according to the specific dietary habits of different populations.

Glucosinolates undergo hydrolysis to isothiocyanates and indoles upon contact with the enzyme myrosinase, which is present within the plant tissues (Verhoeven *et al.* 1997). Experimental studies show that these breakdown products possess a number of anti-carcinogenic activities such as induction of xenobiotic-metabolising enzymes, suppression of cancer expression, and inhibition of DNA methylation (Jongen, 1996; World Cancer Research Fund, 1997; Van Poppel *et al.* 1999; Talalay & Fahey, 2001). As with glucosinolates, these breakdown products have not been detected in non-cruciferous vegetables such as lettuce, spinach, green beans and snow peas (Jiao *et al.* 1998).

In a recent review, Crews *et al.* (2001) highlighted the lack of food composition tables for glucosinolates and the resultant difficulties in conducting epidemiological and dietary intake studies of these compounds in populations. To date, epidemiological studies investigating the cancer-protective activity of constituents of cruciferous vegetables have relied on quantifying exposure based on the weight or servings of cruciferous vegetable consumed. This approach has limitations in that the levels of glucosinolates vary between different cruciferous vegetables and it does not account for different consumption patterns between individuals (Nugon-Baudon & Rabot, 1994). The aim of the present study was to develop a database for the glucosinolate content of cruciferous vegetables that can be used to quantify dietary exposure for use in epidemiological studies investigating diet–disease relationships and overcome some of the limitations of previous studies.

A wide range of individual glucosinolates, isothiocyanates and indoles could have been quantified for the development of this food composition database. However, as research in this area is still progressing it is unclear which of the individual compounds are most important with regard to cancer-protective activity. The intake of total glucosinolates represents a biologically relevant exposure and encompasses exposure to a variety of related compounds with similar biological actions. The use of total glucosinolate intake relies on the assumption that the total glucosinolate content of the cruciferous vegetables is related to the content of hydrolysis products with anti-carcinogenic potential (i.e. isothiocyanates and indoles).

Methods

A literature search was conducted using Medline (United States National Library of Medicine, 2000) and CAB Abstracts (CAB International, 2000) to identify possible sources of published food composition data for glucosinolates. The search terms included cruciferous vegetables, brassica vegetables, glucosinolates, isothiocyanates, indoles, food composition, food and diet. Papers were identified that contained quantitative data on the total glucosinolate levels in cruciferous vegetables eaten by human consumers. Papers that only included qualitative analysis or glucosinolate profiles (that is, identification of glucosinolate compounds rather than quantifying amounts) were excluded. Papers that only measured a specific glucosinolate compound and did not report total glucosinolates were also excluded. Appropriate methods of analysis included measurement of total glucosinolates by the glucose-release method or the measurement of intact glucosinolates by HPLC or GC. Evidence shows that estimation of total glucosinolates using these methods is considered comparable (Ciska *et al.* 1994; Ciska & Kozlowska, 1998; Hrncirik *et al.* 1998). Review papers that contained no new primary data were also excluded; however, the citations used in these reviews were cross-checked with initial literature searching and any additional references were identified.

Each study was considered using established criteria (Rand *et al.* 1987). These criteria have been used in the establishment of food composition databases for other non-nutrient dietary factors such as the United States Department of Agriculture–Nutrition Coordinating Center carotenoid database (United States Department of Agriculture, 1998), the United States Department of Agriculture–Iowa State University isoflavones database (United States Department of Agriculture and Iowa State University, 2000) and the development of a flavonoid database (Peterson & Dwyer, 2000). The five criteria categories by which the studies were assessed are the analytical method used, the number of samples, the sample handling procedures, the sampling plan for selection of foods and the analytical quality control. These criteria have previously been used to calculate formal scores or ratings of data quality; however, in this context due to the relatively small number of studies available, the criteria were used to qualitatively review and compare the studies.

Initially, twenty-seven studies were identified that contained primary quantitative analysis of total glucosinolates for edible cruciferous vegetables. These studies were reviewed in order to assess comparability of data. To allow for comparison across all studies, amounts of total glucosinolates were converted to mg/100 g fresh weight. Values that were expressed on a dry-weight basis were converted to a fresh-weight basis using the reported moisture content or by assuming an expected moisture content based on literature values (National Food Authority, 1995). When glucosinolate values were expressed as μmol/100 g, the average molecular weight of glucosinolates as reported in the study was used in the conversion to mg/100 g based on the appropriate equation (mol = mass/molecular weight). If the study did not report a molecular weight, it was excluded from the database (Carlson *et al.* 1981; Tiedink *et al.* 1988; De Groot *et al.* 1991; Shattuck *et al.* 1991; Rosa & Heaney, 1993; Shattuck & Wang, 1994; Hansen *et al.* 1997; Kushad *et al.* 1999; Rodrigues & Rosa, 1999). Data expressed as mg/kg and parts per million were also converted to mg/100 g (Daxenbichler *et al.* 1979; Lewis & Fenwick, 1988). If studies involved investigation of the effects of a treatment on glucosinolate composition, then only data from control groups that represented standard growing conditions were considered. A number of studies only provided a single mean value for all cultivars whereas some studies presented individual data for each cultivar that was analysed and so in order to maintain consistency a mean value was calculated for these studies and used in the aggregation of data.

Data for identical foods from separate references were aggregated. The vegetables were grouped on the basis of the common name description and the scientific name of the vegetable where provided. Alternate common names for identical or similar foods were confirmed using appropriate references (Rogers, 1995; Conran *et al.* 1997). Both mean and median values were calculated where multiple references provided data in order to assess the effect of extreme values of the aggregated value. The median value has been presented in the database as some mean values were adversely affected by extreme values. The median has been commonly used when compiling food composition data from a limited number of studies (Mangels *et al.* 1993; Reinli & Block, 1996; Pillow *et al.* 1999).

Results

Glucosinolate values from eighteen studies were used for collation of the final database values. A summary of the important aspects of these studies including country or region of the study, the foods analysed, the analytical method, number of cultivars or samples analysed are presented in Table 1. The total glucosinolate content from all references considered for all edible vegetables of the Cruciferae family and the aggregated data are presented in Table 2.

Limited analysis of cooked cruciferous vegetables has been conducted. This resulted in a small number of studies contributing the cooked values for vegetables and in all cases, except cooked Brussels sprouts, values for cooked foods were determined by only one study. Table 3 presents the results of studies that have analysed cruciferous vegetables in both cooked and raw forms. This provides comparable data for the assessment of cooking losses and may be useful when trying to attribute total glucosinolate values for cooked vegetables where no data exist. The decrease in glucosinolate content due to cooking ranges from 18·1 to 59·2 % with a mean decrease of 35·7 %.

Discussion

This is the first attempt to summarise the available literature on the glucosinolate content of cruciferous vegetables. Previously, a number of review papers have compared results of the glucosinolate content of cruciferous vegetables but have not collated data from multiple studies to provide single estimates (McDanell *et al.* 1988; Nugon-Baudon & Rabot, 1994; Jongen, 1996).

The most common method for the measurement of total glucosinolates is based on colorimetric determination of enzymically released glucose. This method is based on the fact that when glucosinolates undergo hydrolysis, equimolar amounts of glucose are produced (De Vos & Blijleven, 1988; McDanell *et al.* 1988; Griffiths *et al.* 1998). Importantly, the production of glucose occurs regardless of the glucosinolate precursor and the conditions of hydrolysis (Fenwick *et al.* 1983). The glucose-release method was used by many of the studies included in the present review although separation and quantification of glucosinolates via HPLC and GC have also become popular (McGregor *et al.* 1983; Griffiths *et al.* 1998; Hrncirik *et al.* 1998). Evidence shows that these methods are comparable for the estimation of total glucosinolates (Ciska *et al.* 1994; Ciska & Kozlowska, 1998; Hrncirik *et al.* 1998).

The majority of literature concerning the glucosinolate content of cruciferous vegetables tends to include only fresh vegetables; however, this may have limited relevance considering that many of these vegetables are consumed after cooking (Heaney *et al.* 1985; De Vos & Blijleven, 1988). It has been suggested that calculating estimates of glucosinolate intake on values obtained from fresh vegetables provides an indication of the maximum possible intake of glucosinolates (Heaney *et al.* 1985). However, determining intakes based on the proportion of cruciferous vegetables eaten raw or cooked may allow better separation of individuals according to intake rather than treating all cruciferous vegetable intake as fresh.

Glucosinolates are lost from vegetables during processing such as storage, cutting and cooking (Heaney *et al.* 1985; De Vos & Blijleven, 1988; Verkerk *et al.* 1997). The data available from the present study suggest that average losses during cooking are approximately 36 % (for vegetables such as Brussels sprouts, cabbage, cauliflower, swede, turnip). Dekker *et al.* (2000) provide an approach to modelling the effects of cooking on the glucosinolate content of cruciferous vegetables, which is dependent on temperature used, the amount of cooking water used and the cooking time. It would be possible to apply this process to the raw food values using the cooking practices of the individual or population under investigation to account for cooking losses and their impact on the intake of glucosinolates.

Glucosinolates and their breakdown products are water-soluble compounds and it has been suggested that loss of glucosinolates during cooking is due to leaching into the cooking water (De Vos & Blijleven, 1988; Verkerk *et al.* 1997), although at least some of the loss of glucosinolates is due to degradation (Heaney *et al.* 1985). It has been shown that the level of leaching into the cooking water is more strongly related to the amount of cooking water used rather than the cooking time or method (Dekker *et al.* 2000).

It appears that not all processing results in a decrease in the content of glucosinolates. Verkerk *et al.* (2001) found that chopping and storage of cabbage leads to increased levels of some individual glucosinolates and similar results have also been shown for broccoli (Rodrigues & Rosa, 1999). Therefore, two opposing processes may be underway within the vegetables, which will affect the final content of glucosinolates in the consumed product.

Jiao *et al.* (1998) conducted studies measuring isothiocyanates in cruciferous vegetables before and after cooking. In eighty-two samples of cruciferous vegetables

Table 1. Summary of studies identified that provide quantitative data on the total glucosinolate content of cruciferous vegetables eaten by human consumers

Source	Country	Analytical method	Foods analysed	No. of samples	Sample handling	Sampling plan
Carlson *et al.* (1985)	USA	Glucose-release method	European radish	Six cultivars	Raw samples analysed. Edible portion only analysed. Storage before preparation and analysis not documented	Samples grown in one geographical location. Multiple cultivars analysed
			European-American radish	Forty-four cultivars		
			Japanese radish	Forty-one cultivars		
			Korean radish	Fifteen cultivars		
Carlson *et al.* (1987)	USA	Glucose-release method	Broccoli	Six cultivars	Raw samples analysed. Edible portion analysed only. Stored frozen after sample preparation	Samples grown in one geographical location. Multiple cultivars analysed
			Brussels sprouts	Six cultivars		
			Cauliflower	Five cultivars		
			Collards	Five cultivars		
			Kale	Five cultivars		
			Mustard greens	Two cultivars		
			Kohlrabi	One cultivar		
Ciska *et al.* (1994)	Poland	HPLC	White cabbage	Seventeen samples	Raw vegetables analysed. Edible portion analysed. Vegetables frozen and stored at −18°C before preparation and analysis	Samples grown in one geographical location. Multiple individual samples analysed
			Red cabbage	Seventeen samples		
			Savoy cabbage	Seventeen samples		
			Brussels sprouts	Forty samples		
Daxenbichler *et al.* (1979)	USA	Glucose-release method	Chinese cabbage	Fourteen cultivars (Eighteen samples)	Raw samples analysed. Edible portion only analysed. Vegetables refrigerated before sample preparation	Samples grown in one geographical location. Multiple cultivars analysed
Goodrich *et al.* (1988)	USA	HPLC	Broccoli	One cultivar	Raw samples analysed. Vegetables were freeze-dried and stored before sample preparation and analysis	Samples grown in one geographical location
			Brussels sprouts	One cultivar		
			Cabbage	One cultivar		
Heaney & Fenwick (1980)	UK	Glucose-release method	Brussels sprouts	Twenty two cultivars	Raw samples analysed. Edible portion only analysed. Vegetables frozen and stored at −40°C before sample preparation	Multiple geographical locations. Multiple cultivars analysed
Hill *et al.* (1987)	USA	Glucose-release method	Mustard greens	Seven cultivars	Raw samples analysed. Edible portion only analysed. Vegetables refrigerated (4°C) before sample preparation and analysis	Seeds from multiple geographical sources, grown in one location. Multiple cultivars analysed
			Chinese kale	Six cultivars		
			Pe-tsai Chinese cabbage	Fourteen cultivars		
			Pak-choi	Seventeen cultivars		
			Turnip	Fifteen cultivars (Four samples of each cultivar)		
Hrncirik & Velisek 1997	Czech Republic	HPLC	Kale	Not reported	Raw samples analysed. Storage before sample preparation and analysis not reported	Samples collected from one geographical location (samples collected from local market so could represent wider region)
			Cauliflower			
			White cabbage			
			Brussels sprouts			
			Kohlrabi			
			Broccoli			

Table 1. *Continued*

Source	Country	Analytical method	Foods analysed	No. of samples	Sample handling	Sampling plan
			Chinese cabbage			
			Turnip			
			Radish			
			Black radish			
			White radish			
			Horseradish			
			Watercress			
Kassahun *et al.* (1995)	Czech Republic	GC	Cabbage	Three cultivars	Raw samples analysed. Stored at 3–6°C before sample preparation and analysis	Samples grown in one geographical location. Multiple cultivars analysed
Lewis & Fenwick (1987)	UK	Glucose-release method	Calabrese (green sprouting broccoli)	Twenty-four cultivars	Raw samples analysed. Vegetables stored at −40°C before sample preparation	Samples grown in one geographical location. Multiple cultivars analysed
Lewis & Fenwick (1988)	UK	HPLC	Pe-tsai Chinese cabbage	Nineteen cultivars	Raw samples analysed. Vegetables stored at −40°C before sample preparation and analysis	Samples grown in one geographical location. Multiple cultivars analysed
			Pak-choi Chinese cabbage	Three cultivars		
McMillan *et al.* (1986)	UK	HPLC	Brussels sprouts	Two samples	Edible portion analysed only. Raw and cooked samples analysed. Cooked samples were boiled or steamed for 9 min.	Samples grown in one geographical location
Sones *et al.* (1984*b*)	UK	GC	White cabbage	Twenty-one cultivars (Thirty-two samples)	Vegetables frozen at −40°C before sample preparation and analysis	Some samples collected from local markets and others grown in multiple geographical sites. Multiple cultivars analysed
			Savoy cabbage	Seven cultivars (Eleven samples)		
			Swede	Sixteen cultivars (Thirty-three samples)		
			Turnip	Three cultivars (Nine samples)		
Sones *et al.* (1984*a*)	UK	GC	Brussels sprouts	Forty-three samples	Raw and cooked vegetables analysed. Cabbage and cauliflower boiled for 10 min; Brussels sprouts and turnip-swede boiled for 15 min. All vegetables frozen at −40°C before preparation and analysis	Samples grown in multiple geographical sites. Multiple individual samples analysed
			Cabbage (spring, savoy and summer types)	Forty-three samples		
			Swede-turnip	Forty-four samples		
			Cauliflower	Forty-four samples		
Sones et al. (1984*c*)	UK	Glucose-release method	Cauliflower	Twenty-seven cultivars	Raw samples analysed. Vegetables stored at −40°C before sample preparation and analysis	Samples from an unspecified number of geographical locations. Multiple cultivars analysed
Van Doorn *et al.* (1999)	Netherlands	Glucose-release method	Brussels sprouts	Ten samples	Raw samples analysed. Samples stored at −20°C before analysis	Samples from multiple geographical sites. Multiple samples analysed

Table 1. *Continued*

Source	Country	Analytical method	Foods analysed	No. of samples	Sample handling	Sampling plan
Van Etten *et al.* (1980)	USA	Glucose-release method	Red cabbage	Eight cultivars	Details provided in separate reference	Samples grown in multiple geographical locations. Multiple cultivars analysed
			Savoy cabbage	Four cultivars		
			White cabbage	Sixty-seven cultivars		
Yen & Wei (1993)	Taiwan	Glucose-release method	Chinese mustard	Two samples	Vegetables were ground, freeze-dried and stored at −40°C before sample preparation and analysis	Samples collected from one geographical location (samples collected from local market so may represent wider region)
			Chinese cabbage	Two samples		
			Chinese kale	Two samples		
			Broccoli	Two samples		
			White cabbage	Two samples		
			Red cabbage	Two samples		
			Cauliflower	Two samples		
			Kohlrabi	Two samples		
			Leaf mustard	Two samples		
			Radish	Two samples		

(nine different types), only three (two from kai choi and one from watercress) were found to contain detectable amounts of isothiocyanates after cooking. However, the amount of isothiocyanates found in these three cooked samples was very small compared with samples that had been cooked and subject to myrosinase hydrolysis (0·4–0·6 *v.* 71·2–81·3 μmol/100 g wet weight). This has confirmed previous reports that breakdown products of glucosinolates were not detectable in cooked cruciferous vegetables (De Vos & Blijleven, 1988). This would suggest that glucosinolates rather than their degradation products are consumed when cooked cruciferous vegetables are eaten (Jiao *et al.* 1998).

The research mentioned earlier suggests that only very small amounts of hydrolysis breakdown products, if any, are found in cooked cruciferous vegetables. The probable effect of the presence of these biologically active breakdown products, if the total glucosinolate content of cruciferous vegetables is used as the measured exposure, is to increase the exposure measurement error. However, it could be expected that this source of measurement error would occur equally for cases and controls and therefore could be interpreted as non-differential measurement error. This would result in attenuation of the diet–disease relationship rather than an alteration in the direction of the relationship (Armstrong *et al.* 1992).

Getahun & Chung (1999) found that when cooked watercress was consumed, despite the complete inactivation of myrosinase in the vegetable, glucosinolates were converted to their biologically active breakdown products and it is suggested that microflora within the intestinal tract are responsible. The metabolism and conversion of glucosinolates to isothiocyanates determines the extent and overall rate of uptake in man (Shapiro *et al.* 1998). However, it has been shown that the bioavailability of the isothiocyanate breakdown products is lower when intact glucosinolates in the diet are consumed compared with pre-hydrolysed glucosinolates (Dekker *et al.* 2000).

There is considerable variation in the glucosinolate composition of cruciferous vegetables as shown by the range of values provided by the individual studies. The median difference between the minimum and maximum values reported by different studies for the same food was 5·8-fold. This variation represents true variation due to the measurement of different cultivars of particular vegetables and different growing conditions such as soil, climate and cultivation practices but it may also represent some inter-laboratory variation in methodology.

The consumption of cruciferous vegetables (for example, in servings per day) could serve as a proxy measure for glucosinolate consumption; however, quantification of glucosinolates provides an improvement in the measurement of exposure. First, not all cruciferous vegetables contain equal amounts of glucosinolates and both the amounts and types of cruciferous vegetables that are consumed have been shown to vary across countries and within population groups (Nugon-Baudon & Rabot, 1994). For example, as income increases, there is an increase in the total fresh green vegetable consumption and a preference for milder-flavoured cruciferous

Table 2. Summary of food composition data sources for the glucosinolate content (mg/100 g fresh weight) of edible cruciferous vegetables

Food description	Scientific name	Processing	Raw data: Mean (mg/100 g)	Raw data: No of samples	Raw data: Reference	Aggregated data*: Median (mg/100 g)	Aggregated data*: Range (mg/100 g)
Broccoli	*Brassica oleracea* var. italica	Raw	40·80	2	Yen & Wei (1993)	61·7	19·3–127·5
			127·49	2	Goodrich *et al.* (1988)		
			86·01	6	Carlson *et al.* (1987)		
			19·28	NR	Hrncirik & Velisek (1997)		
			61·10	NR	Sones *et al.* (1984*a*)		
			62·30	25	Lewis & Fenwick (1987)		
Broccoli		Cooked	37·20	NR	Sones *et al.* (1984*a*)	37·2	
Broccoli, frozen		Raw	50·70	NR	Sones *et al.* (1984*a*)	50·7	
Broccoli, frozen		Cooked	20·70	NR	Sones *et al.* (1984*a*)	20·7	
Brussels sprouts	*Brassica oleracea* var. gemmifera	Raw	445·50	2	Goodrich *et al.* (1988)	236·6	80·1–445·5
			252·72	6	Carlson *et al.* (1987)		
			126·61	40	Ciska *et al.* (1994)		
			200·20	109	Heaney & Fenwick (1980)		
			80·12	NR	Hrncirik & Velisek (1997)		
			226·20	44	Sones *et al.* (1984*a*)		
			292·00	10	Van Doorn *et al.* (1999)		
			247·00	2	McMillan *et al.* (1986)		
Brussels sprouts		Boiled†	148·00	2	McMillan *et al.* (1986)	135·9	
Brussels sprouts		Boiled‡	123·70	44	Sones *et al.* (1984*a*)		
Brussels sprouts, frozen		Raw	90·50	NR	Sones *et al.* (1984*a*)	90·5	
Brussels sprouts, frozen		Cooked	61·30	NR	Sones *et al.* (1984*a*)	61·3	
Cabbage, unspecified	*Brassica oleracea* var. capitata	Raw	58·90	2	Kassahun *et al.* (1995)	58·9	42·7–108·9
			108·90	43	Sones *et al.* (1984*a*)		
			42·66	2	Goodrich *et al.* (1988)		
Cabbage, unspecified		Boiled	78·60	43	Sones *et al.* (1984*a*)	78·6	
Cabbage, Chinese, pak-choi	*Brassica chinensis*	Raw	53·37	3	Lewis & Fenwick (1988)	54·1	17·3–54·8
			17·25	NR	Hrncirik & Velisek (1997)		
			57·20	2	Yen & Wei (1993)		
			54·84	68	Hill *et al.* (1987)		
Cabbage, Chinese, pe-tsai	*Brassica pekinensis*	Raw	19·84	19	Lewis & Fenwick (1988)	20·6	8·9–54·1
			21·34	56	Hill *et al.* (1987)		
			8·90	2	Yen & Wei (1993)		
			54·11	18	Daxenbichler *et al.* (1979)		
Cabbage, red	*Brassica oleracea* var. capitata	Raw	76·62	8	VanEtten *et al.* (1980)	64·2	26·5–76·6
			18·79	1	Kassahun *et al.* (1995)		
			26·50	17	Ciska *et al.* (1994)		
			64·20	2	Yen & Wei (1993)		
			66·90	NR	Sones *et al.* (1984*a*)		
Cabbage, red		Cooked	54·80	NR	Sones *et al.* (1984*a*)	54·8	
Cabbage, savoy	*Brassica oleracea* var. sabauda	Raw	76·99	4	VanEtten *et al.* (1980)	77·0	59·5–209·0
			59·47	17	Ciska *et al.* (1994)		
			209·00	11	(Sones *et al.* (1984*b*)		
Cabbage, white	*Brassica oleracea* var. capitata	Raw	51·10	67	VanEtten *et al.* (1980)	37·7	8·4–90·0
			90·00	32	Sones *et al.* (1984*b*)		
			37·70	17	Ciska *et al.* (1994)		
			22·90	2	Yen & Wei (1993)		
			8·37	NR	Hrncirik & Velisek (1997)		
Cauliflower	*Brassica oleracea* var. botrytis	Raw	43·23	5	Carlson *et al.* (1987)	43·2	11·7–78·6
			11·70	2	Yen & Wei (1993)		

Table 2. *Continued*

Food description	Scientific name	Processing	Raw data: Mean (mg/100 g)	Raw data: No of samples	Raw data: Reference	Aggregated data*: Median (mg/100 g)	Aggregated data*: Range (mg/100 g)
			36·50	NR	Hrncirik & Velisek (1997)		
			62·00	44	Sones *et al.* (1984*a*)		
			78·60	27	Sones *et al.* (1984*c*)		
Cauliflower		Cooked§	42·00	44	Sones *et al.* (1984*a*)	42·0	
Cauliflower, frozen		Raw	40·50	NR	Sones *et al.* (1984*a*)	40·5	
Cauliflower, frozen		Cooked	27·90	NR	Sones *et al.* (1984*a*)	27·9	
Coleslaw	N/A	Raw	42·20	NR	Sones *et al.* (1984*a*)	42·2	
Collards	*Brassica oleracea* var. acephala (sabellica)	Raw	200·67	5	Carlson *et al.* (1987)	200·7	
Cress	*Lepidium sativum*	Raw	120·70	NR	Sones *et al.* (1984*a*)	389·5	
			658·20	NR	Hrncirik & Velisek (1997)		
Horseradish	*Armoracia lapathifolia* Gilib	Raw	160·12	NR	Hrncirik & Velisek (1997)	160·1	
Kale, unspecified	*Brassica oleracea* var acephala	Raw	317·11	1	Carlson *et al.* (1987)	100·7	6·7–317·1
			100·72	5	Carlson *et al.* (1987)		
			6·67	NR	Hrncirik & Velisek (1997)		
Kale, Chinese	*Brassica oleracea* var. alboglabra	Raw	62·20	2	Yen & Wei (1993)	71·3	
		Raw	80·39	24	Hill *et al.* (1987)		
Kale, curly	*Brassica oleracea* var. acephala	Raw	89·40	NR	Sones *et al.* (1984*a*)	89·4	
Kale, curly		Cooked	69·10	NR	Sones *et al.* 1984*a*)	69·1	
Kohlrabi	*Brassica oleracea* var. gongylodes	Raw	52·40	2	Yen & Wei (1993)	45·9	19·7–109·3
			19·07	NR	Hrncirik & Velisek (1997)		
			39·35	1	Carlson *et al.* (1987)		
			109·30	NR	Sones *et al.* (1984*a*)		
Kohlrabi		Cooked	73·40	NR	Sones *et al.* (1984*a*)	73·4	
Mustard greens	*Brassica juncea*	Raw	118·09	28	Hill *et al.* (1987)	281·5	118·1–544·5
			544·47	2	Carlson *et al.* (1987)		
			281·50	2	Yen & Wei (1993)		
Radish, unspecified	*Raphanus sativa*	Raw	12·50	NR	Sones *et al.* (1984*a*)	92·5	
			172·40	2	Yen & Wei (1993)		
Radish, black		Raw	92·81	NR	Hrncirik & Velisek (1997)	108·1	
			123·39	1	Carlson *et al.* (1985)		
Radish, European		Raw	44·79	6	Carlson *et al.* (1985)	44·8	
Radish, white		Raw	70·97	NR	Hrncirik & Velisek (1997)	73·9	
			76·78	7	Carlson *et al.* (1985)		
Radish, red		Raw	67·64	36	Carlson *et al.* (1985)	67·6	
Radish, Asian		Raw	138·01	41	Carlson *et al.* (1985)	123·4	
			108·77	15	Carlson *et al.* (1985)		
Swede	*Brassica napus* var. napobrassica	Raw	92·00	33	Sones *et al.* (1984*b*)	92·0	
Turnip	*Brassica rapa*	Raw	93·00	9	Sones *et al.* (1984*b*)	93·0	20·4–140·5
			140·48	60	Hill *et al.* (1987)		
			20·44	NR	Hrncirik & Velisek (1997)		
Turnip-swede	NR	Raw	56·00	44	Sones *et al.* (1984*a*)	56·0	
Turnip-swede		Cooked‡	29·10	44	Sones *et al.* (1984*a*)	29·1	
Watercress	*Nasturtium officinale*	Raw	95·00	NR	Sones *et al.* (1984*a*)	95·0	

NR, not reported; N/A, not applicable.
* Aggregated data for identical foods from separate references. The median value is presented to minimise the effects of extreme values.
† Boiled for 9 min.
‡ Boiled for 15 min.
§ Boiled for 10 min.

Table 3. Effect of cooking on the glucosinolate content (mg/100 g fresh weight) of cruciferous vegetables

Food description	Reference	Processing	Total glucosinolate content	Percentage decrease
Broccoli	Sones *et al.* (1984*a*)	Raw	61·1	39·1
		Cooked	37·2	
Broccoli, frozen	Sones *et al.* (1984*a*)	Raw	50·7	59·2
		Cooked	20·7	
Brussels sprouts	McMillan *et al.* (1986)	Raw	247·0	40·1
		Boiled*	148·0	
	Sones *et al.* (1984*a*)	Raw	226·2	45·3
		Boiled†	123·7	
Brussels sprouts, frozen	Sones *et al.* (1984*a*)	Raw	90·5	32·3
		Cooked	61·3	
Cabbage	Sones *et al.* (1984*a*)	Raw	108·9	27·8
		Boiled‡	78·6	
Cabbage, red	Sones *et al.* (1984*a*)	Raw	66·9	18·1
		Cooked	54·8	
Cauliflower	Sones *et al.* (1984*a*)	Raw	62·0	32·3
		Boiled‡	42·0	
Cauliflower, frozen	Sones *et al.* (1984*a*)	Raw	40·5	31·1
		Cooked	27·9	
Kale, curly	Sones *et al.* (1984*a*)	Raw	89·4	22·7
		Cooked	69·1	
Kohlrabi	Sones *et al.* (1984*a*)	Raw	109·3	32·8
		Cooked	73·4	
Turnip-swede	Sones *et al.* (1984*a*)	Raw	56·0	48·0
		Boiled†	29·1	

Individual publications stated that vegetables were boiled for: *9 min, †15 min, ‡10 min.

vegetables such as cauliflower or broccoli rather than cabbage or kale (Nugon-Baudon & Rabot, 1994). Compilation of the glucosinolate composition data for the individual vegetables allows for these differences in consumption to be considered. Second, the consumption of cruciferous vegetables is probably correlated with the intake of total vegetables and, as yet, most studies have not determined whether the observed effects are due to cruciferous vegetables specifically or due to the intake of vegetables generally (Verhoeven *et al.* 1996; Van Poppel *et al.* 1999). Third, cruciferous vegetables contain a range of potentially cancer-protective dietary factors, other than glucosinolates, such as vitamins, minerals and fibre (Nestle, 1998). Use of cruciferous vegetable intake as the exposure measure captures intake of all of these dietary factors and prevents the identification of the specific factors that provide protection.

This is the first attempt to collate the existing published scientific data on the glucosinolate content of foods. At this time there is a relative lack of data on the glucosinolate content of cruciferous vegetables and consequently data from different countries must be aggregated and adequate region-specific data are not available. Research in this field is ongoing and it is probable that additional data on the glucosinolate content will become available. As these studies become available, this database will need to be reviewed and updated. Similarly, further research into the importance of specific glucosinolate compounds will require their inclusion into food composition databases. These data serve as an interim measure in the quantification of dietary exposure to the biologically active constituents of cruciferous vegetables. These data will allow the quantification of intakes that can be used to investigate the role of cruciferous vegetables in cancer aetiology and prevention.

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