Variation and Distribution of Glucosinolates in 42 Cultivars of *Brassica oleracea* Vegetable Crops

R. Verkerk, S. Tebbenhoff and M. Dekker
Product Design and Quality Management Group
Department of Agrotechnology and Food Sciences
Wageningen University
Wageningen
The Netherlands

Keywords: cabbage, broccoli, Brussels sprouts, cauliflower, kale, Romanesco, kohlrabi, genetic variation, glucoraphanin

Abstract

***Brassica* vegetables are known to contain glucosinolates that are precursors for bioactive compounds like isothiocyanates that have been shown to play an important role in human health. This study reports the results of a screening of 11 *Brassica oleracea* crops consisting of 42 cultivars (6 white cabbage, 5 red cabbage, 7 Brussels sprouts, 2 kale, 1 tronchuda, 3 oxheart cabbage, 2 kohlrabi, 6 broccoli, 5 cauliflower, 3 romanesco and 2 Savoy cabbage). All these cultivars were cultivated under the same conditions on a single location in the same season. The variation found in the level of glucosinolates is expected to be mainly due to the genetic variation. A large variation was observed in the level and profile of glucosinolates. Total glucosinolates varied from 14 to 625 µmol/100 g fresh weight. Glucoraphanin, the precursor of the isothiocyanate sulforophane, varied from 0 to 141 µmol/100 g fresh weight. Within broccoli glucoraphanin varied from 27 to 141 µmol/100 g fresh weight. Glucoiberin that is structurally related to glucoraphanin varied from 6 to 397 µmol/100 g fresh weight. Within broccoli glucoiberin varied from 21 to 397 µmol/100 g fresh weight.**

INTRODUCTION

Fruits and vegetables are abundant sources of various, extensively studied, health-protective phytochemicals. One important group of these phytochemicals is that of the glucosinolates. Glucosinolates (GS) comprise a group of thioglucosides naturally occurring in *Brassica* vegetables such as broccoli, cauliflower, radish, Brussels sprouts and cabbage. Glucosinolates co-exist with, but are physically separated from the hydrolytic enzyme myrosinase in the intact *Brassica* plant. Upon mechanical injury of the tissue, the enzyme and substrate come into contact resulting in hydrolysis (Mithen et al., 2000). The products of GS hydrolysis, particularly the isothiocyanates and indoles, have been shown to act as anticarcinogens by inhibition of phase I enzymes responsible for bioactivation of carcinogens and by induction of phase II detoxification enzymes that affect xenobiotic transformations (Talalay and Fahey, 2001). Research is ongoing to establish the biological activities of dietary glucosinolates and breakdown products, their bioavailability and metabolism (Mithen et al., 2000).

Epidemiological studies indicate that a diet rich in *Brassica* vegetables can reduce the risk from a number of cancers (Van Poppel et al., 1999; Verhoeven et al., 1997). However, up to now epidemiology cannot reproducibly correlate protection against certain cancers or other diseases with specific vegetables, subgroups or individual components. A plausible explanation for this can be the lack of realistic intake data of specific health protective phytochemicals. Assessment of accurate dietary intake of phytochemicals thus can play a crucial role. With more knowledge on the effects of the complete vegetable production chain a more effective choice can be made on how to enhance phytochemical levels in the final consumed product. Moreover, epidemiological studies can possibly be improved by correcting phytochemical intake data for different steps in the food production chain. Previously we have demonstrated a large variability in levels of glucosinolates within a food production chain of *Brassica* vegetables (Dekker et al., 2000; Dekker and Verkerk, 2003, 2005).

In this article we present a comparative study of glucosinolate distribution and variability between and within groups of the most widely consumed *Brassica* vegetables such as different types of cabbage, broccoli, cauliflower, kale and Brussels sprouts.

MATERIAL AND METHODS

Materials

The various *Brassica* vegetables were commercial hybrids supplied by Bejo Zaden BV (Warmenhuizen, The Netherlands). The plants were grown on the same field (2002) under standard cultivation and harvest conditions. At optimum maturity five plants were harvested of each cultivar. All the edible parts of the vegetables were used for glucosinolate analysis. The vegetables were chopped, mixed thoroughly and directly frozen with liquid nitrogen. The frozen material was ground in a Waring Blender (Model 34BL99, Dynamics Corp. of America, New Hartford, Connecticut, USA) and stored at -30°C until further analysis.

Glucosinolate Analysis

Individual glucosinolates were analysed using high performance liquid chromatography (HPLC) following on-column desulphation as described by Verkerk et al. (2001). Values are reported as µmol/100 g fresh weight (FW).

RESULTS AND DISCUSSION

The results of the analysis of the individual glucosinolate levels of the 42 cultivars of the 11 *Brassica oleracea* crops are given in Table 1.

Broccoli

The predominant glucosinolate in broccoli is glucoraphanin, ranging from 26.6 to 141.2 µmol/100 g FW, with the exception of cultivar ‘Bordeaux’ (purple sprouting broccoli) that has an exceptionally high level of glucoiberin (396.5 µmol/100 g FW). The other broccoli varieties had glucoiberin levels ranging from 20.6 to 52.2 µmol/100 g FW. No sinigrin was detected in broccoli, with the exception of ‘Bordeaux’.

Brussels Sprouts

The total level of glucosinolates in Brussels sprouts is, on average, the highest of all the tested *Brassica* vegetables. The predominant glucosinolate in Brussels sprouts is sinigrin, ranging from 51.9 to 310.9 µmol/100 g FW, followed by progoitrin, ranging from 25.3 to 157.2 µmol/100 g FW.

Cauliflower

Cauliflower contains relatively low amounts of glucosinolates. Glucoiberin is the predominant glucosinolate ranging from 7.6 to 34.2 µmol/100 g FW.

Kale

In one of the varieties glucoiberin is the predominant glucosinolate, while in the other one more gluconasturtiin is present.

Kohlrabi

Kohlrabi contains relatively low amounts of glucosinolates. The red variety (‘Kolibri’) contains four times more compared to the white variety (‘Korist’).

Oxheart Cabbage

The total glucosinolate level of oxheart cabbage ranges from 85 to 165 µmol/100 g FW. In two of the three varieties glucoiberin has the highest levels, ranging from

31.2 to 72.0 µmol/100 g FW. The other variety ('Bejo 2574') has a high level of glucobrassicin (90.7 µmol/100 g FW).

Red Cabbage

Red cabbage has relatively high levels of glucoraphanin, ranging from 19.8 to 105.3 µmol/100 g FW, which is in the same range as the tested broccoli varieties. Other glucosinolates with relatively high levels are glucoiberin, progoitrin, sinigrin and gluconapin. The total level of glucosinolates ranges from 140 to 381 µmol/100 g FW.

Romanesco

Romanesco contains relatively low amounts of glucosinolates, ranging from 46 to 53 µmol/100 g FW.

Savoy Cabbage

Savoy cabbage contains predominantly glucoiberin and sinigrin. The 'Wirosa' variety has an exceptional high level of glucoiberin (289.8 µmol/100 g FW) and total glucosinolates (482 µmol/100 g FW).

White Cabbage

Sinigrin and glucoiberin are the glucosinolates with the highest levels in white cabbage. The total level ranges from 127 to 241 µmol/100 g FW.

Tronchuda

Only one variety of tronchuda (Portuguese kale) was tested. It contains relatively low amount of glucosinolates. The predominant glucosinolate was glucoiberin (22.1 µmol/100 g FW).

CONCLUSIONS

A large variation was observed in the level and profile of glucosinolates of 11 *Brassica oleracea* crops consisting of 42 cultivars (6 white cabbage, 5 red cabbage, 7 Brussels sprouts, 2 kale, 1 tronchuda, 3 oxheart cabbage, 2 kohlrabi, 6 broccoli, 5 cauliflower, 3 romanesco and 2 Savoy cabbage). Total glucosinolates varied from 14 to 625 µmol/100 g fresh weight. Glucoraphanin, the precursor of the isothiocyanate sulforophane, varied from 0 to 141 µmol/100 g fresh weight. Within broccoli glucoraphanin varied from 27 to 141 µmol/100 g fresh weight. Glucoiberin that is structurally related to glucoraphanin varied from 6 to 397 µmol/100 g fresh weight. Within broccoli glucoiberin varied from 21 to 397 µmol/100 g fresh weight.

Since all cultivars were cultivated under the same conditions on a single location in the same season, the observed variation in the level of glucosinolates is expected to be mainly due to the genetic variation. Even within the same vegetable type the variation can be very large.

By selection of cultivars the level of desirable glucosinolate can be enhanced considerably, which can lead to a substantial increase of the intake of health promoting glucosinolates even without increasing the overall vegetable consumption. To reach this goal also the critical points in the food supply chain that determine the retention of glucosinolates in the finally consumed product (industrial processing and consumer preparation) have to be optimized and controlled.

Literature Cited

Dekker, M., Verkerk, R. and Jongen, W.M.F. 2000. Predictive modelling of health aspects in the food production chain, a case study on glucosinolates in cabbage. Trends in Food Science & Technology 11(4/5):174-181.

Dekker, M. and Verkerk, R. 2003. Dealing with Variability in Food Production Chains: A Tool to Enhance the Sensitivity of Epidemiological Studies on Phytochemicals. Eur. J. Nutri. 42:67-72.

Dekker, M. and Verkerk, R. 2005. Modelling the Consequences of Variability in Food Production Chains on Human Health. Acta Hort. 674:71-76.
Mithen, R.F., Dekker, M., Verkerk, R., Rabot, S. and Johnson, I.T. 2000. The nutritional significance, biosynthesis and bioavailability of glucosinolates in human foods. J. Sci. Food Agric. 80:967-984.
Talalay, P. and Fahey, J.W. 2001. Phytochemicals from cruciferous plants protect against cancer by modulating carcinogen metabolism. Journal of Nutrition 131(11 supplement):3027S-3033S.
Van Poppel, G., Verhoeven, D.T.H., Verhagen, H., Goldbohm, R.A. et al. 1999. *Brassica* vegetables and cancer prevention. Epidemiology and mechanisms. Advances in Experimental Medicine and Biology 472:159-68.
Verhoeven, D.T.H., Verhagen, H., Goldbohm, R.A., van den Brandt, P.A. and van Poppel, G.A. 1997. A review of mechanisms underlying anticarcinogenicity by *brassica* vegetables. Chem. Biol. Interact. 103:79-129.

Tables

Table 1. Glucosinolate levels (µmol/100 g fresh weight) of *Brassica oleracea* varieties.

variety	glucoiberin	progoitrin	sinigrine	raphanin	napoleiferin	glucoalysin	gluconapin	4OH-glucobrassicin	glucobrassicanapin	glucobrassicin	gluconasturtiin	4-methoxyglucobrassicin	neoglucobrassicin	total
BROCCOLI														
Alborada	25.9	5.0		69.2			3.9			13.7		8.4	7.5	134
Belstar	26.2	7.4		130.1	1.5		3.6			29.6		9.0	6.8	214
Bordeaux	396.5	5.9	15.7	26.6			42.1	2.7		24.2		10.5	9.6	534
Coronado	52.2	9.0		141.2	0.9		3.4	1.5		23.6		12.7	20.1	265
Lucky	20.6	5.5		35.7	1.2		6.1			6.9		5.1	4.4	86
Surveyor	26.0	5.0		57.4	1.1		2.3			14.4		6.3	8.6	121
BRUSSELS' SPROUTS														
Dominator	83.3	93.2	310.9	9.2			47.6	3.3		54.8	11.0	11.7		625
Doric	38.2	157.2	149.8	26.4	0.4	2.1	110.8	3.1	4.5	60.5	9.9	5.1	0.7	569
Franklin	51.1	105.6	141.5	27.9	1.1		72.9	0.7		101.7	12.2	2.5		517
Glenroy	37.0	48.3	122.5	11.7			22.1	3.3	0.6	76.7	1.9	7.6		332
Maximus	91.5	25.3	64.5	22.8			36.6	2.0	2.5	28.3	9.2	3.4	0.4	287
Nautic	37.0	67.1	51.9	41.8		24.3	32.0	0.8	10.6	43.9	9.2	2.3	1.1	322
Revenge	47.5	111.8	202.3	8.5			52.2	2.6		37.9	7.3	8.7		479
CAULIFLOWER														
Cassius	7.6	3.6	4.9	0.7	1.6	3.5	0.5	1.4		4.9		2.0	0.7	31
Encanto	10.5	6.1	7.4		3.6	9.4	0.3	0.7		2.5		1.2		42
Jerez	16.8	4.8	12.4	2.8	2.7	2.7				2.3		1.4		46
Panther (green)	34.2	3.4		7.9	2.1	4.3	0.8			4.8		1.7		59
Skywalker	10.2	6.1	6.2		3.5	2.1	0.3			3.3		0.8		33

Table 1. Continued.

variety	glucoiberin	progoitrin	sinigrine	raphanin	napoleiferin	glucoalysin	gluconapin	4OH-glucobrassicin	glucobrassicanapin	glucobrassicin	gluconasturtiin	4-methoxyglucobrassicin	neoglucobrassicin	total
KALE														
Redbor	23.4	6.1	10.4				6.6	3.6	6.7	2.8	68.0	4.9	27.2	160
Riphor	35.0	6.3	20.0	1.7			9.4			4.9	5.2	3.5	14.0	100
KOHLRABI														
Kolibri	12.8			28.6	0.8		4.8	1.0		3.1			1.1	52
Korist	6.4				1.0		3.3	1.7						12
OXHEART CABBAGE														
Bejo 2574	32.3	1.6	20.0		2.1	1.7	2.6	0.5		90.7	2.6	8.7	1.5	164
Bejo 2575	72.0	6.3	45.1	9.2	1.1		8.3			19.2		4.1		165
Capricorn	31.2	5.9	24.6	5.0			9.1			6.1		3.0		85
RED CABBAGE														
Azurro	19.5	30.5	31.4	19.8	0.8		25.7	0.7		10.2		1.9		140
Buscaro	51.6	75.7	79.5	66.2	0.4	0.4	59.3	1.6		6.0		2.8		344
Huzaro	21.9	37.3	25.5	105.3	0.8	1.4	26.0	2.2		9.9		3.5		234
Integro	30.1	42.3	53.1	61.0		0.4	35.2	1.6		9.5	1.2			234
Pesaro	57.7	68.6	79.1	97.9	0.9	0.6	59.1	2.1		8.9	1.4	4.7		381
ROMANESCO														
Amfora	13.0	4.7		16.0	2.9	3.9	0.5			6.3		4.4	1.5	53
Bejo 1955	25.4	3.0		2.1	3.1	3.0				5.4		3.2	1.1	46
Veronica	15.9	3.6		12.4	2.0	3.9	0.2			5.5		3.9	0.9	48

Table 1. Continued.

variety	glucoiberin	progoitrin	sinigrine	raphanin	napoleiferin	glucoalysin	gluconapin	4OH-glucobrassicin	glucobrassicanapin	glucobrassicin	gluconasturtiin	4-methoxyglucobrassicin	neoglucobrassicin	total
SAVOY CABBAGE														
Ovasa	54.2		17.2				2.7	0.3		15.2		6.1		96
Wirosa	289.8	6.4	141.8	7.8			3.7			27.6		4.7		482
WHITE CABBAGE														
Almanac	24.8	28.3	32.2	18.9			18.3	0.9		0.9		2.6		127
Deen	60.7	5.8	106.0	3.8			3.0	0.4		8.3	4.9	1.2		194
Krautman	67.7	6.7	84.1	1.9	4.9		1.4	2.0		1.2		2.6		173
Lennox	109.0	8.2	56.1	18.8			4.3	0.7		3.5		2.5		203
Mandy	100.1	14.6	67.4	28.3	6.3		8.2	1.6		4.0		2.9		233
Mentor	57.6	16.0	142.6	3.1	3.4		10.9	1.6		3.1		2.3	0.4	241
TRONCHUDA														
Beira	22.1	1.7	2.1	1.3	4.8		11.7			17.7		3.7	1.6	67