Genetic Variation in Glucosinolate Content within *Brassica rapa* Vegetables

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Abstract

Glucosinolates (GSs) were analyzed in 56 accessions of *Brassica rapa* grown in the greenhouse. Eight different glucosinolates were identified in the *Brassica rapa* group. They are the aliphatic glucosinolates progoitrin (PRO), gluconapin (NAP), glucobrassicanapin (GBN), the indolyl glucosinolates 4-hydroxyglucobrassicin (4OH), glucobrassicin (GBC), 4-methoxyglucobrassicin (4ME), neoglucobrassicin (NEO) and the aromatic glucosinolate gluconasturtiin (NAS). Gluconapin, glucobrassicanapin, progoitrin and gluconasturtiin are the most abundant GSs in the *Brassica rapa*, but there is considerable variation in content among accessions. The total glucosinolate contents in *Brassica rapa* group varied substantially between the different accessions. The highest amount of GSs (361 μmol/100 g FW) was observed in leaves of vegetable turnip, followed by rapid cycling and yellow sarson, with the amount of 200 and 178 μmol/100 g FW respectively. Whereas the lowest GSs content was found in turnip greens (20.8 μmol/100 g FW) and Wutacai (22.6 μmol/100 g FW). The total aliphatic GSs proportion varied from 50 to 90% of the total GS, while generally the content of indolyl glucosinoloates, especially 4OH glucobrassicin and neoglucobrassicin is low. Gluconasturtiin was found in relatively high concentrations in komastsuna (14.6 μmol/100 g FW), yellow sarson (7.1 μmol/ 100 g FW) and constitutes as much as 24% of the total amount of glucosinolates. Relatively high amounts of gluconapin (281 μmol/100 g FW) and glucobrassicanapin (60.0 μmol/100 g FW) were observed in the leaves of vegetable turnip. Compared with the *Brassica oleracea* group, *Brassica rapa* lacks glucoraphanin and sinigrin but contains gluconapin and glucobrassicanapin. Variations in glucosinolate content among genotypes suggest differences in their health-promoting properties and the opportunity for enhancement of their levels through breeding or genetic modification.

INTRODUCTION

Epidemiological studies have revealed an inverse association between vegetable consumption and chronic diseases such as different types of cancer (Steinmetz and Potter 1996; Schreiner, 2004) and cardiovascular disease (Kris-Etherton et al., 2002). Brassica vegetables such as broccoli, cabbage, kale and cauliflower can reduce the risk for a number of cancers (Graham, 1983; Wattenberg, 1993; Kushad et al., 1999). Phytochemicals have been demonstrated to be active components responsible for this observed protective effect by several cellular and biochemical in vitro tests as well as animal experiments (Grubb and Abel, 2006). Glucosinolates (GSs) comprise a group of thioglucosides naturally occurring in the family of *Brassicaceae*. They are a diverse class of S- and N-containing secondary metabolites that are mainly found in members of the Brassicaceae (Fenwick et al., 1983; Rosa et al., 1997). Glucosinolates co-exist with, but are physically separated from the hydrolytic enzyme myrosinase (E.C. 3.2.3.1) in the

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intact Brassica plant. Upon mechanical injury of the tissue, the enzyme and substrate come into contact, resulting in hydrolysis of glucosinolates to biologically active products. Breakdown products are isothiocyanates, thiocyanates and nitriles, depending on the reaction conditions and presence of associated proteins (Fenwick et al., 1983; Chew, 1988). Glucosinolate breakdown products are proposed to act as allelochemicals and to play a role in plant defences and human health (other references). Glucosinolates, myrosinase, their associated proteins, and hydrolysis products constitute a frequently-studied plant defense system that appears to deter generalist herbivores and pathogens, but attracts certain specialist herbivores (Chew, 1988; Bones and Rossiter, 1996; Renwick, 2001). Glucosinolates have also been frequently investigated for their roles in preventing cancer (Grubb and Abel, 2006; Steinmetz et al., 1996). 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 (Zhang et al., 1994). Research is ongoing to establish the biological activities of dietary glucosinolates and breakdown products, their bioavailability and metabolism (Mithen et al., 2000).

B. rapa belongs to the *Cruciferae* (*Brassicaceae*) family. *Brassica rapa* (2n=20) contains various cultivars specialized for oil-seed production. In addition, it is also used as a vegetable, for either leaves or stems are harvested (Rubatzky and Yamaguchi, 1997). The domesticated forms of *B. rapa* grown in Europe are turnip rape (*B. rapa* ssp. *oleifera*), grown for oil-seed production and turnip (*B. rapa* ssp. *rapifera*) which can be used as a vegetable as well as fodder. In Asia there are two oil producing subspecies of importance, *B. rapa* ssp. *trilocularis*, yellow sarson, and *B. rapa* ssp. *dichotoma*, brown sarson or toria (Mansfelds, 1986). Yellow sarson is grown in India, Afghanistan, Nepal, and south China. The green leaves can be utilized as a vegetable. Brown sarson is grown in India, mainly in Punjab. Other turnip variants are widely cultivated in Asia. Moreover, in China many different subspecies such as *B. rapa* ssp. *pekinensis* and ssp. *chinensis* are used mainly for vegetables, for example pak choi, tai-tasi, and choy sum which nowadays are also cultivated in other parts of the world. Previously it has been described that many steps in the food production chain of Brassica vegetables are responsible for a large variation in the final intake by humans of glucosinolates (Verkerk and Dekker, 2004). Primary production, industrial processing and domestic preparation of foods are the main sources of variation. Variation during primary production might be caused by genetic variation or results from differences in cultivation practices and environmental factors.

Glucosinolate content and distribution of most widely consumed *Brassica oleracea* vegetables such as cabbage, cauliflower, Brussels sprouts and broccoli were reported (Mithen et al., 2000; Kushad et al., 1999; Rosa et al., 1997). However, limited studies have been done on the distribution and variation of glucosinolates in *Brassica rapa* vegetables such as Chinese cabbage and Pak choi. Generally the total glucosinolates are lower than that of *B. oleracea* and have different individual glucosinolate profiles (He et al., 2000, 2003; Krumbein et al., 2005). Therefore, the aim of this study is to characterize the existing genetic variation of glucosinolate levels and profiles in *Brassica rapa* germplasm in order to improve crops for health.

MATERIAL AND METHODS

Plant Material

Brassica rapa plants used in this experiment were listed as in Table 1. Seeds used in this experiment were supplied by CGN of Wageningen University and National Engineering Research Centre for Vegetables in Beijing, China. Plants were cultivated in an environmentally controlled greenhouse (UNIFARM, WUR in Netherlands) and the experimental design was laid out with three replications of 3-5 plants. In total 56 accessions were cultivated, representing the different *B. rapa* morphotypes (Table 1). Seeds were sown on 04.03.2005 in plastic pots containing peat substrate. The pots were

held in the greenhouse at a day/night temperature of 20°C/18°C. Two weeks later the seedlings had 3-5 true leaves, they were transplanted into the field. The material was harvested about 40 days after sowing for investigating glucosinolate profiles and variation among *Brassica rapa* plants.

Sample Preparation

After harvesting, leaves of 3-5 plants were pooled and sliced into 1 cm pieces and mixed, about 300 g material were stored at -20°C then freeze dried using the freezing drying instrument GRI 20-85 MP. The freeze dried plant material was ground with a coffee mill to fine powder, and stored at -30°C for further glucosinolate extraction.

Glucosinolate Extraction

The method is based on extraction of glucosinolates with hot methanol (Verkerk et al., 2001) with little modifications. 0.2 g freeze dried material was transferred to a 15 ml Greiner tube adding 5 ml of methanol (100%) at 75ºC. At this moment, 0.25 ml of the internal standard (glucotropaeolin 3 mM) was added. The samples were incubated 20 minutes in a water bath at 75ºC and they were mixed every 5 minutes. After that, the samples were centrifuged 10 minutes at 2500 rpm. The supernatant was collected in a new 15 ml Greiner tube and the pellet was re-extracted twice with 5 ml of 70% methanol at 75ºC, centrifuged and the supernatant was mixed with the first one. The extract was stored at -20ºC until purification and desulphation steps.

Purification and Desulphation

The extracted glucosinolates were purified on a 1.5 cm DEAE Sephadex A-25 anion exchange column. The column was washed twice with 1 ml of Millipore water, and 2 ml of glucosinolate extract were added. Then the column was washed twice with 1 ml of 0.02 M NaAC-solution. Finally, 75 µl of sulphatase enzyme (25 mg/ml) were added and this was incubated overnight at room temperature. After incubation, the desulphated glucosinolates were eluted with Millipore water (3 x 0.5 ml). The eluate was filtered over a 0.45 µm filter and the sample was ready for HPLC analysis.

HPLC Analysis

For the glucosinolate analysis an HPLC method (Verkerk et al., 2001) was used. The desulphated glucosinolates were separated by a Nova Pak C18 (5 µm) reversed phase column (3.9 mm x 150 mm; Waters, Milford, MA, USA). The system used was a HPLC unit (Spectra Physics) with a binary gradient and UV detector at a wavelength of 229 nm. The column had a reversed phase pre column (type C18, Nova Pak 4 µm; 3.9 mm x 20 mm; Waters, Milford, MA, USA). Eluents used: eluent A (0.05% tetramethylammoniumchloride (TMACl) solved in Milli Q water) and eluent B (0.05% tetramethylammoniumchloride in Milli Q/acetonitrile (80/20 v/v)). The total running time was 31 min and the gradient was changed as follows: 100% A/0% B for 1 min, then in 20 min to 0% A/100% B, and in 5 min to 100% A/0% B. Afterward the column was equilibrated at 100% A/0% B for 5 min. The flow was 1 ml/min for each eluent and 20 µl of the sample were injected.

The results were analyzed using the ChromQuest program (Thermo Electron Corporation). The glucosinolate content of each sample was calculated using the response factors referred to the internal standard (glucotropaeolin). The results were expressed as µmol GSL/100 g of fresh material. The total glucosinolate level was calculated by adding up all the individual glucosinolates. The peaks were identified by comparison with standards of individual glucosinolates and reference materials with data obtained from the literature.

Data Analysis

All collected experimental data were statistically analyzed with Excel. Mean glucosinolate contents and SD were calculated of different accessions.

RESULTS AND DISCUSSION

Glucosinolate Profiles in *Brassica rapa*

Eight different kinds of glucosinolates were identified in the *Brassica rapa* group (progoitrin, gluconapin, glucobrassicanapin, gluconasturtiin, 4OH glucobrassicin, Glucobrassicin, 4ME glucobrassicin and NEO glucobrassicin). The predominant glucosinolates were gluconapin, gluobrassicanapin, progoitrin in aliphatic glucosinolates as well as gluconasturtiin in aromatic glucosinolate. All four indolyl GSs were detected in this group but there is relatively lower concentration. Figure 1 shows the typical HPLC chromatogram of *Brassica rapa*. This result is in agreement with previous reports (He et al., 2000, 2003) that analyzed in Pak choi by intact-GSs HPLC method. Similarly, Lewis and Fenwick (1988) and Shattuck and Wang (1994) reported the same glucosinolate profiles in pak choi. However, in recent study Krumbein found that glucoalyssin and glucoraphanin were also detected in this group (Krumbein et al., 2005). In *B. rapa* there is relatively little variation in structure. All genotypes, including wild accessions, accumulate some or all of 3-butenyl, 4-pentenyl glucosinolates and their hydroxylated forms (Mithen et al., 2000). In *B. rapa* group, the same glucosinolate profiles were identified in different varieties all having similar genomes (2n = 2x = 20). This is probably explained by the closely related varieties that have the same profiles of glucosinolates.

Total Glucosinolates in *Brassica rapa*

Total glucosinolate contents in *Brassica rapa* group varied substantially between the different species (Fig. 2). The highest amount of GSs (361.26 μmol/100 g FW) was observed in vegetable turnip leaves, followed by rapid cycling and yellow sarson, with the amount of 200.44 and 177.77 μmol/100 g FW respectively. Whereas the lowest GSs content was found in turnip greens (20.79 μmol/100 g FW) and Wutacai (22.61 μmol/ 100 g FW).

Significant differences of total glucosinolate levels among *Brassica rapa* group were observed in this experiment. It is reported that most likely the genetic control of glucosinolate synthesis in various species (Magrath et al., 1993; Rosa et al., 1997). Glucosinolate content in turnip greens, Wutacai and Pak choi is much less than in vegetable turnip and rapid cycling. Lewis and Fenwick (1988) also point out that both pak choi and pe-tsai were low in glucosinolate content in comparison with other UK Brassicas. Shattuck and Wang (1994) reported that the glucosinolate contents in pak choi ranged from 2.53 to 4.30 μmol g^{-1} DW which is corresponding to our results of 40 μmol 100 g^{-1} FW, whereas about 100 μmol 100 g^{-1} FW of glucosinolates were observed by Lewis and Fenwick (1988). This high level is probably due to the cultivars used and because of different growing conditions and may be attributed to the center of origin and varying parentages. Vegetable turnip, rapid cycling and yellow sarson contain a great deal of glucosinolates as compared with others, it is about 10-30 fold higher than in turnip greens. Dilawari et al. (1987) previously reported that yellow sarson have a higher GSs contents than in Chinese cabbage and taramira. Moreover, there is a higher glucosinolate concentration in seed than in plants (Rahman et al., 1986). This may be caused by the activity of key enzymes in the GSs synthesis pathway or due to the cultivars and geographic variation of these vegetables.

Individual Glucosinolates and Variation in *Brassica rapa*

Gluconapin, gluobrassicanapin, progoitrin and gluconasturtiin are the most predominant GSs in *Brassica rapa* group. The total aliphatic GS proportion varied from 50 to 90% of the total GS in this group, generally they contain relatively low content of indolyl GSs especially 4OH glucobrassicin and neoglucobrassicin. Although GSs profiles in Brassica group are the same, there are much more distribution variations among species and cultivars (Fig. 3). In broccoletto, komatsuna, rapid cycling, vegetable turnip and yellow sarson the predominant glucosinolate is gluconapin, in choy sum and mizuna,

progoitrin is predominant GS. Whereas in winter turnip oilseed rapa and namenia there is higher proporation of glucobrassicanapin compared with others. High concentrations of gluconasturtiin was observed in tai cai, turnip greens and raapstelen.

Results show significant differences in content of individual glucosinolate levels among the varieties in *B. rapa* (Table 2). Aliphatic glucosinolates are the main constitute of the total GSs, the proportation ranged from 41% (tai cai) to 96% (rapid cycling). Whereas aromatic GS gluconasturtiin proportation ranged from 1.3% (rapid cycling) to 24% (tai cai). Generally *B. rapa* contain relatively low indolyl GSs, ranged from 2.6% (komatsuna) to 29% (Chinese cabbage). This result highlights the genotype effects on glucosinolate composition and content (Fenwick et al., 1983; Rosa et al., 1997; He et al., 2000, 2003).

Relatively high amounts of gluconapin (281.12 μmol/100 g FW) and glucobrassicanapin (60.03 μmol/100 g FW) were observed in the leaves of vegetable turnip. The lowest contents were found in mizuna with amount of 3.78 μmol/100 g FW and 0.19 μmol/100 g FW, respectively. In pak choi, the predominant glucosinolates were gluconapin (8.57 μmol/100 g FW) and neoglucobrassicin (4.94 μmol/100 g FW). In choy sum were gluconapin (12.26 μmol/100 g FW) and progoitrin (10.93 μmol/100 g FW). This result is the same as previous research (He et al., 2000, 2003), but the GSs amount is much lower which may be due to different cultivars and growing conditions. Shattuck and Wang (1993) also found higher levels of gluconapin and neoglucobrassicin compared to other glucosinolates in pak choi. An earlier study (Cole, 1976) reported the presence of isopropyl-GS, 2-propenyl-GS and 3-methylthiopropyl-GS in pak choi. 5-Methylsulphinylpentyl-GS was detected in some cultivars as well (Lewis and Fenwick, 1988). In Chinese cabbage, the highest GS is progoitrin (15.20 μmol/100 g FW), followed by gluconapin (10.65 μmol/100 g FW) and glucobrassicanapin (7.94 μmol/100 g FW). The highest concentration of gluconapin was observed in yellow sarson, rapid cycling and komastsuna, which represent about 50-90% of the total GSs. Dilawari et al., (1987) and Rahman et al. (1986) also reported high concentration of gluconapin in yellow sarson, but allyl-, methylthiobutyl-, methyl- GSs were found in their research. Gluconasturtiin was generally found in high concentrations in komastsuna (14.58 μmol/100 g FW), yellow sarson (7.10 μmol/100 g FW), tai cai (6.84 μmol/100 g FW) and Chinese cabbage (6.50 μmol/100 g FW), and constitute as much as 24% of the total amount of GSs. Other studies showed that gluconasturtiin is abundant in Chinese cabbage, radishes, and watercress (Rosa et al., 1997). The typical flavour of Brassica vegetables is largely due to glucosinolate-derived volatiles, notably isothiocyanates and nitrils (Fenwick et al., 1983). Glucosinolates present in the pak choi group possessing but-3-enyl-, pent-4-enyl- and 2-phenethyl- side chains would be expected to generate volatile properties, but the low levels of these compounds in Chinese cabbage, pak choi, choy sum and tai tsai, as compared with mustard and cole groups, are consistent with their mild flavour.

Several intraspecific studies have documented genetic variation for glucosinolate type and concentration in Brassica species (Louda and Rodman, 1983; Kliebenstein et al., 2001; Fahey et al., 2001; Castro et al., 2004; Font et al., 2004; Charron and Sams, 2004). All of the different cruciferous vegetable types contain glucobrassicin, and most contain substantial amounts of sinigrin. In broccoli, sinigrin levels are comparatively low and the predominant glucosinolate is glucoraphanin, frequently making up more than 50% of the total glucosinolates (Rosa et al., 1997; Fahey et al., 2001). In *B. juncea*, sinigrin was identified as the major glucosinolate in seed and leaf tissue (Sang et al., 1984; Carlson et al., 1987). Glucoraphanin and indolyl GSs were found to be the predominant glucosinolate in the seeds and heads of *B. oleracea* var. *italica* (broccoli) (Carlson et al., 1987; Kushad et al., 1999). There is considerable variation in *B. oleracea*. For example, genotypes can be found which have methylthioalkyl, methylsulphinylalkyl, alkenyl or hydroxyalkenyl glucosinolates, in which the alkyl chain has either three or four methyl groups (Mithen et al., 2000). Compared with *Brassica oleracea* group, *Brassica rapa* lacks glucoraphanin and sinigrin but contains gluconapin and glucobrassicanapin (Mithen et al., 2000). In *B. rapa* there is relatively little variation in structure. All genotypes,

including wild accessions, accumulate some or all of 3-butenyl, 4-pentenyl glucosinolates and their hydroxylated forms.

Broccoli, cabbage, kale and Chinese kale are a good source of indolyl glucosinolates (Fahey et al., 2001), being especially rich in 3-indolylmethyl-GS and 1-methoxy-3-indolylmethyl-GS. Indole-3-carbinol, indole-3-acetonitrile, diindolylmethane, ascorbigen and sulforaphane are regarded as inducers of benzo(a)pyrene in rat liver and intestine (McDanel et al., 1988), or as a modifier of P450 enzyme activity and to be potent monofunctional inducers of phase II enzymes (Zhang et al., 1994). In *Brassica rapa* group, they contain all indolyl gluosinolates and gluconasturtiin which have a potential healthy functions, but the amount is much lower than in some *B. oleracea* crops. Moreover, no glucoraphanin was detected in *B. rapa* group. Many researches were conducted in the genetic manipulation of GSs in different Brassica plants (Mithen et al., 2000). The prevalence of methionine-derived glucosinolates in crop species is fortunately also found in *Arabidopsis thaliana*, which has become the "model" species for plant geneticists and molecular biologists (Mithen et al., 2000). The next step of the work will be exploitation of existing variation in *B. rapa* germplasm using molecular genetic tools for quality improvement and human health.

CONCLUSIONS

Gluconapin, glucobrassicanapin, progoitrin and gluconasturtiin are the most abundant GSs in *Brassica rapa* group, but there is much more variations among accessions. The total glucosinolate contents in *Brassica rapa* group varied substantially between the different species. The highest amount of GSs was observed in vegetable turnip leaves, followed by rapid cycling and yellow sarson. Whereas the lowest GSs content was found in turnip greens and Wutacai. The total aliphatic GSs proportion varied from 50 to 90% of the total GS in this group, generally they contain relatively low content of indolyl glucosinoloates. Compared with *Brassica oleracea* group, *Brassica rapa* lacks glucoraphanin and sinigrin but contains gluconapin and glucobrassicanapin. Considerable variations in *B. rapa* group are benefit for breeding programmes to improve health of cultivars and have importance on evaluation of intake of phytochemicals in the food consumption.

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Tables

Table 1. *Brassica rapa* plants used in this experiment.

No.	Vegetables	Latin name
1	Chinese cabbage	*Brassica rapa* pekinensis
2	Pak choi	*Brassica rapa* chinensis
3	Tai Cai	*Brassica rapa* narinosa
4	Mizuna	*Brassica rapa* nipposinica
5	Turnip green	*Brassica rapa* oleifera
6	Choy sum	*Brassica rapa* parachinensis
7	Komatsuna	*Brassica rapa* perviridis
8	Vegetable Turnip	*Brassica rapa* rapifera
9	Yellow sarson	*Brassica rapa* trilocularis
10	Broccoletto	*Brassica rapa* utilis
11	Wutacai	*Brassica rapa* rosularis
12	Namenia	*Brassica rapa*
13	Rapid cycling	Rapid-cycling *Brassica rapa*
14	Raapstelen	*Brassica rapa*
15	Winter turnip oilseed rapa	*Brassica rapa* tournefortii

Table 2. Glucosinolate contents in different *Brassica rapa* accessions (μmol/100 g FW).

	Aliphatic GS				Indolyl GS			Aromatic GS	
	PRO	NAP	GBN	4OH	GBC	4ME	NEO	NAS	Total
Broccoletto									
L29	3.10±0.25	33.57±3.54	15.60±2.72	0.83±0.20	2.79±0.69	1.74±0.39	1.15±0.25	3.56±2.40	62.35±9.04
Choy sum									
CS1	10.93±2.21	12.26±4.12	2.16±0.16	1.11±0.01	3.57±0.20	2.16±0.30	0.22±0.09	2.29±1.30	34.68±5.00
Komatsuna									
L41	1.70±0.07	64.78±5.44	2.05±0.18	0.49±0.01	0.60±0.06	0.99±0.07	0.12±0.01	14.58±3.46	85.29±9.23
Mizuna									
L79	12.36±1.21	3.78±0.43	0.19±0.06	1.18±0.08	1.41±0.37	2.56±0.59	1.01±0.13	5.92±0.15	28.38±3.01
Rapid Cycling									
L144	2.27±0.27	187.00±15.60	2.78±0.55	0.59±0.20	2.22±0.24	2.52±1.05	0.41±0.09	2.65±0.62	200.44±16.85
Tai Cai									
TC1	7.04±3.01	3.38±0.49	1.19±0.20	1.37±0.03	5.70±0.08	2.11±1.27	0.80±0.13	6.84±1.73	28.41±3.31
Turnip greens									
L129	4.66±0.42	5.35±1.90	1.05±0.07	0.47±0.10	2.65±0.78	1.16±0.24	0.63±0.23	4.82±0.49	20.79±3.25
Vegetable turnip									
L115	4.16±0.52	281.12±20.21	60.03±7.79	2.39±0.65	4.82±3.47	2.17±0.77	1.31±0.65	5.25±0.40	361.26±23.75
Winter turnip oilseed rapa									
L24	3.87±1.01	35.28±6.90	32.87±5.62	0.93±0.76	5.79±2.75	0.70±0.37	0.74±0.35	5.01±0.58	85.19±6.41
Wutacai									
W	3.33±1.25	7.76±1.75	1.99±0.47	1.06±0.40	3.38±0.12	0.93±0.56	0.53±0.37	3.63±0.38	22.61±3.43
Yellow Sarson									
33	5.94±1.50	158.28±8.46	1.29±0.30	0.84±0.27	1.94±0.93	1.50±0.40	0.87±0.32	7.10±2.45	177.77±14.28
Chinese Cabbage									
L168	15.20±1.48	10.65±0.23	7.94±0.86	4.18±1.41	7.80±1.27	2.56±0.52	2.05±0.42	6.50±0.89	56.90±5.94
Pak Choi									
L77	6.68±2.50	8.57±0.50	4.48±1.55	0.79±0.34	4.67±1.90	1.13±0.39	2.21±0.09	4.94±0.53	33.65±2.41
Namenia									
PCGN	16.98±1.44	36.32±4.81	25.05±4.50	2.94±0.91	6.29±0.79	2.10±0.65	1.07±0.55	5.44±0.26	96.19±11.32
Raapstelen									
PCGR	36.34±6.26	41.50±2.46	35.41±4.66	6.16±0.68	3.13±0.07	2.49±0.26	0.50±0.12	30.45±2.51	155.96±15.28

*GS: glucosinolates; Data represent the mean ± standard error of three replications.

Figures

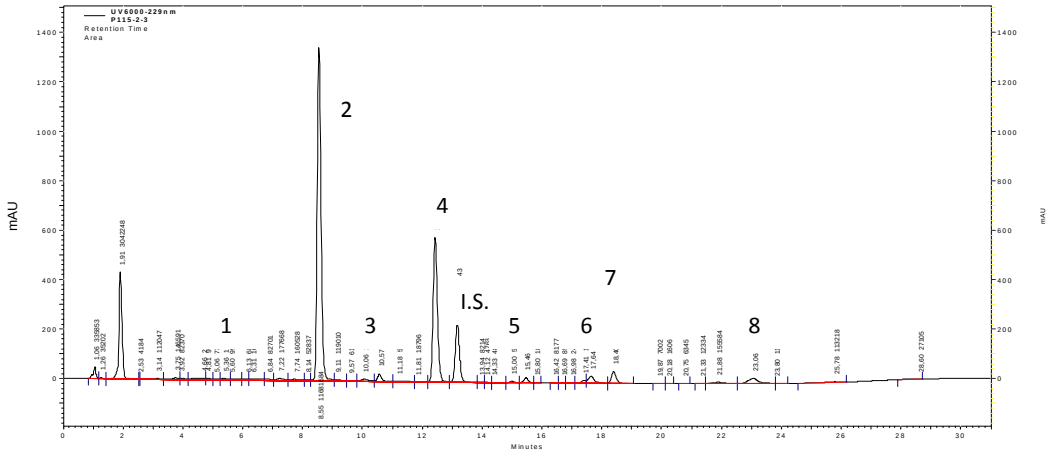

Fig. 1. HPLC chromatogram of vegetable turnip. 1: progoitrin; 2: gluconapin; 3: 4-hydroxyglucobrassicin; 4: glucobrassicanapin; I.S. glucotropaeolin; 5: glucobrassicin; 6: gluconasturtiin; 7: 4-methoxyglucobrassicin; 8: neoglucobrassicin.

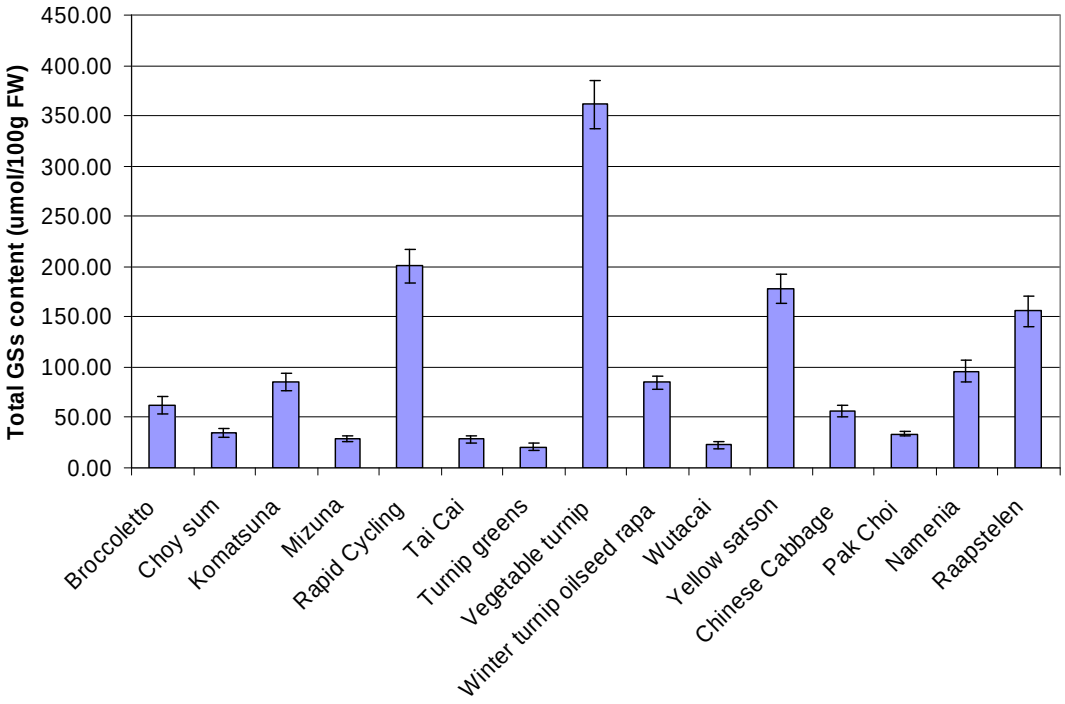

Fig. 2. Total glucosinolate contents in *Brassica rapa.*

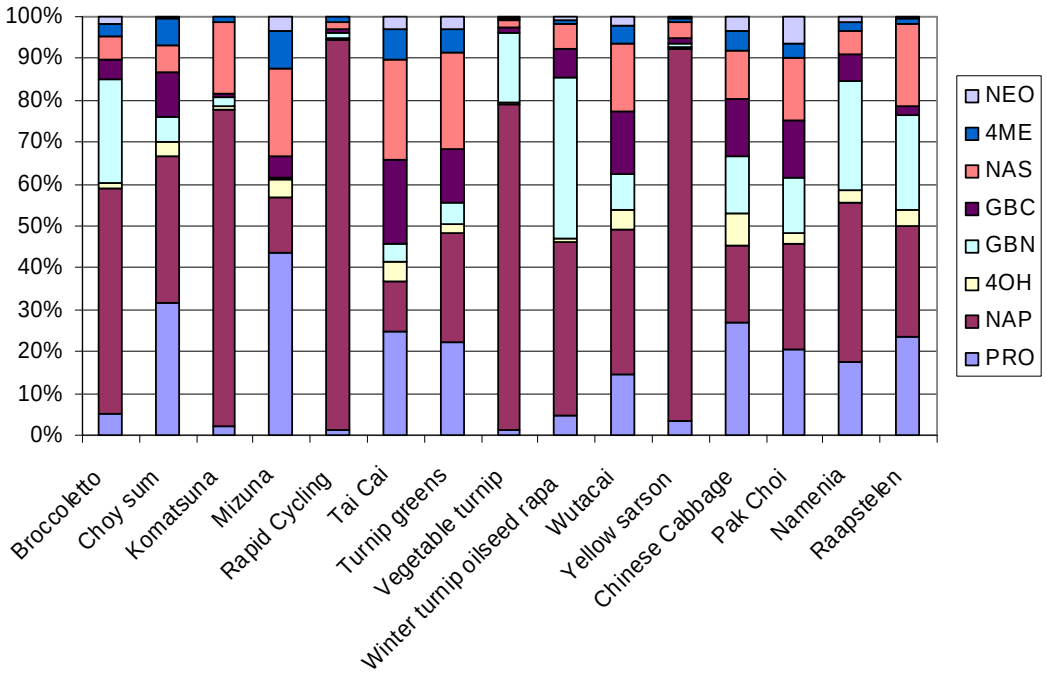

Fig 3. Glucosinolate distribution in *Brassica rapa.*