

## Composition and contents of phytochemicals (glucosinolates, carotenoids and chlorophylls) and ascorbic acid in selected *Brassica* species (*B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera*, *B. rapa* subsp. *chinensis* and *B. rapa* subsp. *rapa*)\*

Angelika Krumbein, Ilona Schonhof, Monika Schreiner

(Received June 3, 2005)

### Summary

Cultivars of selected *Brassica* species (*B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera*, *B. rapa* subsp. *chinensis* and *B. rapa* subsp. *rapa*) showed significant differences in their composition and contents of phytochemicals and ascorbic acid. *B. juncea* was characterised by high proportion of alkenyl glucosinolates (85 to 96%) with a predominance of sinigrin; whereas in *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis*, the alkenyl glucosinolate proportion varied between 27 and 88% and consisted mainly of gluconapin, glucobrassicinapin and progoitrin. In *B. rapa* subsp. *rapa*, the main glucosinolate was the aryl glucosinolate gluconasturtiin (44 to 47%) with a relatively high level between 23.6 and 35.9 mg 100 g<sup>-1</sup> FM. Distinct genotypic variations were also observed for lutein (3.4 to 8.9 mg 100 g<sup>-1</sup> FM),  $\beta$ -carotene (1.8 to 4.3 mg 100 g<sup>-1</sup> FM) as well as chlorophyll a (35.7 to 96.8 mg 100 g<sup>-1</sup> FM) and chlorophyll b (11.4 to 30.5 mg 100 g<sup>-1</sup> FM). The cultivars 'Green Boy' (*B. rapa* subsp. *nipposinica* var. *chinoleifera*), 'Tatsoi' (*B. rapa* subsp. *chinensis*) and 'Green in Snow' (*B. juncea*) were rich in carotenoids (9 to 12 mg 100 g<sup>-1</sup> FM) and chlorophylls (86 to 126 mg 100 g<sup>-1</sup> FM). In contrast to other leafy vegetables tested, the Asian vegetables *B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis* had relatively high ascorbic acid contents of between 49.2 and 89.1 mg 100 g<sup>-1</sup> FM.

### Introduction

Numerous epidemiological studies have found an inverse association between vegetable consumption and chronic diseases such as different types of cancer and cardiovascular diseases (e.g. STEINMETZ and POTTER, 1996; BAZZANO et al., 2002; KRIS-ETHERTON et al., 2002). Members of the *Brassicaceae* are of special interest because not only are these vegetables low in fat and calories, but they are also a rich source of vitamins (e.g. ascorbic acid), minerals and phytochemicals – and all of these factors have been positively linked to cancer protection (NESTLE, 1997).

Glucosinolates, carotenoids and chlorophylls are phytochemicals that are associated with having anticarcinogenic properties (DASHWOOD, 1997; DILLARD and GERMAN, 2000). Hence, it is not unreasonable to suggest that from the about 100 identified glucosinolates specific ones or their breakdown products may have stronger anticarcinogenic properties than others. Key candidates among those identified to date are the breakdown products of the glucosinolates glucoraphanin, sinigrin, gluconasturtiin and the indole glucosinolates (NESTLE, 1997; BONNESEN et al., 2001; LUND, 2003; SMITH et al., 2004).

In *Brassicaceae*, phytochemical composition and content depend mainly on the genotype as well as the plant's response to eco-physiological factors such as temperature and radiation. While numerous studies have documented phytochemical content and

variations caused by pre- and postharvest influences in European *Brassicaceae* of commercial interest, e.g. broccoli and cauliflower (KUSHAD et al., 1999; SCHONHOF et al., 1999, 2004; KRUMBEIN et al., 2001a), only little information is available on phytochemicals in Asian *Brassicaceae* species like leafy vegetables and turnip species (MIYAJIMA, 1994; HILL et al., 1987; HE et al., 2000a, 2000b). However, if Asian vegetables were seen to have a differing phytochemical spectrum to European ones, the consumption of both would allow a highly diversified intake of health-promoting substances.

The aim of this study was to determine the composition and content of glucosinolates, carotenoids, chlorophylls and ascorbic acid of leafy Asian vegetables (*B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis*) as well as the glucosinolate composition and content of Asian turnip (*B. rapa* subsp. *rapa*) in two different growing seasons.

### Materials and methods

#### Plant material

Experiments were carried out in block design with three replications in an environmentally controlled greenhouse at the Institute of Vegetable and Ornamental Crops Grossbeeren/Erfurt e.V. Five plants each of *B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis* were grown in a pot with 800 g substrate. For *B. rapa* subsp. *rapa*, six plants were cultivated in a 8-liter pot, and a total of 80 kg nitrogen ha<sup>-1</sup> was added. Water was supplied on plant demand.

Cultivars of *B. juncea* (2004 and 2005: 'Red Giant' and 'Green in Snow'), *B. rapa* subsp. *nipposinica* var. *chinoleifera* (2004 and 2005: 'Green Boy', 'Mibuna Early') and *B. rapa* subsp. *chinensis* (2004 and 2005: 'Tatsoi'; 2004: 'Pak Choi Green'; 2005: 'Canton Pak Choi') were sown on 3 September 2004 and on 10 January 2005 and fully developed plants were harvested in the middle of October 2004 (autumn) or at the beginning of March 2005 (spring), respectively. In the autumn season, *B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis* were cultivated at a daily mean temperature of 18°C with a daily mean radiation of 18.6 mol m<sup>-2</sup>; in the spring season, there was a daily mean temperature of 13.5°C with a daily mean radiation of 7.3 mol m<sup>-2</sup>.

The different cultivars could be described as followed: *B. juncea* 'Green in Snow' is marked by elongated medium-green shiny leaves with light jagged margins, whereas leaves of *B. juncea* 'Red Giant' showed a sharp edge with red coloured veins. Regarding *B. rapa* subsp. *nipposinica* var. *chinoleifera* the cv Green Boy is characterized by smooth, radish-like leaves with white veins, and the leaves of 'Mibuna Early' have a lanceolate shape. Leaves of the cultivars of *B. rapa* subsp. *chinensis* are arranged spirally, but are spreading and do not form a head. The leaves are marked by an extended white mid-rib. The leaves of 'Tatsoi' have a dark-green, puckered surface. In contrast, leaves of 'Pak Choi Green' and 'Canton Pak Choi' are medium-green with smooth margins.

*B. rapa* subsp. *rapa* (cv Hongyuan) was sown on 21 August 2003 and 18 March 2004 and harvested when the root diameter was 5 cm

\* The paper was presented at the 40<sup>th</sup> meeting of the "Deutsche Gesellschaft für Qualitätsforschung (Pflanzliche Nahrungsmittel) DGQ e.V."

in the middle of October 2003 (autumn) and the middle of May 2004 (spring), respectively. In the autumn season, *B. rapa* subsp. *rapa* was cultivated at a daily mean temperature of 17°C with a daily mean radiation of 17 mol m<sup>-2</sup>; in the spring season, there was a daily mean temperature of 16.7°C with a daily mean radiation of 17.3 mol m<sup>-2</sup>. The turnip of cv Hongyuan is round, compact with purplish coloured periderm. The interior turnip flesh is white to pale yellow.

### Sample preparation

A mixed sample of between 50 and 60 plants of each cultivar of the leafy vegetables was used from each replication (n=3). For glucosinolate determination, about 200 g fresh matter (FM) were immediately deep frozen (-28°C), then freeze-dried and finely ground. For the carotenoids, chlorophylls and ascorbic acid analyses, the rest of the material was freshly cut into small pieces. About 6 to 8 unpeeled roots of turnip from each replication (n=3) were cut in a half, immediately deep frozen (-28°C), then freeze-dried and finely ground.

### Glucosinolate analysis

A modified HPLC method was used to determine the content of desulphoglucosinolates as according to LANGE et al. (1991). Freeze-dried sample material (0.5 g) was heated to and incubated at 75°C for 1 min, extracted with 4 ml of a methanol/water mixture (v/v=7:3, T=70°C) and then, after adding 1 ml 0.4 M barium acetate, centrifuged at 4000 rpm for 10 min. The residue was extracted twice more with 3 ml of the methanol/water mixture (v/v=7:3, T=70°C). The supernatants were pooled and made up to 10 ml with the methanol/water mixture. From this supernatant, 5 ml were applied to a 250 µl DEAE-Sephadex A-25 ion-exchanger (Sigma, acetic acid-activated) and rinsed with 10 ml deionised water. Next, 250 µl of a purified solution of aryl sulphatase (Boehringer-Mannheim GmbH) was applied and left for 12 h. The desulpho compounds were then flushed with 5 ml deionised water. The analysis was conducted by HPLC (Merck: HPLC pump L-7100, DAD detector L 7455, automatic sampler model L-7200 and HPLC Manager-Software D-7000) using a Spherisorb ODS2 column (Bischoff: 5 µm, 250 x 4 mm). A gradient of 0 to 20% acetonitrile in water was selected from minutes 2 to 34, followed by 20% acetonitrile in water until minute 40 and then 100% acetonitrile for 10 min until minute 50. Determination was conducted at a flow rate of 1.3 ml min<sup>-1</sup> and a wavelength of 229 nm. Glucosinolate content was calculated using sinigrin as external standard, and using the response factor of each compound relative to sinigrin. The results were calculated in per 100 g FM (fresh matter). Determination of glucosinolate content was performed in duplicate. Desulphoglucosinolates were identified by HPLC-APCI-MS<sup>3</sup> using Agilent 1100 series in the positive ionisation mode. Nitrogen was used as dry gas (5 l min<sup>-1</sup>, 325°C) and nebuliser gas (60 psi). The corona current was set to 6 µA and the vaporisation temperature to 300°C, respectively. To compare the results with the HPLC-DAD, the same column material with half of the length (125 x 4 mm, 5 µm), the same acetonitrile/water gradient and flow rate of 0.6 ml min<sup>-1</sup> were used. Desulphoglucosinolates were identified from the protonated molecular ions [M + H]<sup>+</sup> and the fragment ions corresponded to [M + H - glucose]<sup>+</sup>.

### Carotenoid and chlorophyll analyses

Carotenoids (lutein and β-carotene) and chlorophylls (chlorophyll a and chlorophyll b) were also determined by HPLC (KRUMBEIN, 1996). To 15 g of cut Asian leafy vegetables, 1 g calcium carbonate, 30 g sodium sulphate and 30 ml acetone were added, and the samples

were homogenised for 2 min. The extract was then filtered under suction, and the solid materials were extracted repeatedly with acetone until the resulting filtrate was colourless. The extract was then filtered through a 0.45 mm filter for HPLC analyses. Carotenoid and chlorophyll compositions and contents were determined by HPLC using a C-18 reversed-phase column Lichosphere 100 (5 µm, 250 x 4 mm; Merck) with an isocratic eluent of 75% acetonitrile, 15% methanol and 10% methylene chloride. The analysis was carried out at a flow rate of 1 ml min<sup>-1</sup>. Wavelengths of 448, 464, 432 and 455 nm were used to determine lutein, chlorophyll b, chlorophyll a and β-carotene, respectively. Contents were quantitatively determined by calibration curves of the related pure standards. The results were converted to per 100 g FM. Chemical analyses were performed in duplicate.

### Ascorbic acid analysis

Ascorbic acid content was determined by a titration method using 2,6 dichlorophenolindophenol (340 mg l<sup>-1</sup>) until a pink colour was observed for 20 ml filtrate (SCHONHOF and KRUMBEIN, 1996). To 40 ml 5% meta-phosphoric acid, 10 g cut sample was added, homogenised for 2 min, and then diluted to 100 ml with deionised water and filtered through a folded filter (Schleicher & Schuell 602 H ½). Polyvinylpyrrolidone was added to coloured filtrates until they were colourless. The results were converted to per 100 g FM. Chemical analyses were performed in duplicate.

### Statistical analysis

Analysis of variance using the program Statistica™ for Windows™ (version 6.1, Statsoft Inc.) was performed. The significant differences (means from three replicates) in the analytical data between cultivars were calculated with Tukey's HSD test (5% significance level).

## Results and discussion

### Glucosinolates

In the investigated *Brassica* species, the alkyl glucosinolates glucoalysinn, glucoraphanin and glucoerucin, the alkenyl glucosinolates sinigrin, gluconapin, glucobrassicinapin, progointrn and gluconapoleiferin, the indole glucosinolates glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin and 4-neoglucobrassicin as well as the aryl glucosinolate gluconasturtiin were identified and quantified. Significant differences in the percentages of the major and the total amount of glucosinolates were found among the *Brassica* species and also partly among seasons.

The total content of glucosinolates in leafy vegetables of *B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis* varied from 6.3 to 112.6 mg 100 g<sup>-1</sup> FM in autumn and 4.7 to 32.8 mg 100 g<sup>-1</sup> FM in spring, respectively (Tab. 1 and 2). The alkenyl glucosinolates ranged from 85 to 96% of the total glucosinolate content in both cultivars of *B. juncea* for both seasons mainly determined by sinigrin. HILL et al. (1987) also reported high proportions of sinigrin in other *B. juncea* cultivars. The cultivar 'Red Giant' when compared to 'Green in Snow' had a higher sinigrin content, and thus a higher total glucosinolate content; this finding highlights the genotype effects on glucosinolate composition and content. Moreover, the glucosinolate content of both cultivars was higher in the autumn than in the spring. This observation could be due to the higher radiation level in autumn compared to spring. Among *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis*, the cultivar 'Mibuna Early' had the highest total glucosinolate content with about 30 mg 100 g<sup>-1</sup> FM. The predominant

**Tab. 1:** Glucosinolate composition and content of different cultivars of leafy Asian vegetables harvested in autumn

Glucosinolates (GSs)	<i>B. juncea</i>		<i>B. rapa</i> subsp. <i>nipposinica</i>		<i>B. rapa</i> subsp. <i>chinensis</i>	
	'Red Giant'	'Green in Snow'	'Green Boy'	'Mibuna Early'	'Tatsoi'	'Pak Choi Green'
Total glucosinolates (mg 100 g <sup>-1</sup> FM)	112.6 ± 15.14	42.2 ± 1.63	6.3 ± 0.90	29.9 ± 2.24	12.9 ± 1.68	7.1 ± 0.48
Total alkyl glucosinolates (%) of total GSs			6	3	2	9
Total alkyl glucosinolates (mg 100 g <sup>-1</sup> FM)			0.4 ± 0.05	0.9 ± 0.02	0.2 ± 0.05	0.7 ± 0.01
Glucoalyssin (mg 100 g <sup>-1</sup> FM)	nd	nd	0.4 ± 0.05	0.5 ± 0.07	0.2 ± 0.05	0.7 ± 0.01
Glucoraphanin (mg 100 g <sup>-1</sup> FM)	nd	nd	nd	0.4 ± 0.06	nd	nd
Total alkenyl glucosinolates (%) of total GSs	95	96	59	88	77	66
Total alkenyl glucosinolates (mg 100 g <sup>-1</sup> FM)	107.3 ± 14.76	40.7 ± 1.70	3.6 ± 0.56	26.4 ± 2.24	10.0 ± 1.27	4.6 ± 0.38
Sinigrin (mg 100 g <sup>-1</sup> FM)	102.7 ± 14.19	39.7 ± 1.60	nd	nd	nd	nd
Gluconapin (mg 100 g <sup>-1</sup> FM)	4.3 ± 0.54	1.0 ± 0.11	1.4 ± 0.27	21.7 ± 1.81	7.6 ± 0.90	2.3 ± 0.26
Glucobrassicinapin (mg 100 g <sup>-1</sup> FM)	0.2 ± 0.03	nd	1.5 ± 0.23	3.1 ± 0.49	2.0 ± 0.34	1.3 ± 0.03
Progoitrin (mg 100 g <sup>-1</sup> FM)	nd	nd	0.7 ± 0.08	1.6 ± 0.07	0.3 ± 0.07	1.0 ± 0.19
Total indole glucosinolates (%) of total GSs	3	3	16	7	15	13
Total indole glucosinolates (mg 100 g <sup>-1</sup> FM)	2.7 ± 0.11	1.1 ± 0.05	1.1 ± 0.14	1.9 ± 0.08	1.8 ± 0.19	0.9 ± 0.15
Glucobrassicin (mg 100 g <sup>-1</sup> FM)	1.0 ± 0.13	0.3 ± 0.03	0.5 ± 0.05	0.9 ± 0.02	1.0 ± 0.11	0.4 ± 0.06
4-Hydroxyglucobrassicin (mg 100 g <sup>-1</sup> FM)	1.1 ± 0.08	0.6 ± 0.02	0.2 ± 0.02	0.5 ± 0.05	0.3 ± 0.03	0.1 ± 0.04
4-Methoxyglucobrassicin (mg 100 g <sup>-1</sup> FM)	0.6 ± 0.04	0.2 ± 0.01	0.3 ± 0.05	0.3 ± 0.01	0.2 ± 0.01	0.3 ± 0.07
Neoglucobrassicin (mg 100 g <sup>-1</sup> FM)	nd	nd	0.1 ± 0.04	0.2 ± 0.05	0.3 ± 0.07	0.1 ± 0.00
Aryl glucosinolate						
Gluconasturtiin (%) of total GSs	2	2	19	2	6	12
Gluconasturtiin (mg 100 g <sup>-1</sup> FM)	2.6 ± 0.35	0.5 ± 0.10	1.2 ± 0.26	0.6 ± 0.12	0.8 ± 0.19	0.8 ± 0.13

nd: not detectable

glucosinolate group in 'Mibuna Early' and in the mini pak choi cultivars 'Tatsoi', 'Pak Choi Green' and 'Canton Pak Choi' were the alkenyl glucosinolates which ranged from 45 to 88%. These alkenyl glucosinolates were characterised by gluconapin, followed by glucobrassicinapin and then progoitrin; although the mustard spinach 'Green Boy' had a comparable low level of gluconapin and glucobrassicinapin contents in both seasons. However, overall the predominance of these alkenyl glucosinolates seems to be typical for *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis* (HILL et al., 1987; HE et al., 2000b), though the proportion of individual alkenyl glucosinolates differs depending on the cultivar. In contrast to *B. juncea*, no sinigrin was found in the investigated *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis* cultivars; thus, indicating the use of dihomomethionine as precursors in glucosinolate synthesis (HALKIER and DU, 1997). In the investigated leafy Asian vegetables (*B. juncea*, *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis*), the content of health-promoting indole glucosinolates and gluconasturtiin (aryl glucosinolate) was relatively low between 0.9 and 3.6 mg 100 g<sup>-1</sup> FM and 0.5 and 3.8 mg 100 g<sup>-1</sup> FM, respectively, in both seasons.

In contrast to the investigated leafy Asian vegetables, *B. rapa* subsp. *rapa* cv. Hongyuan was characterised by a relatively high percentage of the health-promoting aryl glucosinolate gluconasturtiin (44 to 47%) with 35.9 mg 100 g<sup>-1</sup> FM in autumn and 23.6 mg 100 g<sup>-1</sup> FM in spring (Tab. 3). In contrast to this study, KIM et al. (2001) found only

between 0.7 and 5.4% gluconasturtiin of the total glucosinolate content in other cultivars of vegetable turnip rape. The indole glucosinolate content varied between 3.5 and 6.4 mg 100 g<sup>-1</sup> FM accounting for 7 to 8% of the total glucosinolate content and was slightly higher than the indole glucosinolate content in the investigated leafy Asian vegetables. This finding is in agreement with KIM et al. (2001) who reported between 0.5 and 10.2% indole glucosinolate of the total glucosinolate content. The individual alkenyl glucosinolates (40 to 44%) present comparable levels of glucobrassicinapin and progoitrin, followed by gluconapin and gluconapoleiferin. This demonstrates that gluconapin and glucobrassicinapin undergo hydroxylation and are thus converted to hydroxyalkenyl glucosinolates like progoitrin and gluconapoleiferin (HALKIER and DU, 1997); a process that seemingly does not occur in *B. rapa* subsp. *nipposinica* var. *chinoleifera* and *B. rapa* subsp. *chinensis*. Overall, the total glucosinolate content of the autumn harvest was higher than that of the spring one based on differences in alkenyl glucosinolates and gluconasturtiin. The reason for this could be that the temperature was extremely high during the last two weeks of spring cultivation period with daily mean temperature between 18 and 20°C up to the middle of May at turnip harvest; thus, leading to decreasing alkyl glucosinolate content as has also been found for broccoli heads (KRUMBAIN and SCHONHOF, 2001b). Taken together when considering the anticarcinogenic potential of sinigrin, gluconasturtiin and the indol glucosinolates, specific cultivars of *B. juncea* as well as *B. rapa* subsp. *rapa* 'Hongyuan' are

**Tab. 2:** Glucosinolate composition and content of different cultivars of Asian vegetables harvested in spring.

Glucosinolates (GSs)	<i>B. juncea</i>		<i>B. rapa</i> subsp. <i>nipposinica</i>		<i>B. rapa</i> subsp. <i>chinensis</i>	
	'Red Giant'	'Green in Snow'	'Green Boy'	'Mibuna Early'	'Tatsoi'	'Canton Pak Choi'
Total glucosinolates (mg 100 g <sup>-1</sup> FM)	32.8 ± 0.52	25.7 ± 0.98	4.7 ± 0.42	32.2 ± 2.57	5.9 ± 1.52	6.4 ± 1.57
Total alkyl glucosinolates (%) of total GSs			4	3	2	4
Total alkyl glucosinolates (mg 100 g <sup>-1</sup> FM)			0.2 ± 0.03	0.9 ± 0.25	0.1 ± 0.04	0.3 ± 0.11
Glucoalyssin (mg 100 g <sup>-1</sup> FM)	nd	nd	0.2 ± 0.03	0.6 ± 0.20	0.1 ± 0.04	0.2 ± 0.04
Glucoraphanin (mg 100 g <sup>-1</sup> FM)	nd	nd	nd	0.3 ± 0.05	nd	0.1 ± 0.07
Total alkenyl glucosinolates (%) of total GSs	85	93	27	74	45	46
Total alkenyl glucosinolates (mg 100 g <sup>-1</sup> FM)	27.9 ± 0.56	23.9 ± 0.91	1.3 ± 0.17	23.9 ± 2.26	2.8 ± 1.24	3.1 ± 1.13
Sinigrin (mg 100 g <sup>-1</sup> FM)	27.0 ± 0.49	23.5 ± 0.99	nd	nd	nd	nd
Gluconapin (mg 100 g <sup>-1</sup> FM)	1.0 ± 0.07	0.4 ± 0.10	0.5 ± 0.05	19.1 ± 2.00	2.4 ± 1.09	2.8 ± 1.07
Glucobrassicinapin (mg 100 g <sup>-1</sup> FM)	nd	nd	0.4 ± 0.08	4.8 ± 0.44	0.4 ± 0.15	0.2 ± 0.09
Progoitrin (mg 100 g <sup>-1</sup> FM)	nd	nd	0.3 ± 0.06	nd	nd	0.1 ± 0.01
Total indole glucosinolates (%) of total GSs	7	5	20	11	22	18
Total indole glucosinolates (mg 100 g <sup>-1</sup> FM)	2.2 ± 0.07	1.3 ± 0.06	0.9 ± 0.03	3.6 ± 0.27	1.3 ± 0.09	1.0 ± 0.17
Glucobrassicin (mg 100 g <sup>-1</sup> FM)	0.9 ± 0.02	0.6 ± 0.03	0.4 ± 0.01	2.3 ± 0.12	0.7 ± 0.03	0.5 ± 0.11
4-Hydroxyglucobrassicin (mg 100 g <sup>-1</sup> FM)	0.6 ± 0.03	0.2 ± 0.03	0.1 ± 0.01	0.5 ± 0.09	0.2 ± 0.04	0.1 ± 0.02
4-Methoxyglucobrassicin (mg 100 g <sup>-1</sup> FM)	0.5 ± 0.02	0.5 ± 0.03	0.3 ± 0.03	0.4 ± 0.06	0.3 ± 0.04	0.3 ± 0.04
Neoglucobrassicin (mg 100 g <sup>-1</sup> FM)	0.1 ± 0.02	nd	0.1 ± 0.00	0.4 ± 0.02	0.1 ± 0.01	0.1 ± 0.03
Aryl glucosinolate						
Gluconasturtiin (%) of total GSs	8	2	49	12	30	32
Gluconasturtiin (mg 100 g <sup>-1</sup> FM)	2.7 ± 0.09	0.5 ± 0.03	2.3 ± 0.24	3.8 ± 0.20	1.7 ± 0.24	2.0 ± 0.39

nd: not detectable

of key interest either to be consumed directly or as raw material for nutraceuticals aimed at improving overall human nutrition.

### Carotenoids and chlorophylls

The predominant carotenoid detected in the selected leafy Asian vegetables was lutein followed by  $\beta$ -carotene. Among species and cultivars, significant differences were found in lutein content with ranges of 3.4 to 6.8 mg 100 g<sup>-1</sup> FM in autumn and 3.7 to 8.9 mg 100 g<sup>-1</sup> FM in spring (Fig. 1).  $\beta$ -carotene content also varied significantly with a range of 2.1 to 4.3 mg 100 g<sup>-1</sup> FM in autumn and 1.8 to 4.4 mg 100 g<sup>-1</sup> FM in spring (Fig. 2). For both seasons, the cultivars 'Green Boy', 'Tatsoi' and 'Green in Snow' were the richest in carotenoid. Lutein content was higher in spring harvested plants compared with those in autumn; in contrast,  $\beta$ -carotene content did not appear to be influenced by seasonal harvest. These observations are in agreement with those for broccoli (SCHONHOF et al., unpublished results) where daily mean temperature of <16°C increased lutein content in the broccoli heads. In our study, the daily mean temperature during the spring cultivation period (13.5°C) was lower than in October (18°C).

For all cultivars, the predominant chlorophyll detected was chlorophyll a followed by chlorophyll b. Among cultivars, significant differences were found in chlorophyll a contents which ranged from

35.8 to 72.7 mg 100 g<sup>-1</sup> FM in autumn and 42.8 to 96.8 mg 100 g<sup>-1</sup> FM in spring (Fig. 3). Chlorophyll b content also varied significantly and was in the range of 11.4 to 22.8 mg 100 g<sup>-1</sup> FM in autumn and 12.3 to 30.5 mg 100 g<sup>-1</sup> FM in spring (Fig. 4). For both seasons, the cultivars 'Green Boy', 'Tatsoi' and 'Green in Snow' were not only the richest in carotenoids, but were also the richest in chlorophylls. A relationship between carotenoid and chlorophyll contents was previously reported in different types of broccoli in which high carotenoid contents correlated with high chlorophyll ones (SCHONHOF and KRUMBEIN, 1996). Finally, a similar influence of growing season as found for lutein was observed with chlorophyll content being higher in the spring than in the autumn harvested plants.

In leafy Asian vegetables, the carotenoid and chlorophyll contents were much higher than in other leafy vegetables like iceberg lettuce (*Lactuca sativa* var. *capitata*) which has far lower contents of lutein from 0.4 to 1.1 mg 100 g<sup>-1</sup> FM,  $\beta$ -carotene from 0.3 to 0.5 mg 100 g<sup>-1</sup> FM, chlorophyll a from 3.6 to 17.7 mg 100 g<sup>-1</sup> FM and chlorophyll b from 1.2 to 6.6 mg 100 g<sup>-1</sup> FM in medium and outer leaves (DREWS et al., 1997). Carotenoid contents were also higher than those found in spinach (*Spinacia oleracea*) which had a lutein content between 2.4 and 5.1 mg 100 g<sup>-1</sup> FM and  $\beta$ -carotene content between 1.0 and 2.2 mg 100 g<sup>-1</sup> FM; however, the chlorophyll contents were relatively comparable with those found in spinach grown under different N-supplies (chlorophyll a: 27.0 to 82.2 mg 100 g<sup>-1</sup> FM; chlorophyll b: 7.1 to 22.6 mg 100 g<sup>-1</sup> FM) (KRUMBEIN et al., 2003).

**Tab. 3:** Glucosinolate composition and content of turnip harvested in autumn and spring.

Glucosinolates (GSs)	<i>B. rapa</i> subsp. <i>rapa</i> 'Hongyuan'	
	Autumn	Spring
Total glucosinolates (mg 100 g <sup>-1</sup> FM)	81.7 ± 10.11	50.4 ± 4.88
Total alkyl glucosinolates (%) of total GSs	4	6
Total alkyl glucosinolates (mg 100 g <sup>-1</sup> FM)	3.1 ± 0.61	3.2 ± 0.34
Glucoalyssin (mg 100 g <sup>-1</sup> FM)	1.3 ± 0.35	2.0 ± 0.17
Glucoraphanin (mg 100 g <sup>-1</sup> FM)	nd	0.3 ± 0.05
Glucorucin (mg 100 g <sup>-1</sup> FM)	1.8 ± 0.46	1.0 ± 0.12
Total alkenyl glucosinolates (%) of total GSs	44	40
Total alkenyl glucosinolates (mg 100 g <sup>-1</sup> FM)	36.3 ± 9.05	20.0 ± 0.23
Gluconapin (mg 100 g <sup>-1</sup> FM)	4.0 ± 2.09	2.7 ± 0.09
Glucobrassicinapin (mg 100 g <sup>-1</sup> FM)	11.6 ± 2.87	8.0 ± 0.52
Progoitrin (mg 100 g <sup>-1</sup> FM)	16.1 ± 4.16	7.1 ± 0.41
Gluconapoleiferin (mg 100 g <sup>-1</sup> FM)	4.5 ± 0.30	2.1 ± 0.31
Total indole glucosinolates (%) of total GSs	8	7
Total indole glucosinolates (mg 100 g <sup>-1</sup> FM)	6.4 ± 1.13	3.5 ± 0.81
Glucobrassicin (mg 100 g <sup>-1</sup> FM)	2.2 ± 0.24	1.2 ± 0.19
4-Hydroxyglucobrassicin (mg 100 g <sup>-1</sup> FM)	0.8 ± 0.15	0.8 ± 0.24
4-Methoxyglucobrassicin (mg 100 g <sup>-1</sup> FM)	0.7 ± 0.21	0.3 ± 0.17
Neoglucobrassicin (mg 100 g <sup>-1</sup> FM)	2.8 ± 1.07	1.3 ± 0.26
Aryl glucosinolate		
Gluconasturtiin (%) of total GSs	44	47
Gluconasturtiin (mg 100 g <sup>-1</sup> FM)	35.9 ± 2.16	23.6 ± 5.08

nd: not detectable

### Ascorbic acid

The investigated leafy Asian vegetables were characterised by relatively high ascorbic acid contents (65.2 to 89.1 mg 100 g<sup>-1</sup> FM) (Fig. 5). 'Green in Snow' had the highest ascorbic acid content. These relatively high ascorbic acid contents were surprisingly when compared to values from other leafy vegetables, for example 3 to 11 mg 100 g<sup>-1</sup> FM in greenhouse- and field-grown lettuce (*Lactuca*

*sativa* var. *capitata*) (DREWS et al., 1995), and 59 and 52 mg 100 g<sup>-1</sup> FM in cress (*Lepidium sativum*) and spinach (*Spinacia oleracea*), respectively (HERRMANN, 2001).

### Conclusions

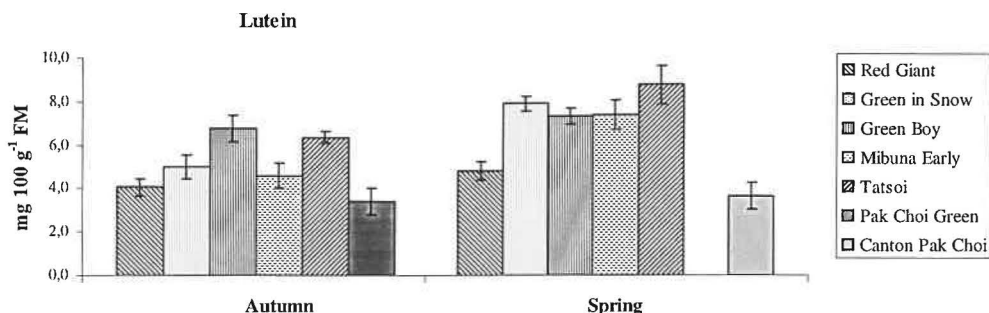
Taken together, consumption of the investigated Asian vegetables should lead to improved consumer's health as well as to increased consumer choice. Due to the wide spectrum of health-promoting substances identified within the different cultivars, eating a mixture of these Asian vegetables would produce the most health benefit. However, one barrier to consuming healthy vegetables is taste. Therefore, our next step will be to characterise aroma promoting substances as well as to analyse the sensory properties of these Asian vegetables.

### Acknowledgements

We thank A. Jankowsky and A. Maikath for phytochemical analyses, U. Zentner and E. Buesch for their help with the cultivation of the plants, and A. Platalla for technical assistance.

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**Fig. 1:** Lutein content of different cultivars of leafy Asian vegetables harvested in autumn and spring.

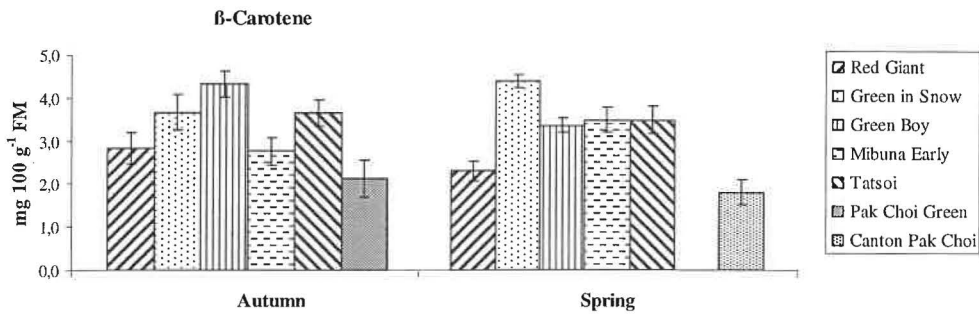


Fig. 2: β-Carotene content of different cultivars of leafy Asian vegetables harvested in autumn and spring.

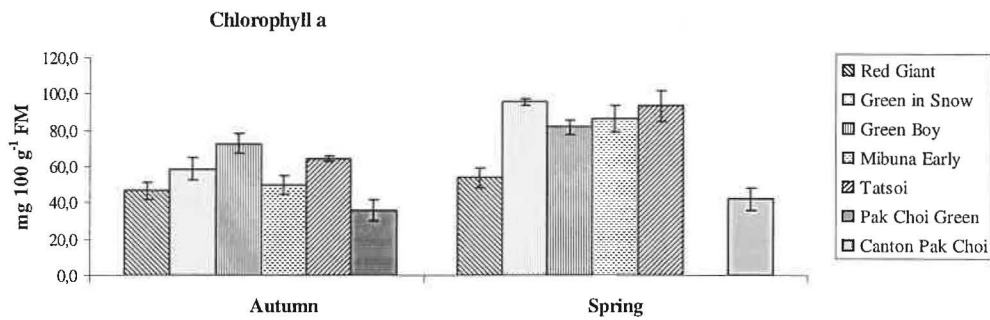


Fig. 3: Chlorophyll a content of different cultivars of leafy Asian vegetables harvested in autumn and spring.

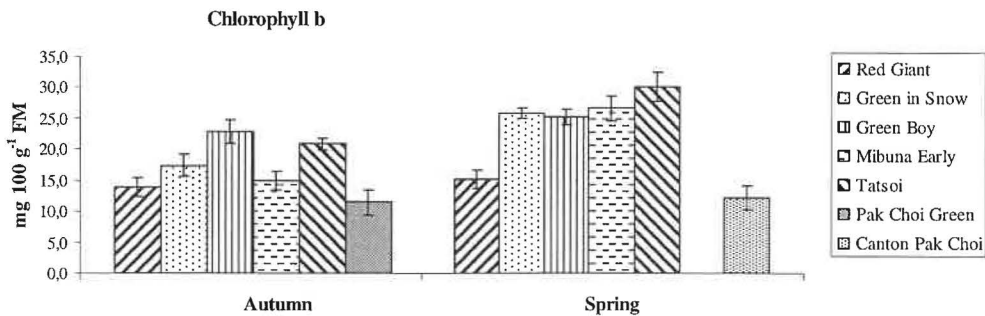


Fig. 4: Chlorophyll b content of different cultivars of leafy Asian vegetables harvested in autumn and spring.

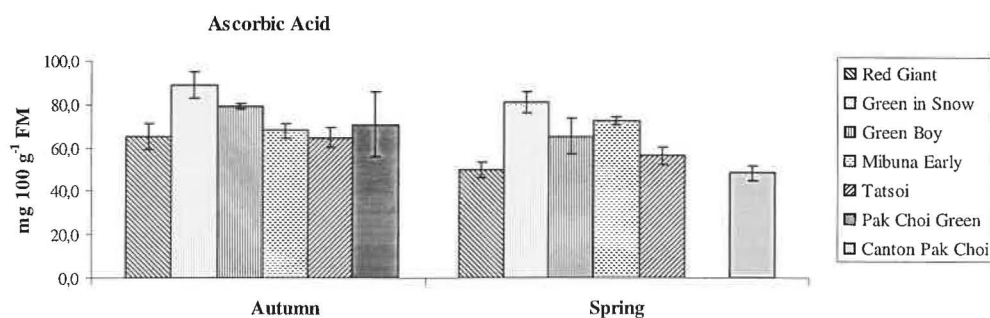


Fig. 5: Ascorbic acid content of different cultivars of leafy Asian vegetables harvested in autumn and spring.

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Address of the authors:

Dr. Angelika Krumbein, Dr. Ilona Schonhof, Dr. Monika Schreiner, Institute of Vegetable and Ornamental Crops Großbeeren/Erfurt e.V., Department Quality, Theodor-Echtermeyer-Weg 1, D-14979 Großbeeren, Germany, corresponding author: krumbein@igzev.de