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Young shoots of red cabbage are a better source of selected nutrients and glucosinolates in comparison to the vegetable at full maturity

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Abstract

Cruciferous vegetables are a valuable source of ingredients with health benefits. The most characteristic compounds of cruciferous vegetables with identified anticancer properties are glucosinolates. Young shoots and sprouts of red cabbage are becoming a popular fresh food rich in nutrients and bioactive compounds. The objective of this research was to determine, for the first time in a comprehensive approach, whether young shoots of red headed cabbage are a better source of selected nutrients and glucosinolates in the human diet in comparison to the vegetable at full maturity. The proximate composition (protein, fat, digestible carbohydrates, fiber), fatty acids profile, minerals (calcium, magnesium, potassium, sodium, iron, zinc, manganese, copper), as well as glucosinolates were examined. The red headed cabbage was characterized by a significantly larger amount of dry matter, and total and digestible carbohydrates in comparison to young shoots. The ready-to-eat young shoots, which are in the phase of intensive growth, are a better source of protein, selected minerals, and especially glucosinolates. The level of some nutrients can be enhanced and the intake of pro-healthy glucosinolates can be significantly increased by including young shoots of red cabbage into the diet.

Keywords Young shoots of red cabbage · Functional food · Minerals · Glucosinolates

Introduction

Nowadays, growing consumer awareness of nutritional issues is accompanied by an interest in safe, natural, and 'functional' food that perform important functions, e.g., improve health or reduce the risk of diet-related diseases such as obesity, diabetes, cardiovascular disease, and some types of cancer [1]. The consumption of vegetables around the world has increased significantly due to their taste and, above all, excellent health-promoting properties. Most vegetables contain large amounts of water, carbohydrates, little sugars, and a relatively high amount of dietary fiber, which makes them low calorie products. In addition, vegetables are a good source of minerals, vitamins, and many non-nutritious compounds with proven health-promoting properties [2].

Brassicaceae plants are amongst the most consumed vegetables in the World. These vegetables are a plant family containing about 3500 species [3]. One of the most important cruciferous vegetables consumed in Central Europe is red headed cabbage (*Brassica oleracea* var. *capitata* f. *rubra*), which is a traditional food product in the diet of this region. Red cabbage is easily accessible at local markets, which is consumed in large quantities throughout the whole year, both raw and after technological treatment [4]. Production of local vegetables, including red cabbage, plays an integral part in supplying healthy foods rich mainly in micronutrients and some phytochemicals such as vitamins C, K, β-carotene, minerals, fiber, total polyphenols, and glucosinolates [5]. Brassica vegetables are a rich source of bioactive compounds and epidemiological studies have confirmed that a high intake of these vegetables has been associated with the risk reduction of certain cancers, such as lung, colorectal, breast, and prostate [6].

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Aforementioned glucosinolates (GLS) are a large group of sulfur-containing plant secondary metabolites that occur in all varieties of Brassica vegetables [7]. Currently, over 200 individual, different naturally occurring GLS have been detected and have been grouped into aliphatic, aromatic and indolic GLS, depending on the structure of their side chain [8]. GLS are not biologically active, but their enzymatic derivatives are. Mechanical and thermal damage to the cells leads to the activation of the enzyme myrosinase, which causes the hydrolysis of GLS to active compounds such as thiocyanates, isothiocyanates, indoles, nitriles, epithionitrile, and oxazoidines which have strong anticancer properties [9]. The release of the end products of hydrolyzed GLS depends on the chemical structure of GLS, epithiospecifier protein presence in vegetables, ascorbic acid, or iron ions, as well as environmental conditions [10].

The sprouts of cruciferous vegetable are considered to have greater nutritional value than the mature vegetable. They are also characterized by low calories, high concentrations, and bioavailability of micronutrients and non-nutrients and high biological activity [11]. In the available literature, there are no data about the basic chemical composition of young shoots of vegetables, including red headed cabbage and their health-promoting properties. The objective of this research was to verify the hypothesis that young shoots of red headed cabbage are a better source of selected nutrients and glucosinolates in the human diet in comparison to vegetable at full maturity. Therefore, the proximate composition (digestible carbohydrates, dietary fiber, protein, crude fat and fatty acids), minerals, as well as glucosinolates were examined.

Materials and methods

Plant material

Young shoots of red cabbage and the vegetable at full maturity (Polish variety Haco) were the analyzed material. Fourteen-day young shoots were grown in sowing boxes filled with a standard garden substrate in a greenhouse, in late May. To obtain mature vegetables, the same seedlings were planted into the ground, in the field near Krakow, Poland. The seedlings were sown on brown soil with pH 6.5, salinity 0,57 g/l NaCl, NH_4 3,5 mg/l, NO_3 52.5 mg/l, /P/187 mg/l, /K/187 mg/l, /Ca/1324 mg/l, /Mg/188,45 mg/l. The young shoots were collected in May 2018 and 2019, and the vegetable at full maturity was collected in October 2018 and 2019. The average temperature (°C) and total monthly rainfall (mm) during the 5-month vegetables growth in 2018 was as follows: June—18.9 and 72; July—19.9 and 142; August—20.6 and 71; September—15.6 and 43; October—10.4 and 52, respectively. The same parameters were measured in 2019: June—22.3 and 4; July—19.2 and 74; August—20.3 and 79; September—14.5 and 78; October—10.4 and 35. Analyses were carried out on the freeze-dried samples. Young shoots were analyzed in their entirety. Samples of red cabbage at full maturity were prepared by cutting along the axis 1/8 part, from different sized heads. Ready samples were transferred to plastic plates and frozen at −80 °C. Next, the samples were placed in a freeze dryer for 24 h [Christ Alpha 1–4 (Osterode am Harz, Germany)]. After freeze drying, the samples were closed in a plastic bag to protect them from moisture.

Proximate composition

The chemical composition of the freeze-dried samples of vegetables was measured using the AOAC methods [12]. Total proteins were measured according to procedure no. 950.36; crude fat according to procedure no. 935.38; and ash according to procedure no. 930.05. The level of dietary fiber was measured using a commercially available kit (cat no. K-TDFR-100A, Megazyme International Ireland, Wicklow, Ireland). The digestible carbohydrate content was calculated using the following equation: digestible carbohydrates = 100 − (protein + crude fat + ash + dietary fiber) [13].

Fatty acid profile

The fatty acid profile was analyzed with gas chromatography (GCMS) after extraction of lipids from lyophilized samples of young shoots and mature red cabbage using Folch's method [14]. The free fatty acids were converted into their respective methylated derivatives in BF3/MetOH using the method described by Morrison and Smith [15]. Fatty acid methyl esters were extracted using hexane and separated with the GC-17A-QP5050 GC–MS model (Shimadzu, Japan) equipped with the capillary SP-2560 column (30 m × 0.25 mm × 0.25 µm; Supelco, Bellefonte, PA, USA). Chromatographic analysis was performed under the following conditions: the carrier gas was helium with flow through the column 1.8 mL/min, injection port temperature was 245 °C, and injected sample volume was 1 µl. The initial temperature of the column was kept at 60 °C for 5 min and then increased up to 220 °C (5 °C/min). This temperature was maintained for 20 min.

Minerals content

Samples of lyophilized cabbage for metal ions analysis were wet mineralized (Mars Express microwave oven) with 5 mL of 65% HNO_3 in sealed pressure vessels (170 °C, 15 min). After that, the samples were diluted with deionized water. Metal ions such as Ca^{2+}, Mg^{2+}, K^+, Na^+, Fe^{3+}, Zn^{2+}, Cu^{2+}, and Mn^{2+} were quantified using Atomic Absorption

Spectrometry with flame atomization (Varian AA240FS), incorporating a Sample Introduction Pump System (SIPS-20). The gas flow rate was 14 L/min[1] for air and 3.5 L/min[1] for acetylene. The absorbance of the samples was determined at wavelengths of 422.7 nm for Ca^{2+}, 202.6 nm for Mg^{2+}, 404.4 nm for K^{+}, 589.6 nm for Na^{+}, 248.3 nm for Fe^{3+}, 213.9 nm for Zn^{2+}, 324.7 nm for Cu^{2+}, and 279.5 nm for Mn^{2+}.

Glucosinolate profile

Determination of glucosinolates (GLS) was performed according to the standard ISO 9167 procedure with the modification described by Kusznierewicz et al. [16]. The extraction of GLS was carried out from 0.2 g freeze-dried plant material using boiling methanol (70%, 3 mL). After shaking (10 min), the sample was centrifuged (5000 rpm, 10 min, 4 °C), and the supernatant was collected. Solid plant residue was extracted again with a new portion of methanol (70%, 3 mL). Just before the first extraction, a water solution of glucotropaeolin (GTL) (AppliChem) (5 mM, 0.2 mL) was added to each sample as an internal standard for quantitative analysis. The GLS present in extracts was purified and hydrolyzed to desulfo-derivatives on a column filled with 1 mL of a suspension of DEAE Sephadex A-25 anion exchange resin (Sigma Chemical). Beforehand, the column was pre-washed with 2 mL of imidazole formate (6 M) and twice with 1 mL of water. The extract (~6 mL) was loaded into the column, and desulfation reaction was carried out overnight at room temperature with the aid of sulphatase (*Helix pomatia* type H1, Sigma Chemical) water solution (1 mg/mL, 250 µL). The next day, the desulfo-GLS were eluted with water (1 mL) and injected (30 µL) into LC–DAD–ESI–MS system (Agilent Technologies, 1200 series) equipped with SynergiTM Hydro-RP 80 Å column (150 × 4.6 mm, 4 µm, Phenomenex). The mobile phase contained water (A) and acetonitrile/water (20:80, v/v) (B). The chromatographic resolution was performed at 30 °C with 1 mL/min flow rate and the following gradient program: linear gradient rising from 5 to 100% B within 25 min and then isocratic separation with 100% B for 5 min. The chromatographic peaks were first detected with DAD at 229 nm, and then, the identity of individual DS–GLS was confirmed via API–ESI–MS (Agilent Technologies, 6130 Quadrupole). MS parameters were as follows: capillary voltage, 3000 V; fragmentor voltage, 120 V; drying gas temperature, 350 °C; gas flow (N_2), 12 L/min; nebulizer pressure, 35 psig. The instrument was operated both in positive and negative ion modes, scanning from m/z 100 to 800. The GLS level in each sample was quantified with the standard internal method using GTL as recommended by the ISO protocol (ISO:9167-1, 1992). However, in calculations of the content of individual GLS, the updated UV response factors proposed by Clarke [17] were used. GLS concentrations were expressed in micromoles per gram of dry weight.

Statistical analysis

Determination of selected nutrients was carried out separately in 2018 and 2019. The determination of glucosinolates was carried out in 2019. The analyses were conducted in triplicate each year. The results, calculated on dry weight of samples (DW), were expressed as the means for 2 or 1 years ± S.D. Differences between young shoots and mature vegetable were analyzed with one-way ANOVA using Statistica software 13.3 (Tulsa, OK, USA). Duncan's test was used for the determination of the statistical differences. p values ≤ 0.05 were considered as significant.

Results

The content of chemical compounds of 14-day young shoots and mature red headed cabbage per DW significantly differed ($p \leq 0.05$), except for total dietary fiber ($p > 0.05$). Among the analyzed samples, the significantly largest amount of dry matter was found in red headed cabbage (about 13.3%) (Table 1). In turn, the young shoots had a statistically significant higher amount of protein (about 48.7%) and crude fat (about 65.2%) in comparison to red headed cabbage at full maturity (Table 1).

The gas chromatographic analysis of the fatty acid profile from young shoots and vegetable at full maturity revealed the presence of 10 different fatty acids, 6 of which were saturated and 4 unsaturated (fatty acids from C14:0 to C:20:0). The following fatty acids were determined:

Table 1 Basic chemical proximate composition of young shoots of red cabbage and vegetable at full maturity (g/100 g DW)

Vegetative form of plant	Dry matter (g)	Ash	Protein	Crude fat	Dietary fiber	Digestible carbohydrates
Young shoots	$7.33^{a} \pm 0.5$	$21.4^{a} \pm 1.4$	$33.21^{a} \pm 1.6$	$2.5^{a} \pm 0.4$	$30.2^{a} \pm 1.7$	$12.69^{a} \pm 3.8$
Vegetable at full maturity	$8.45^{b} \pm 0.5$	$8.66^{b} \pm 1.1$	$17.03^{b} \pm 0.5$	$0.87^{b} \pm 0.1$	$28.85^{a} \pm 1.35$	$44.59^{b} \pm 0.03$

DW dry weight

Result are expressed as mean ± SD ($n = 6$)

Mean values with different letters (a, b) within the each column are statistically different ($p \leq 0.05$)

myristic acid, pentadecylic acid, palmitic acid, palmitoleic acid, margaric acid, stearic acid, oleic acid, linoleic acid, α-linolenic acid, and arachidic acid. Palmitic acid, linoleic acid, and α-linolenic acid were the dominant fatty acids in both samples. The largest group was polyunsaturated fatty acids (PUFA). A similar amount ($p > 0.05$) of pentadecylic acid and arachidic acid was found in both samples. A statistically significant higher amount of NNKT (linoleic acid, α-linolenic acid), palmitic acid, and stearic acid was revealed in red headed cabbage. However, the content of the remaining fatty acids, including oleic acid, was significantly higher in young shoots (Table 2).

A significantly higher content of digestible carbohydrates (about 71.6%) was found in red cabbage at full maturity as compared with young shoots. However, the level of total dietary fiber in young shoots did not differ significantly from mature red cabbage ($p > 0.05$) (Table 1). Our study showed that young shoots were significantly higher in minerals than matured cabbage–calcium (about 90.2%), magnesium (about 57.5%), sodium (about 92.9%), potassium (about 35.8%), iron (about 38.5%), zinc (about 58%), and manganese (about 60.9). There were only no statistically significant differences in copper contents ($p > 0.05$) in both types of cabbage (Table 3). A higher content of minerals was in line with the higher level of ash in young shoots (Table 1).

The analyzed young shoots and vegetable at full maturity were identified the aliphatic glucosinolates: glucoiberin (GIB), progoitrin (PRO), glucoraphanin (GRA), sinigrin (SIN), glucoalyssin (GAL), as well as indoles: glucobrassicin (GBS), metoxybrassicin (mGBS), and neoglucobrassicin (neoGBS) (Figs. 1, 2; Table 4). The total glucosinolates content in the analyzed samples of the vegetable differed significantly ($p \leq 0.05$). A higher mean content of total glucosinolates was found in young shoots in comparison to the vegetable at full maturity (about 38%). In both analyzed samples, the aliphatic glucosinolates were the dominant form of these compounds. A similar amount ($p > 0.05$) of sinigrin and metoxybrassicin was found in both samples. A statistically significant higher amount of glucoiberin,

Table 2 Fatty acid profile of young shoots of red cabbage and vegetable at full maturity

Fatty acid (% of total fatty acid)	Vegetative form of plant	
	Young shoots	Vegetable at full maturity
Myristic acid C14:0	$1.09^{a} \pm 0.22$	$0.39^{b} \pm 0.02$
Pentadecylic acid C15:0	$0.73^{a} \pm 0.0$	$0.69^{a} \pm 0.05$
Palmitic acid C16:0	$18.69^{a} \pm 0.01$	$27.45^{b} \pm 0.4$
Palmitoleic acid C16:1	$3.68^{a} \pm 0.18$	$0.41^{b} \pm 0.01$
Margaric acid C17:0	$0.76^{a} \pm 0.01$	$0.34^{b} \pm 0.03$
Stearic acid C18:0	$3.72^{a} \pm 0.04$	$5.8^{b} \pm 0.42$
Oleic acid C18:1	$19.69^{a} \pm 0.49$	$7.15^{b} \pm 0.08$
Linoleic acid C18:2	$14.96^{a} \pm 0.05$	$18.73^{b} \pm 0.23$
α-linolenic acid C18:2	$36.26^{a} \pm 0.06$	$38.71^{b} \pm 0.45$
Arachidic acid C20:0	$0.25^{a} \pm 0.08$	$0.36^{a} \pm 0.18$

Result are expressed as mean ± SD ($n = 6$)

Mean values with different letters (a, b) within the each row are statistically different ($p \leq 0.05$)

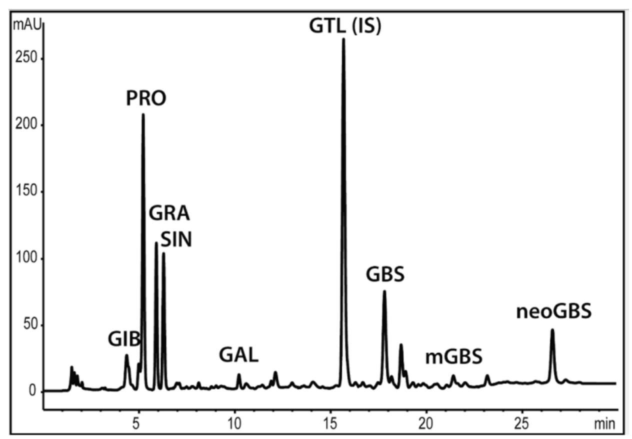

Fig. 1 Chromatographic profile of young shoots of red headed cabbage glucosinolates (GLS) obtained during high-performance liquid chromatography analysis of samples. The GLS detected include glucoiberin (GIB), progoitrin (PRO), glucoraphanin (GRA), sinigrin (SIN), glucoalyssin (GAL), glucotropaeolin (GTL; internal standard), glucobrassicin (GBS), metoxybrassicin (mGBS), and neoglucobrassicin (neoGBS)

Table 3 Mineral composition of young shoots of red cabbage and vegetable at full maturity (mg/100 g DW)

Vegetative form of plant	Calcium	Magnesium	Potassium	Sodium	Iron	Zinc	Manganese	Copper
Young shoots	$2413.74^{a} \pm 47,9$	$398.42^{a} \pm 45.5$	$5320.48^{a} \pm 328.9$	$242.06^{a} \pm 52.1$	$19.7^{a} \pm 0.9$	$6.21^{a} \pm 0.16$	$3.45^{a} \pm 0.08$	$0.35^{a} \pm 0.004$
Vegetable at full maturity	$235.72^{b} \pm 61.0$	$169.27^{b} \pm 12.5$	$3416.39^{b} \pm 623.17$	$17.27^{b} \pm 1.8$	$12.11^{b} \pm 0.1$	$2.61^{b} \pm 0.1$	$1.35^{b} \pm 0.06$	$0.3^{a} \pm 0.07$

DW dry weight

Result are expressed as mean ± SD ($n = 6$)

Mean values with different letters (a, b) within the each column are statistically different ($p \leq 0.05$)

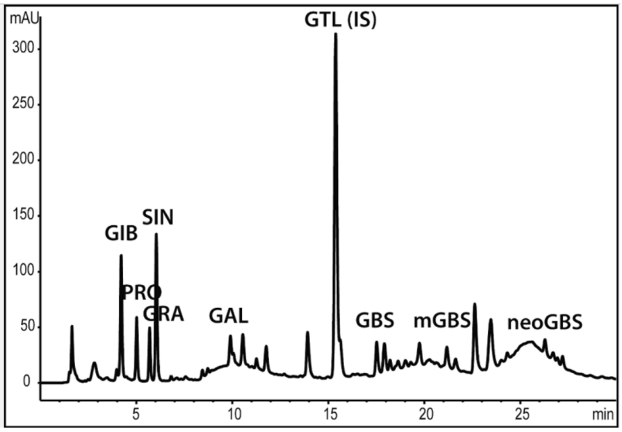

Fig. 2 Chromatographic profile of red headed cabbage var. Haco POL glucosinolates (GLS) obtained during high-performance liquid chromatography analysis of samples. The GLS detected include glucoiberin (GIB), progoitrin (PRO), glucoraphanin (GRA), sinigrin (SIN), glucoalyssin (GAL), glucotropaeolin (GTL; internal standard), glucobrassicin (GBS), metoxybrassicin (mGBS), and neoglucobrassicin (neoGBS)

Table 4 Content of glucosinolates in young shoots of red cabbage and vegetable at full maturity (μmol/g DW)

Glucosinolates	Vegetative form of plant	
	Young shoots	Vegetable at full maturity
Glucoiberin	$0.56^{a} \pm 0.18$	$1.3653^{b} \pm 0.12$
Progoitrin	$2.935^{a} \pm 0.13$	$0.5936^{b} \pm 0.04$
Glucoraphanin	$1.3076^{a} \pm 0.06$	$0.4625^{b} \pm 0.04$
Sinigrin	$1.4249^{a} \pm 0.09$	$1.4229^{a} \pm 0.08$
Glucoalyssin	$0.1701^{a} \pm 0.01$	$0.4417^{b} \pm 0.08$
Glucobrassicin	$0.6097^{a} \pm 0.14$	$0.1103^{b} \pm 0.01$
Metoxybrassicin	$0.0474^{a} \pm 0.01$	$0.0727^{a} \pm 0.02$
Neo-glucobrassicin	$0.2129^{a} \pm 0.03$	$0.0353^{b} \pm 0.01$
Total glucosinolates	$7.2677^{a} \pm 0.22$	$4.5044^{b} \pm 0.35$

DW dry weight

Result are expressed as mean ± SD ($n = 3$)

Mean values with different letters (a, b) within the each column are statistically different ($p \leq 0.05$)

progoitrin, glucoraphanin, glucoalyssin, glucobrassicin, and neo-glucobrassicin was found in young shoots (Table 4).

Discussion

While searching for new sources of functional food, a special attention should be paid to young shoots, sprouts, and germination seeds (about a half time period of cultivation compared to our cultivation of young shoots) of the Cruciferae family. During germination, a reactivation of seed metabolism (according to higher activity of enzymes) takes place, promoting the hydrolysis of storage proteins and carbohydrates and the synthesis/accumulation of metabolites with health-promoting properties [18]. To the best of our knowledge, there are a little literature data regarding chemical composition and the amount of minerals and glucosinolates in young shoots of red cabbage. In addition, in the available literature, there are a little data about comparison content of nutrients and non-nutrients in young shoots/sprouts/germination seeds and vegetable at full maturity.

Proximate composition

The content of dry matter in young shoots of red cabbage and in the vegetable at full maturity (var. Haco POL) was on average 7.33 and 8.45 g/100 g, respectively. Similar results for red headed cabbage were shown by Wojciechowska et al. [19]. Our results do not correspond to the results published by Majkowska-Gadomska and Wierzbicka [20]. They indicated that the content of dry matter varied significantly depending on the analyzed cultivars. Biesiada et al. [21] showed that dry matter content and soluble solids in red headed cabbage leaves decreased under the influence of intensive nitrogen fertilization.

Our results indicate a high protein content in the young shoots of red cabbage (33.21 g/100 g DW), while mature vegetable was characterized by lower content of protein (on average 17.03 g/100 g DW). Results of Vale et al.'s [22] research indicated lower content of protein for sprouts produced under light cycles—26.95 and under dark conditions—29.95 g/100 g DW (sprouts harvested when they reached a commercial size of approximately 7 cm length). A similar amount of protein was determined by Tanongkankit et al. [23] in whole leaves of headed cabbage (the variety was not mentioned). Different results for the vegetable at full maturity were shown by Mohammed and Luka [24] and Kahlon et al. [25].

It was found that young shoots contained a higher concentration of crude fat (2.5 g/100 g DW) than mature cabbage (0.87 g/100 g DW). Our results do not correspond to the results published by Vale et al. [22]. Mohammed and Luka [24] and Nilnakara et al. [26] obtained similar results to ours for the content of crude fat in the vegetable at full maturity.

The analysis of the fatty acid profile in young shoots and the vegetable at full maturity showed the presence of ten different fatty acids. Palmitic acid (saturated fatty acid, SFA), oleic (monounsaturated fatty acid, MUFA), and α-linolenic acid (polyunsaturated fatty acid, PUFA) were dominant fatty acids in both, young shoots and red headed cabbage. These data corresponded to the result obtained by Vale et al. [22], who reported that the red cabbage sprouts contained a large amount of palmitic acid (SFA) and oleic acid (MUFA). A higher amount of palmitic acid and lower amount of oleic acid was also reported by Vidrih et al. [27] for the red headed cabbage, in comparison to our results for mature vegetable. Among the analyzed fatty acids, in both samples, the largest group was PUFA-α-linolenic and linoleic fatty acid. These compounds were determined in higher amount in studied red headed cabbage. According to Vale et al. [22], the main group of fatty acids in the red cabbage sprouts was monounsaturated fatty acids (MUFA) and sprouts were characterized by a large amount of eicosenoic acid (MUFA) and linoleic acid (PUFA). α-linolenic acid is known to be present in many plants, also in Brassica [28]. Similarly to our results, Vidrih et al. [27] reported that linoleic acid followed by α-linolenic acid was the most abundant in red headed cabbage. We determined that the content of myristic, pentadecylic, palmitoleic, margaric, and stearic acids in young shoots was higher than in red cabbage sprouts, as reported by Vale and coworkers [22]. Although the content of fatty acids in the tested vegetables is rather low, they still represent an important nutritional factor and may supplement fatty acids of vegetable origin in a wholesome diet. The fatty acid profile of young shoots of red headed cabbage and the vegetable at full maturity revealed these products to be a good source of monounsaturated and polyunsaturated fatty acids.

The young shoots of red cabbage were a poorer source of digestible carbohydrates than mature vegetables (12.69 and 44.59 g/100 g DW, respectively). The content of total carbohydrates in our study was 42.8 g/100 g DW in young shoots and 73.41 g/100 g DW in the vegetable at full maturity. Different results were obtained by Kahlon et al. [25] and Nilnakara et al. [26].

Dietary fiber has a beneficial effect, e.g., in the prevention and dietotherapy of obesity. It causes a longer persistence of satiety while preventing rapid hunger, which can have a significant impact in the treatment of obesity. Due to the beneficial effects of dietary fiber on the human body, it is recommended to consume it in an amount of 25–40 g daily [29, 30]. In this study, we have demonstrated that the level of total dietary fiber in the young shoots and the vegetable at full maturity was similar and amounted to 30.2 and 28.85 g/100 g DW, respectively. Cabbage sprouts produced under light cycles and under dark conditions had 25.04 and 29.02 g/100 g DW of total dietary fiber [22]. Other researchers have indicated a similar level of total dietary fiber in red headed cabbages [25, 31]. The similar content of dietary fiber in our samples can be reason to increase the consumption of young shoots of red cabbage in the daily diet. This young part of vegetable can be consumed raw to avoid about a 5–10% loss of dietary fiber which occurs it is cooked, as reported by some researchers [32].

We have found that the average ash content in young shoots and in vegetables at full maturity was statistically different—21.4 g/100 g DW and 8.66 g/100 g DW, respectively. Vale et al. [22] found that the content of ash was 16.25 and 19.62 g/100 g DW for sprouts produced under light cycles and under dark conditions, respectively. Other authors who studied the level of ash in the red headed cabbage reported similar values [24–26, 33].

Mineral content

Our research confirmed that sprouted seeds of various vegetables are a good source of macroelements and microelements. Deficiency of calcium in human populations is a worldwide problem. Interestingly, it is documented that calcium absorption from cabbage is higher than from the other plant sources, owing to its content of organic acids like malic and citric acids [34]. The obtained results showed that the content of calcium in young shoots was much higher than in red headed cabbage—2413.74 and 235.73 mg/100 g DW, respectively. Vale et al. [22] have shown that red cabbage sprouts produced under light cycles and under dark conditions had a lower content of calcium than in our young shoots. The results of Zieliński et al. [35] indicated that the average content of calcium in 7-day cruciferous sprouts was also lower. The calcium content in our studies is within the range of calcium concentration in the conventionally and organically grown cabbage as described by the Warman and Havard [36]. According to Majkowska-Gadomska and Wierzbicka [20] and Ekholm et al. [37], the content of calcium in different varieties of red cabbages was higher than in our research.

The results of tests carried out using Atomic Absorption Spectrometry showed that young shoots were the richest source of magnesium (398.42 mg/100 g DW) compared to headed cabbage (169.27 mg/100 g DW). Similar results were obtained by Zieliński et al. [35]. Vale et al. [22] have reported that red cabbage sprouts produced under light cycles and also dark conditions had higher content of magnesium than indicated by our results for young shoots. In red headed cabbage which was analyzed by Ekholm et al. [37], the content of magnesium was 165 mg/100 g DW and these results correspond to our value. Red cabbage var. Haco POL, Koda, and Kissendrup SWE which were studied by Majkowska-Gadomska and Wierzbicka [20] as well as conventionally and organically grown cabbage which was analyzed by Warman and Havard [36] were characterized by a lower level of magnesium.

Analysis of minerals contents showed that the level of potassium was the highest compared to other described minerals, in both analyzed samples. The content of this mineral in young shoots was 5320.48 mg/100 g DW and was higher than in results obtained by Vale et al. [22]. The potassium content of 3416.39 mg/100 g DW in the vegetable at full maturity do not fall within the range of 1800–2620 and 2000–2440 mg/100 g DW reported for conventionally and organically grown cabbages [36]. The content of this mineral in the leaves red cabbages analyzed by Majkowska-Gadomska and Wierzbicka [20] and Ekholm et al. [37] was similar to that reported in this study.

The content of iron in tested young shoots and the vegetable at full maturity was 19.7 and 12.1 mg/100 g DW, respectively. Other authors have reported a different content of this mineral in cruciferous sprouts [22, 34]. Czech et al. [38] who also analyzed the var. Haco POL found a lower content of iron with respect to that reported in this study.

The obtained results showed that the content of zinc in young shoots was much higher than in the vegetable at full maturity (6.21 and 2.61 mg/100 g DW, respectively). Other authors who examined cruciferous sprouts, including red cabbage sprouts, showed similar findings to our data [22, 34]. The zinc content in red headed cabbage is comparable to the results obtained by Warman and Havard [36]. The average zinc content in red cabbage collected in Polish marketplaces was higher than in our studies [38].

Our results showed that the content of manganese in young shoots was 3.45 mg/100 g DW and it was lower than obtained by Zieliński et al. [35]. The content of the same mineral in tested red headed cabbage was 1.35 mg/100 g DW and it was generally similar to the level reported by the other authors [33, 36, 37]. Copper content in young shoots is in line with the value reported by Zieliński et al. [35]. The average copper content in red headed cabbage collected in Polish marketplaces was more or less the same as analyzed red cabbage [20, 38].

It is important to consider that the content of macroelements and microelements in different varieties or analyzed parts of plants is the fact that bioaccumulation of nutrients depends on many factors. The differences in the concentrations of analyzed minerals depend on the types and cultivars of cabbage, geographical location, climate and soil conditions, use of fertilizers, and the local agrotechnical practices [33, 39]. It is observed that the following minerals are reduced during cooking: sodium, calcium, magnesium, iron, manganese, copper, and zinc [34]; therefore, it is important to eat raw vegetables. The mineral content found in sprouts (and also in our young shoots) was, in general, higher than the values described for mature cabbages, which makes those parts of vegetables, a better dietary source of these minerals.

According to the Nutrition Standards for the Polish Population [30], the daily intake of calcium should be 1000–1200 mg for adults. The content of calcium in the studied young shoots is 176.9 mg/100 g fresh vegetable; therefore, this part of the vegetable can be a good source of dietary calcium. A diet with a high ratio of sodium to potassium is associated with increased risk of cardiovascular diseases [40]. The ratio of sodium-to-potassium ion in young shoots is less than one ($Na^+/K^+ < 1$). Young shoots contain such amounts of iron and magnesium that they can provide 7% of the RDA for females and 9% for males (Fe) and 14% of the RDA for females and 8% for males (Mg). Therefore, especially worthy is the high content of zinc found in young shoots, which indicates that 100 g of fresh shoots can provide 6% of the RDA for females and 4% for males over the age of 18. Therefore, total content of minerals in the tested young shoots could complement other sources of these minerals in the daily diet.

Glucosinolate profile

The health-promoting effects from Brassica vegetables are directly related to their glucosinolates (GLS) content and myrosinase activity. The mechanisms of the anti-tumor action of glucosinolate degradation products are based on the ability to modulate the expression of enzymes of phase I and II detoxification, the prevention of DNA damage in the cell, as well as cell cycle regulation and apoptosis [2]. Brassica sprouts and shortly cooked mature Brassica vegetables contain active myrosinase and present an increased bioavailability of isothiocyanates [41]. Studies of the glucosinolate contents of the growing sprouts and young shoots are scarce, since most research focuses on the vegetables at full maturity [42–46] or seeds [47, 48]. It is worth mentioning that rapid changes in the glucosinolates profile were observed during plant germination and early seedling growth [49]. A higher content of glucosinolates for a given species has been found in sprouts than in the fully grown plants [50, 51].

In our research, a higher concentration of total glucosinolates was found in young shoots in comparison to the vegetable at full maturity. Other authors have reported a decreased content of GLS in some Brassica species during seedling growth [49, 52]. Seeds have the largest amount of these reserve metabolites and this is consistent with their roles in plant defense and survival. It has also been a consequence of glucosinolates metabolism and dilution of their concentration during tissue expansion [53, 54].

The main glucosinolates in young shoots were aliphatic components such as progoitrin, sinigrin, and glucoraphanin which occurred at concentrations above 5.66 µmol/g DW (78% of total GLS). Other aliphatic components, glucoiberin and glucoalyssin, were present in low concentration (0.73 µmol/g DW; 10% of total GLS). The indolyl components such as glucobrassicin, metoxybrassicin, and neo-glucobrassicin were at an average concentration of 0.87 µmol/g DW (12% of total GLS). Other working groups reported a higher level of total GLS in Brassica sprouts (ready for harvest, between the 4th and 12th day after sowing) as compared to our results for young shoots [49, 50, 55].

In general, the literature data do not confirm the results obtained in this study for total glucosinolate content in red headed cabbage [44, 45, 51, 56, 57]. The results obtained by Ciska et al. [46] for the total content of GLS in different red headed cabbages varied about years of harvest. Different results were attributed to climatic factors like rainfall and temperature during the growing period. In our research, the main GLS in red headed cabbage were aliphatic components—sinigrin, glucoiberin, and progoitrin, which occurred at concentrations above 3.38 µmol/g DW (75% of total GLS). Other aliphatic components such as glucoraphanin and glucoalyssin were at a concentration of 0.9 µmol/g DW (20.1% of total GLS), while indolyl components glucobrassicin, metoxybrassicin, and neo-glucobrassicin, with a concentration of 0.21 µmol/g DW (4.9% of total GLS), represent minor components. Meyer and Adam [51] showed similar results concerning the main group of GLS in red headed cabbage, which were glucoraphanin, sinigrin, and progoitrin. The indole components represented a minor group. Other results showed that the aliphatic GLS were the major group in headed cabbage [45, 46, 50].

The composition of the glucosinolates profile is important as the beneficial effects depend on the breakdown products, after degradation and absorption. The total amount of glucosinolates aliphatic forms accounted for about 88% in young shoots and 95% in headed cabbage, respectively. Aliphatic GLS were the major group present in seeds and sprouts of Brassica varieties during the monitored stages [49, 55]. This tendency was especially observed in red cabbage and broccoli sprouts, confirming that sprouts can be a better source of aliphatic glucosinolates than mature vegetables [44, 55]. Higher quantities of progoitrin and similar amount of sinigrin were detected in young shoots as opposed to the vegetable at full maturity. Together, those compounds constituted 68.1 and 47% of the total aliphatic GLS in young shoots and headed cabbage, respectively. In young shoots, glucoraphanin was detected in a higher concentration compared to other glucosinolates. In addition, more of this compound was found in young shoots than in mature vegetable. Other authors who examined the content of aliphatic glucosinolates in red cabbage sprouts showed that progoitrin, glucoraphanin, and sinigrin were the major GLS [49, 55]. The content of glucoraphanin observed in headed cabbage in our studies was similar to data obtained by Uhl et al. [57] who reported glucoraphanin concentrations of 0.75 µmol/g DW in red cabbage, cv. Roxy. In addition, in the same work of Uhl et al. [57], similarly to our results, sinigrin and glucoraphanin were the most abundant glucosinolates in red cabbage. Aliphatic GLS, especially sinigrin and glucoraphanin, are known to be an important source of isothiocyanates (e.g., sulforaphane), a potent inducer of phase II enzymes, which may reduce risk of some cancers [58].

The highest concentration of total indole GLS, represented by glucobrassicins and neoglucobrassicin, was observed in young shoots in comparison to headed cabbage. The amount of 4-methoxyglucobrassicin was at a similar level. The breakdown product of the 4-methoxyglucobrassicin (4-methoxyindole-3-carbinol) has been studied, because it might play a role in cancer prevention, inhibiting cell proliferation and causing cell death of human cancer cells in vitro [59]. High amounts of this GLS were found in some varieties of growing Brassica sprouts, including red cabbage [50]. Another group of cancer-preventive breakdown products of indole glucosinolates is glucobrassicins [58]. Of the total indole glucosinolates, a higher content of glucobrassicin was determined in young shoots (70.1% of total indole GLS) in comparison to red headed cabbage (50% of total indole GLS). The total amount of and glucosinolates profile may vary significantly between tissues and organs: roots, leaves, seeds, and young sprouts and shoots [6, 60]. The composition of glucosinolates in the variety of vegetables depends on many factors, as the type of cultivars, growing conditions, availability of nutrients, harvest date, and signal molecules associated with reaction to biotic and abiotic stresses. Water shortage leads to lower glucosinolate content, because the sulfur uptake by plant is limited. In the other hand, excess water leads to lush plant growth and dilution of glucosinolate, and leaking of sulfur from the roots occurs [61–63].

Conclusions

Red headed cabbages are popular cruciferous vegetables that are eaten raw or after being processed at home or in food plants. Their popularity is also evidenced through their cultivation and consumption worldwide. Cabbage sprouts and young shoots could be potentially new natural functional foods. Raw fresh vegetables, including young shoots, are believed to be more nutritious. A significantly larger amount of dry matter, and total and digestible carbohydrates were found in the red headed cabbage in comparison to young shoots. Palmitic acid, oleic, and α-linolenic acid were the dominant fatty acids in both young shoots and mature vegetable. Young shoots could be a better source of protein and some minerals, i.e., calcium, magnesium, potassium, iron, zinc, and manganese in comparison to the red cabbage. Additionally, young shoots were characterized by a significantly larger amount of total glucosinolates. Due to the different glucosinolate content in various Brassica vegetables, it is difficult to estimate their daily intake. By choosing red cabbages, especially young shoots, consumer can enrich their diet in some nutrients and substantially increase the intake of health-promoting glucosinolates.

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Compliance with ethics standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics requirements This article does not contain any studies with human or animal subjects.

References

1. Gorinstein S, Park YS, Heo BG et al (2009) A comparative study of phenolic compounds and antioxidant and antiproliferative activities in frequently consumed raw vegetables. Eur Food Res Technol 228:903–911. https://doi.org/10.1007/s00217-008-1003-y
2. Manchali S, Chidambara Murthy KN, Patil BS (2012) Crucial facts about health benefits of popular cruciferous vegetables. J Funct Foods 4:94–106. https://doi.org/10.1016/j.jff.2011.08.004
3. Cartea ME, Francisco M, Soengas P, Velasco P (2011) Phenolic compounds in Brassica vegetables. Molecules 16:251–280. https://doi.org/10.3390/molecules16010251
4. Herr I, Büchler MW (2010) Dietary constituents of broccoli and other cruciferous vegetables: implications for prevention and therapy of cancer. Cancer Treat Rev 36:377–383. https://doi.org/10.1016/j.ctrv.2010.01.002
5. Kapusta-Duch J, Kopeć A, Piatkowska E, Borczak B et al (2012) The beneficial effects of Brassica vegetables on human health. Rocz Państwowego Zakładu Hig 63:389–395
6. Ciska E, Pathak DR (2004) Glucosinolate derivatives in stored fermented cabbage. J Agric Food Chem 52:7938–7943. https://doi.org/10.1021/jf048986+
7. Park S, Valan Arasu M, Lee MK et al (2014) Quantification of glucosinolates, anthocyanins, free amino acids, and vitamin C in inbred lines of cabbage (*Brassica oleracea* L.). Food Chem 145:77–85. https://doi.org/10.1007/s00217-008-1003-y
8. Agerbirk N, Olsen CE (2012) Glucosinolate structures in evolution. Phytochemistry 77:16–45. https://doi.org/10.1016/j.phytochem.2012.02.005
9. Wennberg M, Ekvall J, Olsson K, Nyman M (2006) Changes in carbohydrate and glucosinolate composition in white cabbage (*Brassica oleracea* var capitata) during blanching and treatment with acetic acid. Food Chem 95:226–236. https://doi.org/10.1016/j.foodchem.2004.11.057
10. Mithen RF, Dekker M, Verkerk R et al (2000) The nutritional significance, biosynthesis and bioavailability of glucosinolates in human foods. J Sci Food Agric 80:967–984. https://doi.org/10.1002/(sici)1097-0010(20000515)80:7%3c967:aid-jsfa597%3e3.3.co;2-m
11. Luo YW, Xie WH, Jin XX et al (2014) Effects of germination on iron, zinc, calcium, manganese, and copper availability from cereals and legumes. CyTA J Food 12:22–26. https://doi.org/10.1080/19476337.2013.782071
12. Horwitz W, Latimer GW (2005) Official methods of analysis of AOAC International, 18th edn. AOAC Int, Gaithersburg
13. Fortuna T, Rożnowski J (2012) Wybrane zagadnienia z chemii żywności: skrypt do ćwiczeń. Wydawnictwo Uniwersytetu Rolniczego, Kraków **in Polish**
14. Folch J, Lees M, Sloane Stanley GH (1957) A simple method for the isolation and purification of total lipides from animal tissues. J Biol Chem 226:497–509
15. Morrison WR, Smith LM (1964) Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride–methanol. J Lipid Res 5:600–608
16. Kusznierewicz B, Iori R, Piekarska A, Namieśnik J (2013) Convenient identification of desulfoglucosinolates on the basis of mass spectra obtained during liquid chromatography-diode array-electrospray ionisation mass spectrometry analysis: method verification for sprouts of different Brassicaceae species extracts. J Chromatogr A 1278:108–115. https://doi.org/10.1016/j.chroma.2012.12.075
17. Clarke DB (2010) Glucosinolates, structures and analysis in food. Anal Methods 2:310–325. https://doi.org/10.1039/b9ay00280d
18. Rosental L, Nonogaki H, Fait A et al (2015) Activation and regulation of primary metabolism during seed germination. Seed Sci Res 24:1–15. https://doi.org/10.1017/S0960258513000391
19. Wojciechowska R, Rożek S, Kotłon A (2007) Zawartość wybranych składników w plonie kapusty czerwonej w zależności od formy azotu nawozowego Roczniki Akademi Rolniczej w Poznaniu 41:667–671 **in Polish**
20. Majkowska-Gadomska J, Wierzbicka B (2008) Content of basic nutrients and minerals in heads of selected varieties of red cabbage (Brasicca oleracea var capitata f rubra). Polish J Environ Stud 17:295–298
21. Biesiada A, Nawirska-Olszańska A, Kucharska A, Sokół-Łętowska A, Kedra K (2010) The effect of nitrogen fertilization on nutritive value and antioxidative activity of red cabbage. Acta Sci Pol Hortorum Cultus 9:13–21
22. Vale AP, Santos J, Brito N et al (2015) Light influence in the nutritional composition of *Brassica oleracea* sprouts. Food Chem 178:292–300. https://doi.org/10.1016/j.phytochem.2015.02.004
23. Tanongkankit Y, Chiewchan N, Devahastin S (2012) Physicochemical property changes of cabbage outer leaves upon preparation into functional dietary fiber powder. Food Bioprod Process 90:541–548. https://doi.org/10.1016/j.fbp.2011.09.001
24. Mohammed M, Luka CD (2013) Comparative analysis of the different Brassica Oleracea varieties grown on Jos, Plateau using albino rats IOSR. J Pharm Biol Sci 6:85–88. https://doi.org/10.9790/3008-628588
25. Kahlon TS, Chapman MH, Smith GE (2007) *In vitro* binding of bile acids by spinach, kale, brussels sprouts, broccoli, mustard greens, green bell pepper, cabbage and collards. Food Chem 100:1531–1536. https://doi.org/10.1016/j.foodchem.2005.12.020
26. Nilnakara S, Chiewchan N, Devahastin S (2009) Production of antioxidant dietary fibre powder from cabbage outer leaves. Food Bioprod Process 87:301–307. https://doi.org/10.1016/j.fbp.2008.12.004
27. Vidrih R, Filip S, Hribar J (2009) Content of higher fatty acids in green vegetables. Czech J Food Sci 27:125–129. https://doi.org/10.17221/621-cjfs
28. Pereira C, Li D, Sinclair AJ (2001) The α-linolenic acid content of green vegetables commonly available in Australia. Int J Vitam Nutr Res 71:223–228. https://doi.org/10.1024/0300-9831.71.4.223

29. Joint WHO/FAO exper comsultation (2003) Diet, nutrition and the prevention of chronic diseases WHO technical reports series 91634-63
30. Jarosz M (2017) Nutrition Standards for the Polish Population IZZ: Warsaw, Poland
31. Komolka P, Górecka P (2012) Wpływ obróbki termicznej warzyw kapustnych na zawartość błonnika pokarmowego. Żywn Nauka Technol Jakość 2:68–76 **in Polish**
32. Khanum F, Siddalinga Swamy M, Sudarshana Krishna KR et al (2000) Dietary fiber content of commonly fresh and cooked vegetables consumed in India. Plant Foods Hum Nutr 55:207–218. https://doi.org/10.1023/A:1008155732404
33. Ashfaq F, Butt MS, Nazir A, Jamil A (2018) Compositional analysis of pakistani green and red cabbage. Pakistan J Agric Sci 55:191–196. https://doi.org/10.21162/PAKJAS/18.6547
34. Kawashima LM, Valente Soares LM (2003) Mineral profile of raw and cooked leafy vegetables consumed in Southern Brazil. J Food Compos Anal 16:605–611. https://doi.org/10.1016/S0889-1575(03)00057-7
35. Zieliński H, Frias J, Piskuła MK et al (2005) Vitamin B1 and B2, dietary fiber and minerals content of *Cruciferae sprouts*. Eur Food Res Technol 221:78–83. https://doi.org/10.1007/s00217-004-1119-7
36. Warman PR, Havard KA (1997) Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage. Agric Ecosyst Environ 61:155–162. https://doi.org/10.1016/S0167-8809(96)01110-3
37. Ekholm P, Reinivuo H, Mattila P (2007) Changes in the mineral and trace element contents of cereals, fruits and vegetables in Finland. J Food Compos Anal 20:487–495. https://doi.org/10.1016/j.jfca.2007.02.007
38. Czech A, Pawlik M, Rusinek E (2012) Contents of heavy metals, nitrates, and nitrites in cabbage. Polish J Environ Stud 21:321–329
39. Sady W, Wojciechowska R, Rożek S (2001) The effect of form and placement of N on yield and nitrate content in white cabbage. Acta Hort 563:123–128
40. Yang Q, Liu T, Kuklina EV (2011) Sodium and potassium intake and mortality among US adults. Arch Intern Med 171:1183–1191. https://doi.org/10.1001/archinternmed.2011.257
41. Verkerk R, Schreiner M, Krumbein A et al (2009) Glucosinolates in Brassica vegetables: the influence of the food supply chain on intake, bioavailability and human health. Mol Nutr Food Res 53:219–265. https://doi.org/10.1002/mnfr.200800065
42. Kapusta-Duch J, Kusznierewicz B, Leszczyńska T, Borczak B (2016) Effect of cooking on the contents of glucosinolates and their degradation products in selected Brassica vegetables. J Funct Foods 23:412–422. https://doi.org/10.1016/j.jff.2016.03.006
43. Kusznierewicz B, Bartoszek A, Wolska L et al (2013) Partial characterization of white cabbages (Brassica oleracea var capitata f alba) from different regions by glucosinolates, bioactive compounds, total antioxidant activities and proteins. LWT Food Sci Technol 41:1–9. https://doi.org/10.1016/j.lwt.2007.02.007
44. Volden J, Borge GIA, Bengtsson GB et al (2008) Effect of thermal treatment on glucosinolates and antioxidant-related parameters in red cabbage (*Brassica oleracea* L. ssp. capitata f rubra). Food Chem 109:595–605. https://doi.org/10.1016/j.foodchem.2008.01.010
45. Charron CS, Saxton AM, Sams CE (2005) Relationship of climate and genotype to seasonal variation in the glucosinolate-myrosinase system. I. Glucosinolate content in ten cultivars of Brassica oleracea grown in fall and spring seasons. J Sci Food Agric 85:671–681. https://doi.org/10.1002/jsfa.1880
46. Ciska E, Martyniak-Przybyszewska B, Kozłowska H (2000) Content of glucosinolates in cruciferous vegetables grown at the same site for two years under climatic conditions. J Agric Food Chem 48:2862–2867. https://doi.org/10.1021/jf981373a
47. West LG, Meyer KA, Balch BA et al (2004) Glucoraphanin and 4-Hydroxyglucobrassicin Contents in seeds of 59 cultivars of broccoli, raab, kohlrabi, radish, cauliflower, brussels sprouts, kale, and cabbage. J Agric Food Chem 52:916–926. https://doi.org/10.1021/jf0307189
48. Matthäus B, Luftmann H (2000) Glucosinolates in members of the family Brassicaceae: separation and identification by LC/ESI-MS-MS. J Agric Food Chem 48:2234–2239. https://doi.org/10.1021/jf991306w
49. Bellostas N, Kachlicki P, Sørensen JC, Sørensen H (2007) Glucosinolate profiling of seeds and sprouts of B oleracea varieties used for food. Sci Hortic (Amsterdam) 114:234–242. https://doi.org/10.1016/j.scienta.2007.06.015
50. Baenas N, Moreno DA, García-Viguera C (2012) Selecting sprouts of Brassicaceae for optimum phytochemical composition. J Agric Food Chem 60:11409–11420. https://doi.org/10.1021/jf302863c
51. Meyer M, Adam ST (2008) Comparison of glucosinolate levels in commercial broccoli and red cabbage from conventional and ecological farming. Eur Food Res Technol 226:1429–1437. https://doi.org/10.1007/s00217-007-0674-0
52. Valente Pereira FM, Rosa E, Fahey JW et al (2002) Influence of temperature and ontogeny on the levels of glucosinolates in broccoli (Brassica oleracea var italica) sprouts and their effect on the induction of mammalian phase 2 enzymes. J Agric Food Chem 50:6239–6244. https://doi.org/10.1021/jf020309x
53. Ciska E, Honke J, Kozłowska H (2008) Effect of light conditions on the contents of glucosinolates in germinating seeds of white mustard, red radish, white radish, and rapeseed. J Agric Food Chem 56:9087–9093. https://doi.org/10.1021/jf801206g
54. Chen S, Andreasson E (2001) Update on glucosinolate metabolism and transport. Plant Physiol Biochem 39:743–758. https://doi.org/10.1016/S0981-9428(01)01301-8
55. Vale AP, Santos J, Brito NV et al (2015) Evaluating the impact of sprouting conditions on the glucosinolate content of Brassica oleracea sprouts. Phytochemistry 115:252–260. https://doi.org/10.1016/j.phytochem.2015.02.004
56. Tabart J, Pincemail J, Kevers C et al (2018) Processing effects on antioxidant, glucosinolate, and sulforaphane contents in broccoli and red cabbage. Eur Food Res Technol 244:2085–2094. https://doi.org/10.1007/s00217-018-3126-0
57. Uhl M, Kassie F, Rabot S et al (2004) Effect of common Brassica vegetables (Brussels sprouts and red cabbage) on the development of preneoplastic lesions induced by 2-amino-3-methylimidazo[4,5- f]quinoline (IQ) in liver and colon of Fischer 344 rats. J Chromatogr B 802:225–230. https://doi.org/10.1016/j.jchromb.2003.11.014
58. Cieślik E, Leszczyńska T, Filipiak-Florkiewicz A et al (2007) Effects of some technological processes on glucosinolate contents in cruciferous vegetables. Food Chem 105:976–981. https://doi.org/10.1016/j.foodchem.2007.04.047
59. Kronbak R, Duus F, Vang O (2010) Effect of 4-Methoxyindole-3-Carbinol on the proliferation of colon cancer cells in vitro, when treated alone or in combination with indole-3-Carbinol. J Agric Food Chem 58:8453–8459. https://doi.org/10.1021/jf101806t
60. Fahey JW, Zalcmann AT, Talalay P (2001) The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. Phytochemistry 56:5–51. https://doi.org/10.1016/S0031-9422(00)00316-2
61. Kestwal RM, Lin JC, Bagal-Kestwal D, Chiang BH (2011) Glucosinolates fortification of cruciferous sprouts by sulphur supplementation during cultivation to enhance anti-cancer activity. Food Chem 126:1164–1171. https://doi.org/10.1016/j.foodchem.2010.11.152
62. Hasegawa T, Yamada K, Kosemura S et al (2006) Phototropic stimulation induces the conversion of glucosinolate to

phototropism-regulating substances of radish hypocotyls. Phytochemistry 54:275–279. https://doi.org/10.1016/S0031-9422(00)00080-7

63. Koritsas VM, Lewis JA, Fenwick GR (1991) Glucosinolate responses of oilseed rape, mustard and kale to mechanical wounding and infestation by cabbage stem flea beetle (Psylliodes chrysocephala). Ann Appl Biol 118:209–221. https://doi.org/10.1111/j.1744-7348.1991.tb06099.x