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1 **Effects of thermal and non-thermal processing of cruciferous vegetables**  
2 **on glucosinolates and their derived forms**

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13

14 **Running title:** Effect of processing on the glucosinolate content of *brassic*

15

16 **Abbreviations:** HPP: High pressure processing; UV: Ultraviolet; IPL: Intense pulsed light,  
17 PEF: Pulsed electric field.

18 **Abstract**

19 *Brassica* vegetables, which include broccoli, kale, cauliflower, and Brussel sprouts, are  
20 known for their high glucosinolate content. Glucosinolates and their derived forms  
21 namely isothiocyanates are of special interest in the pharmaceutical and food industries  
22 due to their antimicrobial, neuroprotective, and anticarcinogenic properties. These  
23 compounds are water soluble and heat-sensitive and have been proved to be heavily lost  
24 during thermal processing. In addition, previous studies suggested that novel non-thermal  
25 technologies such as high pressure processing, pulsed electric fields, or ultraviolet  
26 irradiation can affect the glucosinolate content of cruciferous vegetables. The objective  
27 of this paper was to review current knowledge about the effects of both thermal and non-  
28 thermal processing technologies on the content of glucosinolates and their derived forms  
29 in *brassica* vegetables. This paper also highlights the importance of the incorporation of  
30 *brassica* vegetables into our diet for their health-promoting properties beyond their  
31 anticarcinogenic activities.

32 **Keywords:** Glucosinolates, crucifers, thermal processing, novel technologies, non-thermal  
33 processing, *brassica*

## 34 **Introduction**

35 Consumers are nowadays more aware of the relationship between food, diet, and health,  
36 and this has led to increased interest in natural ingredients and in the consumption of  
37 foods that are tasty, nutritious, and healthy. Consumption of a diet rich in *brassica*  
38 vegetables has been associated with health effects such as neuroprotective effects  
39 (Angeloni et al. 2017) or reduced abundance of intestinal sulphate-reducing bacteria  
40 (Kellingray et al. 2017), cardiovascular diseases (Francisco et al. 2017), and some types  
41 of cancer (Mori et al. 2017).

42 The chemoprotective activities of cruciferous vegetables were first recognized in the early  
43 1990s and are nowadays accepted after large amounts of scientific evidence in various  
44 cancer models including breast cancer (Lin et al. 2017). Follow-up studies have attributed  
45 this activity to the metabolic products of glucosinolates, a class of secondary sulphur-  
46 containing metabolites produced by crucifers (Watson et al. 2013). The enzymatic  
47 breakdown of glucosinolates is also of key importance for food quality as isothiocyanates,  
48 the main breakdown products, are responsible for the sharp taste of mustard, radish, or  
49 broccoli sprouts (Hanschen and Schreiner, 2017). Although more than 120 different  
50 glucosinolates have been identified in cruciferous vegetables, only some of these are  
51 present in high quantities (Possenti et al. 2017). Glucoraphanin is the predominant  
52 glucosinolate in broccoli and broccoli sprouts (Westphal et al. 2017) followed by  
53 progoitrin, glucoiberin, and glucobrassicin (Possenti et al. 2017). However, the  
54 glucosinolates profile of broccoli is highly different from those of kale, cauliflower, or  
55 Brussel sprouts and can vary even between plants belonging to the same family and  
56 between different parts of the same plant (Possenti et al. 2017).

57 The conditions of post-harvest processing and cooking are important factors of food  
58 quality (Francisco et al. 2017). *Brassica* vegetables are generally eaten cooked after

59 steaming, boiling, or microwaving. However, glucosinolates, vitamins, phenolic  
60 compounds, and other health-promoting compounds have been shown to be heavily lost  
61 during thermal processing (Kapusta-Duch et al. 2016; Soares et al. 2017). The food  
62 industry is very active in technological innovation and over the last two decades novel  
63 non-thermal processing technologies have been viewed as useful for microbial  
64 inactivation while maintaining quality of fresh and processed fruits and vegetables.  
65 The objective of this paper was to review current knowledge on the effects of both thermal  
66 and non-thermal technologies on the content of glucosinolates and its derived products in  
67 cruciferous vegetables. Furthermore, the current paper also reviews the known  
68 phytochemicals found in cruciferous vegetables and highlights the importance of their  
69 inclusion into our diet.

## 70 **Cruciferous vegetables: Economic and health importance**

71 *Brassica* foods which have been identified as important components of a healthy diet are  
72 among the top 10 economic crops in the world (Francisco et al. 2017). Indeed, *Brassica*  
73 oilseed production has increased over the last 40 years and has become the most important  
74 source of vegetable oil after soybean and cotton seed (Rakow, 2004). The genus *Brassica*,  
75 which contains over 37 species, is one of 51 genera in the tribe Brassiceae belonging to  
76 the crucifer family. Many crop species are included in the *Brassica* genus which includes  
77 edible roots, leaves, stems, buds, flowers, and seeds. Figure 1 shows the production  
78 quantities of some common *brassica* vegetables. Several studies have predicted the  
79 human population to grow by two to four billion people by 2050 (Cohen, 2003). This  
80 expanded population is expected to consume twice as much food than currently consumed  
81 today and production of crucifers is likely to continue to grow. Indeed, according to data  
82 accessed from FAOSTAT, production quantities of common *brassica* vegetables such as  
83 cabbages and broccolis are increasing every year. The principal *Brassica* vegetable  
84 species is *B. oleracea* which includes a large range of unique cole and cabbage types that  
85 include Brussel sprouts, cauliflower, broccoli, and others. Much of the production is  
86 locally consumed. Top producers of cauliflowers and broccolis are China and India, with  
87 a total production of approximately 9.2 and 8.5 million tonnes per year (FAOSTAT,  
88 2017).

89 Cruciferous vegetables are rich sources of bioactive health promoting compounds  
90 including vitamin C and E, dietary fiber, and the glycosides of the flavonoids quercetin  
91 and kaempferol (Jeffery and Araya, 2009). However, the components that set cruciferous  
92 vegetables apart from other vegetables are the glucosinolates. Glucosinolates are  $\beta$ -  
93 thioglucoside *N*-hydroxysulfates with a side chain and a sulfur linked  $\beta$ -D-glucopyranose  
94 moiety (Possenti et al. 2017). Glucosinolates can be divided into three major groups based

95 on the structure of their amino acid precursors: (i) aliphatic glucosinolates derived from  
96 methionine, isoleucine, leucine, or valine; (ii) aromatic glucosinolates, those derived from  
97 phenylalanine or tyrosine; and (iii) indole glucosinolates which are those derived from  
98 tryptophan (Possenti et al. 2017). Myrosinase (EC 3.2.3.1), which is physically separated  
99 from the glucosinolates in the intact plant cells, catalyzes the hydrolysis of glucosinolates  
100 (Deng et al. 2015). When crucifers are processed, myrosinase can interact with  
101 glucosinolates and, based on reaction conditions namely pH and temperature, release  
102 either isothiocyanates, thiocyanates, or nitriles from their precursors (Wagner et al. 2013).  
103 Sulforaphane is the most widely studied isothiocyanate and is considered to be  
104 responsible for the major part of cancer prevention by broccoli (Jeffery and Araya, 2009).  
105 *In vitro* and *in vivo* studies have reported that glucosinolate breakdown products can affect  
106 several stages of cancer development, including the inhibition of activation enzymes  
107 (phase I) and the induction of detoxification enzymes (phase II) (Possenti et al. 2017). In  
108 addition, isothiocyanates and indole products formed from glucosinolates may regulate  
109 cancer cell development by regulating target enzymes, controlling apoptosis, inhibiting  
110 angiogenesis, inhibiting metastasis and migration of cancer cells, and blocking the cell  
111 cycle (Possenti et al. 2017). Sulforaphane is derived from glucoraphane and sinigrin,  
112 glucotropaeolin, and gluconasturtiin are the precursors of allyl, benzyl, and phenethyl  
113 isothiocyanates respectively. Epithionitriles are important, but yet underestimated  
114 glucosinolate hydrolysis products generated instead of isothiocyanates (Hanschen et al.  
115 2018). Epithionitriles including 1-cyano-2,3-epithiopropene have been suggested to  
116 possess cancer cell-killing properties involving both intrinsic and extrinsic apoptotic  
117 signaling pathways (Conde-Rioll et al. 2017).  
118 Besides their anticarcinogenic properties, glucosinolates obtained from broccoli also  
119 showed antimicrobial activities against Gram positive and Gram negative bacterial strains

120 and were suggested as potential antibacterial agents for use as such in food products  
121 (Hinds et al. 2017). As mentioned previously, cruciferous vegetables are also rich sources  
122 of vitamins, including those listed in Table 1, phenolic compounds, and flavonoids  
123 (Bhandari and Kwak, 2015). *Brassica* vegetables contain high concentrations of vitamin  
124 C, which includes ascorbic acid and its oxidation product dehydroascorbic acid. Vitamin  
125 C which has several biological activities in the human body and is also thought to have  
126 cancer-protective capacities (Bakker et al. 2016) and a positive association has been made  
127 between dietary vitamin C and bone mineral density (Sahni et al. 2016). *Brassica*  
128 vegetables such as kale or mustard spinach are rich sources of minerals such as calcium  
129 and potassium - Table 1.



## 130 **Thermal processing of *brassica* vegetables**

131 Although some crucifers can be eaten fresh, these vegetables are most commonly eaten  
132 cooked after blanching, steaming, boiling, or microwaving. Thermal processing strategies  
133 have been used in the food industry since ancient times with the aim of not only making  
134 certain foods edible but delaying the inevitable deterioration of perishable foods between  
135 production and consumption. This is achieved by the destruction of microbial pathogens  
136 and the reduction of spoilage microorganisms as well as the inactivation of enzymes  
137 involved in food deterioration.

138 Thermal processing of *brassica* vegetables improves palatability and extends shelf-life.  
139 However, high temperatures also result in changes in the content of health-promoting  
140 compounds including glucosinolates, which intakes are associated with a reduced risk of  
141 several forms of cancer (Capuano et al. 2017). Indeed, Kapusta-Duch et al. (2016)  
142 recently reported a significant reduction in the content of glucosinolates and their derived  
143 products in green and purple cauliflower and rutabaga after boiling (100 °C, 15 min).  
144 Similar results were published by Cieślik et al. (2007), who evaluated the effects of  
145 blanching, boiling, and freezing on the glucosinolate content of a number of cruciferous  
146 vegetables including Brussel sprouts, white and green cauliflower, broccoli, and curly  
147 kale. The authors of this study observe considerable losses of total glucosinolates after  
148 blanching and cooking, from 2.7 to 30.0% and from 35.3 to 72.4%, respectively.  
149 Furthermore, no changes in the total glucosinolate content were found in vegetables that  
150 were blanched and frozen for 48 h. In addition, Tiwari et al. (2015) modeled and  
151 quantified the level of glucosinolates in broccoli, cabbage, cauliflower, and Brussel  
152 sprouts upon thermal processing and reported that thermal processing had a major impact  
153 on the level of glucosinolates in cruciferous vegetables. The authors of this study also  
154 evaluated subsequent human exposure to glucosinolates, based on dietary surveys, and

155 concluded that consumption of processed crucifers indicated a low mean weakly intake.  
156 However, the model observed a higher level of exposure following consumption of  
157 steamed vegetables compared to boiling, *sous-vide*, and grilling processes. In a different  
158 study, Sarvan et al. (2014) modeled the degradation kinetics of glucosinolates during  
159 processing of four crucifers namely broccoli, red cabbage, white cabbage, and Brussels  
160 sprouts. This study demonstrated that glucosinolates are heavily lost after thermal  
161 processing and that their thermostability varied not only in different media such as the  
162 food matrix or the cooking water, but also with the vegetable variety in which the  
163 glucosinolates were present. Several studies suggested steaming as the most efficient  
164 process to retain glucosinolates in cruciferous vegetables when compared with blanching,  
165 boiling, or microwaving (Bongoni et al. 2014; Deng et al. 2015; Soares et al. 2017; Tiwari  
166 et al. 2015; Volden et al. 2008) and Florkiewicz et al. (2017) recently suggested *sous-vide*  
167 as an advantageous processing method of broccoli, Brussels sprouts, and cauliflower.  
168 Table 2 lists the predicted effects of blanching (3 min, 95 °C), cooking (40 min, 100 °C),  
169 and canning (40 min, 120 °C) on the residual percentage of glucosinolates in red cabbage  
170 as a result of thermal degradation. Results, previously reported by Oerlemans et al. (2006)  
171 showed that mild heat treatments, such as blanching, have little impact on glucosinolates.  
172 Furthermore, Giambanelli et al. (2015) reported that broccoli glucosinolates degradation  
173 can be reduced by performing the thermal treatment in binary systems with other food  
174 ingredients such as onion, pointing out that the interaction of different ingredients may  
175 not only improve the taste of a dish, but also its healthiness.

176 Thermal processing does not affect all phytochemicals in the same way. Indeed,  
177 Oerlemans et al. (2006) demonstrated tha conventional cooking did not affect aliphatic  
178 glucosinolates but significantly decreased the concentration of indole glucosinolates.  
179 However, in that study the more severe heat treatment significantly affected all

180 glucosinolates and the authors suggested that those conditions would have a great impact  
181 on the health promoting compounds available in canned *Brassica* vegetables. In addition,  
182 Cieřlik et al. (2007) reported how the glucoiberin content in broccoli decreased from 0.42  
183 to 0.21 mg/100 g while the glucoraphanin and glucoalyssin content varied from 48.7 to  
184 30.1 mg/100 g and 0.52 to 0.32 mg/100 g, respectively. Similarly, blanching and boiling  
185 of Brussel sprouts resulted in significant losses of sinigrin (25.4 and 58.6%, respectively)  
186 and glucobrassicin (22.3 and 72.8%, respectively). Cieřlik et al. (2007) suggested that the  
187 relative stabilities of individual glucosinolates may be a function of their respective  
188 chemical structures as, for example, aliphatic glucosinolates are generally more stable  
189 than indole glucosinolates.

190 Previous studies reported that thermal processing could inactivate the enzyme  
191 myrosinase. Indeed, Verkerk and Dekker (2004) studied the effect of various microwave  
192 treatments on the activity of myrosinase in red cabbage (*Brassica oleracea* L. Var.  
193 *Capitata f. rubra* DC.) and reported that a substantial myrosinase activity was retained in  
194 cabbage treated at low (24 min, 180 W) and intermediate (8 min, 540 W) microwave  
195 powers while microwave cooking for 4.8 min at 900 W resulted in a complete loss of  
196 hydrolytic activity. Therefore, thermal processing can also affect the concentration of  
197 indoles, isothiocyanates, and other glucosinolate breakdown products. Kapusta-Duch et  
198 al. (2016) reported a decrease in the total indoles content of 48.5 and 75.8% and a  
199 reduction in the content of total isothiocyanates of 11.0 and 42.4% after processing of  
200 green and purple cauliflower at 100 °C during 15 min, when compared to vegetables  
201 before treatment. Boiling, frying, and microwaving of broccoli also resulted in losses of  
202 ascorbic acid, the predominant form of vitamin C, of 33, 24, and 16% respectively (Soares  
203 et al. 2017). High temperatures can result in the loss of nutritional quality attributes of

204 cruciferous vegetables and for this reason, thermal treatment conditions namely  
205 temperature and duration should be kept at the least possible values.

206 **Non-thermal technologies: Beyond food safety**

207 High-pressure processing (HPP) has been successfully applied to a large variety of foods  
208 during the last two decades. The potential of this technology to improve both safety, by  
209 eliminating pathogenic microorganisms, and health-promoting attributes of foods has  
210 been largely studied. Several studies have evaluated the impact of HPP on glucosinolates  
211 and their derived forms. For example, Westphal et al. (2017) studied the effects of HPP  
212 (100-600 MPa, 3 min, and 30 °C) on the glucosinolates content and conversion to  
213 isothiocyanates during storage in fresh broccoli sprouts. Myrosinase was active after HPP  
214 and a formation of isothiocyanates was observed in all HPP-treated sprouts. The degrees  
215 of conversion in the sprouts treated at 100-300 MPa ranged from 11 to 18% and from 400  
216 MPa onward, the degree of conversion increased up to 85% for 600 MPa. Similar results  
217 were obtained by Wang et al. (2016) who observed a maximum degradation of  
218 glucosinolates in seedlings from Brussel sprouts at 600 MPa. This study also evaluated  
219 the effect of HPP on purified myrosinase and observed that although the enzyme was still  
220 active after processing at 600 MPa, a decrease in its activity upon increasing pressure to  
221 800 MPa was detected. Alvarez-Jubete et al. (2014) observed higher concentrations of  
222 isothiocyanates after processing of white cabbage at 600 MPa when compared to  
223 blanching. HPP-treated samples also showed significantly higher levels of total phenols  
224 and a higher antioxidant capacity when compared to thermally-treated samples (Table 3).  
225 Overall, maximum degradation of glucosinolates in cruciferous vegetables has been  
226 observed at 600 MPa. Myrosinase is active after HPP at 100-600 MPa. However, a  
227 reduction in myrosinase activity has been observed at higher pressures.

228 Ultraviolet (UV) irradiation has emerged as a potential alternative to currently used post-  
229 harvest treatments. For example, UV-C irradiation has been efficiently used to reduce  
230 microbial contamination of foods and food contact surfaces (Lim and Harrison, 2016) and

231 it is known that UV-B irradiation enhances vitamin D production in mushrooms (Urbain  
232 et al. 2016). Although UV light has been shown to be effective in modifying the activity  
233 of certain enzymes commonly found in cruciferous vegetables such as peroxidase (Cruz  
234 et al. 2016), to promote the production of certain flavonoids (Neugart et al. 2014) or  
235 ascorbic acid (Topcu et al. 2015), and to increase antioxidant capacity (Darré et al. 2017)  
236 of different *brassica* vegetables, little is known about the effect of UV light on  
237 glucosinolates and isothiocyanates. Formica-Oliveira et al. (2017) recently observed that  
238 single or combined UV-B (5, 10, and 15 KJ/m<sup>2</sup>) and UV-C (9 KJ/m<sup>2</sup>) treatments could  
239 revalorize broccoli by-products by increasing their concentration of glucosinolates after  
240 a 3-day storage period. Supplementary UV radiation (2.2, 8.8, and 16.4 KJ/m<sup>2</sup>/day) during  
241 the vegetative period of broccoli also resulted in increased glucosinolates content (Topcu  
242 et al. 2015). Similar results were obtained by Mewis et al. (2012) who observed increased  
243 levels of glucosinolates in broccoli sprouts after pre-harvest UV-B radiation at 0.3-1.0  
244 KJ/m<sup>2</sup>/day. However, other studies reported no differences in the glucosinolates content  
245 of cruciferous vegetables after UV-B exposure at 20 KJ/m<sup>2</sup>/day (Rybarczyk-Plonska et  
246 al. 2016). The majority of the paper published to date focused on broccoli and knowledge  
247 on the effect of UV processing on other crucifers is lacking. From the latest reports it can  
248 be observed that low intensity UV-B treatments seem to be more efficient in enhancing  
249 glucosinolates production in broccoli. However, further research studies are needed in  
250 order to optimize glucosinolate production in different *brassica* vegetables. Intense  
251 pulsed light (IPL) is a non-thermal food processing technology with potential for being  
252 used in the food industry. Although, up to the best of the authors knowledge, no studies  
253 have been published over the last couple of years on the effects of IPL on the  
254 glucosinolates content of cruciferous vegetables, results obtained using this technology  
255 on other foods are encouraging. For example, carrots treated with pulsed light doses of

256 2.26 J/cm<sup>2</sup> showed increased falcarindiol and  $\beta$ -carotene content when compared to the  
257 control (Aguiló-Aguayo et al. 2017).

258 Pulsed electric field (PEF) is a novel technique able to permeabilize vegetable tissue  
259 without an important increase of the product temperature, avoiding an excessive  
260 deterioration of the product (Puértolas et al. 2016). PEFs have the ability to inactivate  
261 microorganisms and enzymes while preserving the nutritional quality of fresh and  
262 minimally processed foods (Odriozola-Serrano et al. 2016). Indeed, previous studies  
263 suggested that PEF processing at 15, 25, or 35 kV was efficient in preserving bioactive  
264 compounds and antioxidant activity of broccoli when compared to thermal processing at  
265 90 °C during 1 min (Sánchez-Vega et al. 2015). Only few studies have assessed the effect  
266 of PEF processing on the glucosinolates content of broccoli and broccoli-derived  
267 products. It is believed that PEF processing, especially at moderate conditions, could be  
268 a suitable method to promote glucosinolates production in broccoli. Indeed, Aguiló-  
269 Aguayo et al. (2015) used a response surface methodology to calculate 4 kV/cm for 525  
270 and 1000  $\mu$ s as the optimum conditions to maximize glucosinolate levels in broccoli  
271 florets and stalks, which ranged from 187.1 to 212.5% and 110.6 to 203,0%, respectively.  
272 These results contrast to those obtained by Frandsen et al. (2014) who processed broccoli  
273 puree with either 3, 10, or 20 kV/cm and varied number of pulses and observed that,  
274 although most of the glucosinolates were degraded during pureeing, the PEF conditions  
275 studied did not negatively affect the activity of myrosinase as a further intensity-  
276 dependent degradation was observed. The observed degradation was especially high at  
277 stronger processing conditions. The authors of this study suggested that an initial  
278 myrosinase inactivation step would be needed if glucosinolates are intended to be kept  
279 intact while PEF processing. Overall, results obtained so far are contradictory and further  
280 research is needed to understand the effects of this technology on glucosinolates in

281 cruciferous vegetables. Studying the effects of different PEF processing parameters on  
282 the glucosinolates content of crucifers as well as combinations of PEF with other non-  
283 thermal strategies is worthy studying.



284 **Conclusions**

285 Glucosinolates and its derived products have the potential for being used as ingredients  
286 in functional foods, which is one of the top trends in the food industry. The incorporation  
287 of cruciferous vegetables into our diet or the use of glucosinolates and their derived  
288 products as ingredients in functional foods is of special interest due to their anticancer  
289 properties. However, temperature processing degrades glucosinolates and other  
290 compounds such as vitamins, and phenolic compounds and this needs to be considered  
291 when calculating the dietary intake of these compounds from cooked crucifers. Thermal  
292 processing conditions namely temperature and duration should be kept at the least  
293 possible values. Several studies concluded that steaming is the most efficient process to  
294 retain glucosinolates in cruciferous vegetables when compared with blanching, boiling,  
295 microwaving, frying, or *sous-vide* processing. Furthermore, the conditions of post-harvest  
296 processing are essential to improve the nutritional and health-promoting properties of  
297 cruciferous vegetables. Overall, non-thermal processing technologies are promising  
298 strategies that could be used to promote the production of glucosinolates in cruciferous  
299 vegetables or to minimize their degradation during processing. For example, previous  
300 studies suggested that UV irradiation or PEF processing could promote glucosinolate  
301 production in cruciferous vegetables including broccoli. Further studies are needed in  
302 order to optimize the conditions needed to generate cruciferous vegetables enriched in  
303 glucosinolates and to assess their resistance to cooking and gastrointestinal degradation.

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313

314 **Conflict of interests**

315 The authors declare no conflict of interests

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483 **FIGURE CAPTIONS**

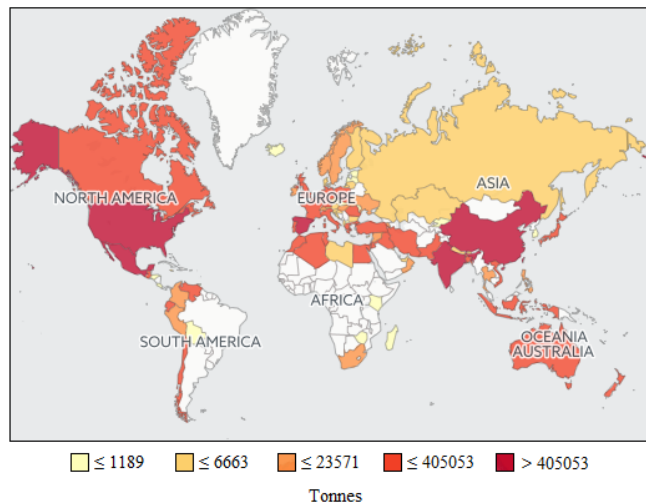
484 **FIGURE 1. *Brassica* production quantities per country**

485 Data accessed from the Food and Agriculture Organization Corporate Statistical Database

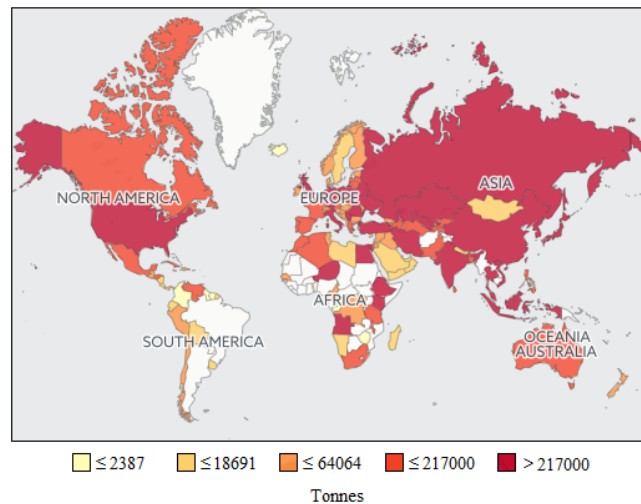
486 (FAOSTAT) available at <http://www.fao.org/faostat/en/>

487 **FIGURE 1.**

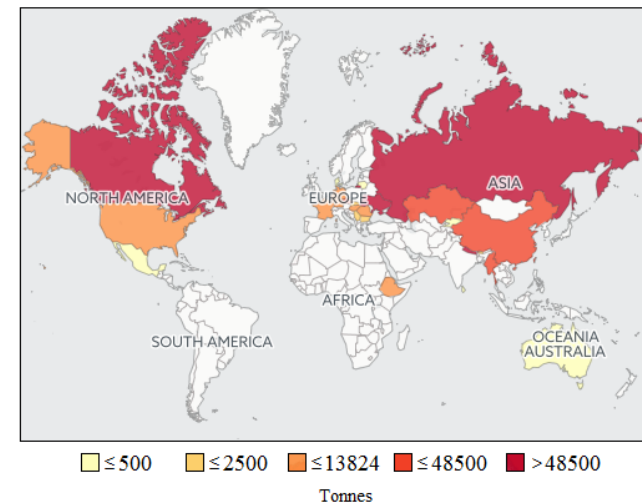
CAULIFLOWERS AND BROCCOLIS



CABBAGES AND OTHER BRASSICAS



MUSTARD SEEDS





489 **TABLE 1. Nutritional composition of raw cruciferous vegetables per 100 g of fresh produce**

	Broccoli	Kale)	Cauliflower	Brussel sprouts	Mustard spinach
Proximates					
Water (g)	89.3	84.04	92.07	86	92.2
Energy (kcal)	34	49	25	43	22
Protein (g)	2.82	4.28	1.92	3.38	2.2
Total lipid (g)	0.37	0.93	0.28	0.3	0.3
Carbohydrate (g)	6.64	8.75	4.97	8.95	3.9
Dietary fiber (g)	2.6	3.6	2	3.8	2.8
Sugars (g)	1.7	2.26	1.91	2.2	N/A
Minerals					
Calcium, Ca (mg)	47	150	22	42	210
Iron, Fe (mg)	0.73	1.47	0.42	1.4	1.5
Magnesium, Mg (mg)	21	47	15	23	11
Phosphorus, P (mg)	66	92	44	69	28
Potassium, K (mg)	316	491	299	389	449
Sodium, Na (mg)	33	38	30	25	21
Zinc, Zn (mg)	0.41	0.56	0.27	0.42	0.17
Vitamins					
Vitamin C (mg)	89.2	120	48.2	85	130
Thiamin (mg)	0.071	0.11	0.05	0.139	0.068
Riboflavin (mg)	0.117	0.13	0.06	0.09	0.093
Niacin (mg)	0.639	1	0.507	0.745	0.678
Vitamin B-6 (mg)	0.175	0.271	0.184	0.219	0.153
Folate, DFE (mg)	0.063	0.141	0.057	0.061	0.159
Vitamin B-12 (mg)	0	0	0	0	0

Vitamin A (mg)	0.031	0.5	0	0.038	0.495
Vitamin E (mg)	0.78	1.54	0.08	0.88	N/A
Vitamin D	0	0	0	0	0
Vitamin K (mg)	0.101	0.704	0.015	0.177	N/A
Lipids					
Saturated fatty acids (mg)	0.039	0.091	0.13	0.062	0.015
Monounsaturated fatty acids (mg)	0.011	0.052	0.034	0.023	0.138
Polyunsaturated fatty acids (mg)	0.038	0.338	0.031	0.153	0.057
Trans fatty acids (mg)	0	0	0	0	0
Cholesterol (mg)	0	0	0	0	0

490 N/A: Data not available

491 Data accessed from the Food Composition Database of the United States Department of Agriculture (USDA) available at

492 <https://ndb.nal.usda.gov/ndb/>

493 **TABLE 2. Predicted effects of three different heat treatments (blanching, cooking, and canning) on the residual percentage of**  
 494 **glucosinolates in red cabbage as a result of thermal degradation. Data reprinted from Oerlemans et al. (2006) with permission from**  
 495 **Elsevier.**

<b>Glucosinolate</b>	<b>Initial concentration set to 100% (<math>\mu\text{mol}/100 \text{ g FW}</math>)</b>	<b>Blanching for 3 min at 95 °C (%)</b>	<b>Cooking for 40 min at 100 °C (%)</b>	<b>Canning for 40 min at 120 °C (%)</b>
Glucoiberin	14.8	100	94	18
Progoitrin	23.8	100	93	38
Sinigrin	14.7	100	91	12
Glucoraphanin	48.2	100	90	15
Gluconapin	36.9	100	93	53
4-Hydroxyglucobrassicin	1.9	93	26	3
Glucobrassicin	8.8	99	72	1
4-Methoxyglucobrassicin	1.6	97	48	1

Total aliphatic glucosinolates	138.4	100	92	29
Total indole glucosinolates	12.3	98	62	2
Total glucosinolates	150.8	100	89	27

496

497 **TABLE 3. Total phenolic content, antioxidant capacity and total isothiocyanate content of non-treated, blanched, and high pressure**  
 498 **processed white cabbage. Table modified from Alvarez-Jubete et al. (2014) with permission from Springer. Different letters within a row**  
 499 **are used to indicate significant differences among treatments**

	Untreated	Blanching	200 MPa		400 MPa		600 MPa		P
			20°C	40 °C	20 °C	40 °C	20 °C	40 °C	
Total phenols (mg/100 g DW)	338.27 ± 17.93 abc	282.47 ± 7.14 c	310.04 ± 43.2 c	340.09 ± 14.31 abc	319.32 ± 34.84 bc	340.97 ± 12.40 abc	384.55 ± 18.57 ab	401.47 ± 16.97	< 0.001
Antioxidant capacity (Trolox equivalents)	354.16 ± 38.06 a	258.39 ± 17.1 b	82.63 ± 10.37 c	100.37 ± 19.56 c	80.95 ± 6.63 c	79.77 ± 4.11 c	322.42 ± 13.80 a	303.76 ± 35.18 ab	< 0.001
Total isothiocyanates (µmol/g DW)	0.73 ± 0.03 bc	0.41 ± 0.04 c	2.34 ± 0.31 b	1.38 ± 0.23 bc	5.18 ± 0.08 a	5.11 ± 0.49	5.07 ± 0.49 a	5.12 ± 0.38 a	< 0.0001

500